Volume 2

Sections 3-5

SELECTED TECHNICAL REFERENCES AND SUPPORTING DOCUMENTS

Prepared in Conjunction With

Report to Congress

Class V Injection Wells

- Current Inventory
- Effects on Groundwater
- Technical Recommendations

Compiled For

U.S. EPA, Washington, D.C.

November, 1987

Respectfully Submitted By:

EEI ENGINEERING ENTERPRISES, INC.

WATER RESOURCES SPECIALISTS

Under EPA Contract No. 68-03-3416

Assignment No. 0-5

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AND SUPPORTING DOCUMENTS

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Foreword

These references and documents were compiled by Engineering Enterprises, Inc. from data gathered during preparation of Report to Congress Class V Injection Wells: Current Inventory, Effects on Groundwater, Technical Recommendations (EPA 570/09-87-006) under EPA Contract No. 68-03-3416. The references are representative of data gathered by the States, Territories, and Possessions of the United States in fulfilling the regulatory requirement of 40 CFR 146.52 (b). The EPA project manager was L. Lawrence Graham, and the EEI project officer was Lorraine C. Council.

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SECTION 3

Geothermal Wells

Section 3.1

Electric Power and Direct Heat Reinjection Wells Supporting Data

SECTION 3.1.1

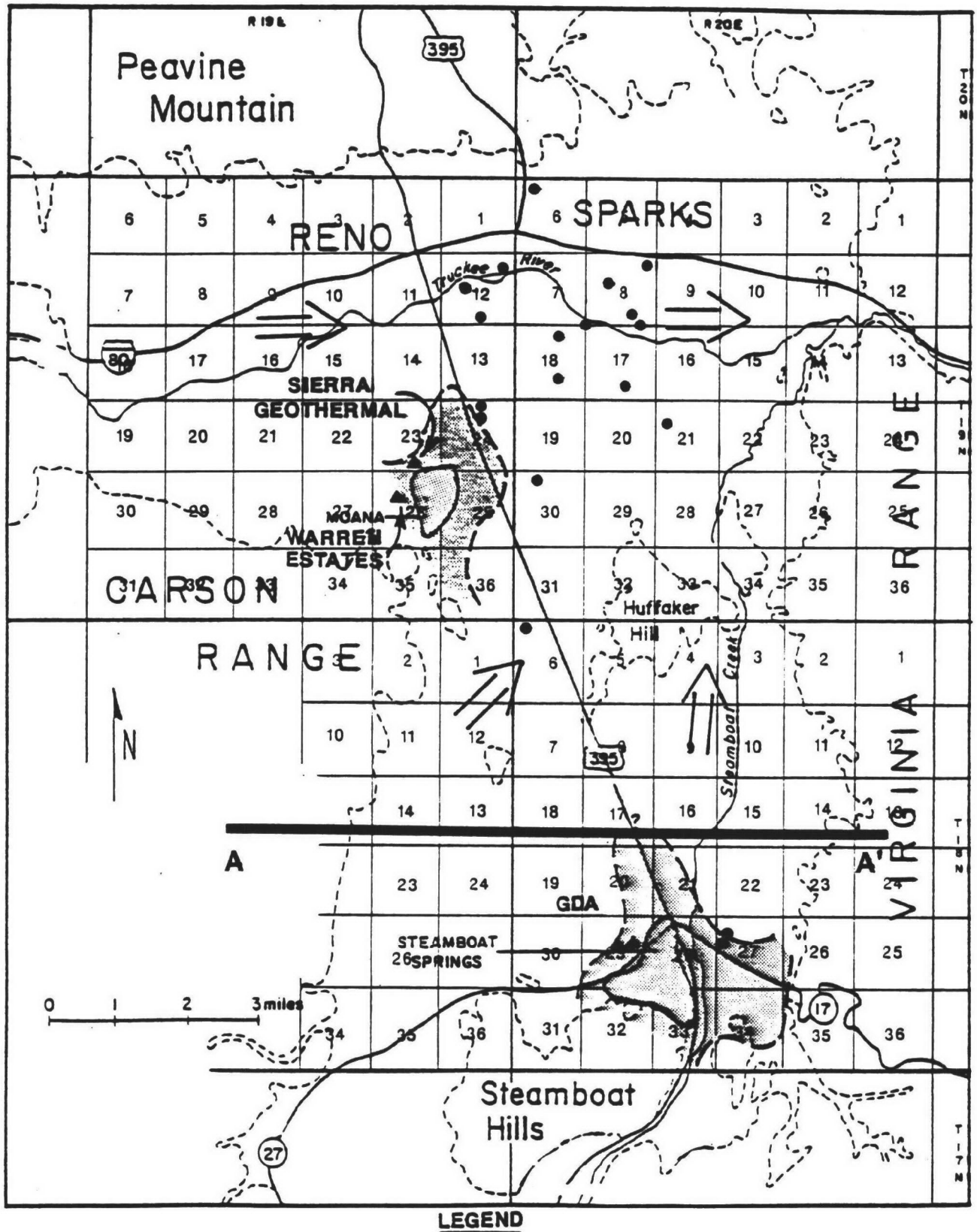
TITLE OF STUDY: (or SOURCE OF INFORMATION)	From Reporting on Class V Injection Well Inventory and Assessment in California
AUTHOR: (OR INVESTIGATOR)	Engineering Enterprises, Inc.
DATE:	May, 1987
STUDY AREA(S):	Moana - Steamboat Springs, Nevada, USEPA Region IX
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	Wells in the Moana geothermal area are considered to have a low contamination potential. Wells in this area return fluids to the same geologic formation from which they were withdrawn. In addition, the natural leakage in the USDW which occurs from the deeper, primary geothermal reservoir, is far greater than potential leakage resulting from increased hydraulic head near injection wells. Wells in the Steamboat Springs area are believed to have a moderate to high contamination potential. Although the wells inject back into the geothermal reservoir, the reservoir is believed to be connected to the overlying valley-fill aquifer (USDW). Therefore, the spatial pattern of withdrawals and injections could have an unknown effect on the mixing of thermal and non-thermal waters.

Geothermal Electric Power Reinjection and Direct Heat Reinjection Wells (5A5/5A6) - Case Studies

Moana - Steamboat Hot Springs

These two geothermal areas are located in west-central Nevada. The Moana area is in suburban Reno, and Steamboat Hot Springs is about twelve miles to the south in unincorporated Washoe County. Physiographically, this area is near the western limit of the Great Basin. Both resource areas are within the Truckee River Basin and subdividing that, within a hydrographic area known as the Truckee Meadows shown in FIgure V-13 (Denburgh et. al. 1973). In 1978 the population of the Truckee River Basin was 177,000 of which the vast majority live in the Reno-Sparks metropolitan area (Nevada, Division of Water Planning, Bulletin No. 1, 1980).

Two major orogenic events are responsible for the structural and stratigraphic configuration in the area. The first episode, beginning in the Late Mesozoic, caused eugeosynclinal sedimentary and volcanic rocks to be folded, faulted, and regionally metamorphosed to greenschist facies and continued with intrusion of granitic plutons in the Cretaceous (Bonham, 1969). The second period of deformation began in the Tertiary and continues to the present. Normal faulting, block tilting, wrench faulting and folding associated with wrench faulting are features associated with this deformation (Bonham, 1969). The current topography is a result of the latest orogenic event and erosion.



TRUCKEE MEADOWS BASE MAP
MOANA GEOTHERMAL AREA AND
STEAMBOAT HOT SPRINGS

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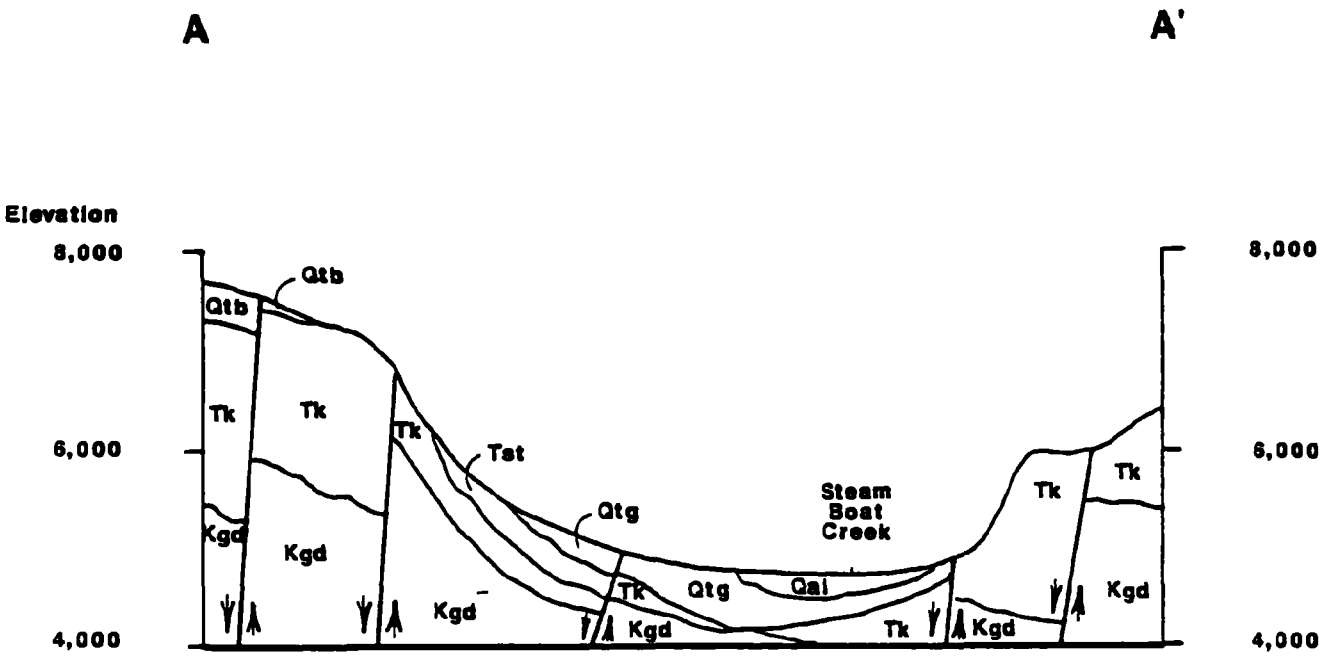
609.012.06 Figure V-13

[3-5

The Truckee Meadows is located in a valley between the Carson Range to the west and the Virginia Range to the east. Both ranges consist primarily of granitic rocks that intruded older metavolcanic and metasedimentary rocks of which a few isolated outcrops can be found (Bonham, 1969). Following a period of erosion a thick sequence of Tertiary, volcanic flows covered the region. Late Tertiary deposition also included clastics and diatomite (Sandstone of Hunter Creek, Bingler, 1975). Clastics deposition continued into the Quaternary in the form of stream deposits, alluvial fan deposits, pediment gravels, talus and slope ash (Bingler, 1975; Bonham, 1969). Figure V-14 is a schematic geologic cross section oriented approximately east-west across Truckee Meadows illustrating the structure and stratigraphy in the area.

The climate and water budget of the Truckee Meadows is typical of other areas in the Great Basin Region (Todd, 1983). Precipitation is low in the valleys (avg. 7.6 inches/year at Reno) but high (up to 40 inches/year) in the surrounding mountains (Denburgh et. al. 1973). Recharge to groundwater reservoirs is dominantly due to mountain front runoff which then seeps into valley-fill sediments. Potential recharge from this source is estimated to be 27,000 acre-feet/year (Denburgh et. al. 1973). Total recharge may be up to 35,000 acre-feet/year taking seepage losses from streams, basin underflow and infiltration into account (Cohen and Loeltz, 1964). Groundwater discharge occurs through municipal wells, domestic wells, springs, evapotranspiration and baseflow to streams. Municipal usage of



Qal = Pleistocene to Recent, stream deposits, talus, slope wash, alluvial fan and eolian deposits.

Qtg = Pleistocene to Recent, terrace, alluvial fan and pediment gravels, deeply weathered, highly dissected.

Qtb = Pliocene, basalt to andesite, flows and pyroclastics.

Tst = Pliocene, sedimentary rocks (the Sandstone of Hunter Creek).

Tk = Miocene-Pliocene, flows, flow breccia, tuff breccia, mudflow breccia, agglomerate, volcanic conglomerate, andesite to rhyodacite composition, Kate Peak Fm.

Kgd = Undifferential plutonic rocks, typically granodiorite.

(based on Bonham, 1969, plate 1 and Bingler, 1975)

SCHEMATIC GEOLOGIC CROSS SECTION OF THE TRUCKEE MEADOWS

ENGINEERING ENTERPRISES, INC.

609.012.06 Figure V-14

groundwater has increased from an average 656 acre-feet/year for the thirty years prior to 1960 to 3,931 acre-feet/year from 1960-69. Groundwater supplied 18% of the water used in the Reno-Sparks municipal system during 1969 (Denburgh et. al. 1973). Total groundwater pumpage in the Truckee Meadows during 1969 was 7,100 acre-feet (Denburgh et. al. 1973). Using data for 1975 Bedinger et. al. (1984) put groundwater withdrawal at 7,400 acre-feet/year.

The principal aquifer in Truckee Meadows is unconsolidated to semi-consolidated valley-fill. These sediments are grouped into two units partly because of hydrologic properties (Denburgh et. al., 1973). "Older alluvium" is mainly Pleistocene alluvial fan deposits in the southern part of Truckee Meadows, especially along valley margins, but becomes dominantly glacial outwash close to the Truckee River (Bingler, 1975; Bonham, 1969). Older alluvium is unconsolidated to consolidated, gravelly, muddy sand and is locally deformed with dips of 10o-20o (Bingler, 1975; Bonham, 1969). Thicknesses of up to 1,000 feet may occur in the main Truckee River Valley (Bingler, 1975). Younger alluvium is unconsolidated and consists of alluvial fan deposits, lacustrine deposits and stream deposits. Maximum thickness of younger alluvium is estimated to be 100' (Bingler 1975; Denburgh et. al., 1973).

Estimated transmissivity of the valley-fill aquifer from municipal wells ranges from 210 m^2/day (16,000 gpd/ft) to 745 m^2/day (60,000 gpd/ft) using specific capacity data and the

method of Walton (1962). Table V-5 contains well construction data used to estimate aquifer transmissivity which is also shown. A few domestic wells are completed in rocks of volcanic origin in the Truckee Meadows. Estimated transmissivity of these units is in the 1-40 m2/day (100-3200 gpd/ft) range. Yields from these units indicate they would not be a target for development of municipal water supplies. The groundwater flow direction is to the north and east in the Truckee Meadows (Bedinger et. al., 1984).

Water quality is generally very good in the valley-fill aquifer. Total Dissolved Solids (TDS) is in the 200-700 mg/l range for most wells (Denburgh et. al., 1973). Weathering of hydrothermally altered rock around the margins of Truckee Meadows is believed responsible for more highly mineralized groundwater in close proximity to those areas (Denburgh et. al., 1973). Arsenic and fluoride concentrations in groundwater near the geothermal resource areas of Moana and Steamboat Hot Springs exceed National Primary Drinking Water Standards (Flynn and Ghusn, 1984; Bateman and Scheiback, 1975; Denburgh et. al., 1973).

In the Moana geothermal resource area spent geothermal fluids are being reinjected to the formation they are produced from, the Kate Peak Andesite. Injection zones are 739' - 1436' below ground level. The injection zone has a TDS concentration of about 1000 mg/l (Flynn and Ghusn, 1984; Bateman and Scheiback, 1975).

T V

TRANSMISSIVITY DATA FOR SELECTED MUNICIPAL AND INDUSTRIAL WELLS IN THE TRUCKEE MEADOWS

Location[1] T/R, Sec.	Depth (m)	Thickness[2] (m)	Diameter (m)	Duration of Pumping	Spec. Cap. (gpm/ft)	T[3] m2/day	T[3] (gpd/ft)
18/20, 6	87.2	39.6	.30	48 hrs.	14	286	23,000
18/20, 27	57.3	24.0	.30	16 hrs.	17	360	29,000
19/19, 12	179	113	.30	48 hrs.	33	745	60,000
19/20, 4	202	65.6	.30	48 hrs.	25	621	50,000
19/20, 6	162	82.3 (est.)	.30	48 hrs.	47	1,100	89,000[4]
19/20, 8	83.5	39.6	.46	48 hrs.	24	600	48,300
19/20, 17	81.1	?	.30	48 hrs.	20	497	40,000
19/20, 18	209	58	.30	48 hrs.	8	210	16,900
19/20, 30	252	201 (est.)	.30	48 hrs.	18	435	35,000

(from data in Denburgh et. al., 1973)

1 - Township/Range, Section

2 - Producing zone thickness from perforation or screened intervals, less accurate thickness resul when only gross producing intervals were reported.

3 - T = transmissivity

4 - Production zone appears to be the Sandstone of Hunter Creek.

The injection zone at Steamboat Hot Springs is about 400' to 500' below ground level into a volcanic tuff which is also the production zone. TDS of the injection zone is in the 2000-3000 mg/l range (Bateman and Scheiback, 1975).

Available information suggests USDW's are present down to at least 1000' below ground level in most of the Truckee Meadows. Quaternary valley-fill and Tertiary valley-fill (the Sandstone of Hunter Creek) may be up to 4000' thick near the center of Truckee Meadows (Bingler, 1975; Denburgh et. al., 1973). However, water quality at those depths is unknown.

Fault zones appear to be a limiting factor in the isolation of the injection zone from other USDW's. Production and injection zones at both resource areas are located in or near faults. These faults have no doubt contributed to the overall transmissivity of the rock units present by producing fracture permeability. Evidence of this connection comes from geochemical and water temperature data which indicate there is a natural discharge of geothermal fluids into the Tertiary and Quaternary valley-fill aquifers (Flynn and Ghusn, 1984; Bateman and Scheiback, 1975). Water more mineralized and warmer than expected is detectable for about one mile away from presumed geothermal source areas (Bateman and Scheiback, 1975; Flynn and Ghusn, 1984).

SUMMARY OF CONTAMINATION POTENTIAL

Moana Geothermal System

This geothermal resource area in Reno, Nevada, currently has two multi-home geothermal space heating operations which utilize injection wells. These are Sierra Geothermal and Warren Estates. Both operations have been assessed as having low contamination potential. Major factors leading to this assessment are (1) both operations use closed loop systems and return the heat spent geothermal fluid to the same geologic formation it was withdrawn from and (2) while data on parameters of the Primary Drinking Water Standards are lacking, overall injectate chemistry is not drastically different from non-thermal waters in the valley-fill aquifer. The following paragraphs elaborate further on these points plus some remarks on mechanical integrity of the injection wells.

These wells are considered by the investigators to have been mechanically sound when operations began and ongoing operational monitoring is considered sufficient. However, the MIT requirements could be improved. The wells were constructed with a cement filled annular space between the well casing and geologic formations. This cemented interval extends from the top of the injection zone to ground level. Casing integrity was also tested at the time of construction by twenty-four hour pressure fall-off tests. Continued operational monitoring consists of daily checks on the dynamic fluid levels in the wells. At Warren

Estates these levels are being continuously recorded. Recommendations for upgrading mechanical integrity testing are made in Section VII.

Injection zone water quality will essentially be unaffected by these injection operations. This determination is made based on the fact that heat spent geothermal fluids are being returned to the same formation from which they were withdrawn. Another factor minimizing changes to the geothermal fluid chemistry is that both space heating systems are the closed loop type. As such there are no concentrating effects due to evaporation and other pH, Eh changes due to a loss of volatiles or exposure to oxygen in the atmosphere are largely avoided. This type of system should have less problems with precipitation of solids or scale formation, causing well or formation plugging, than an open system.

The last point in addressing the contamination potential deals with the effects of mixing injectate and waters of other USDW's. In this case the only other USDW besides the geothermal reservoir which has been identified is the "valley-fill aquifer". Mixing might occur due to a loss of mechanical integrity in the injection wells or by natural interconnection of the injection zone and USDW's. As described in the hydrogeology section faults or fractures are numerous in the Moana area and thermal waters occur at shallow depths. This indicates natural discharge from a deeper primary geothermal reservoir, the Kate Peak Andesite, into the valley-fill aquifer. A fine grained confining layer above

the Kate Peak Andesite, the Sandstone of Hunter Creek, is absent in some areas. Direct leakage across formation boundaries can occur in those areas. This natural leakage has diminished water quality in the valley-fill aquifer at a few municipal wells bordering the Moana area (Bateman and Scheiback, 1975). Diminished water quality occurs primarily in terms of arsenic, fluoride, and TDS concentrations.

Effects of increased leakage due to greater hydraulic head around injection wells causing upward movement of thermal waters along nearby faults or fractures would be minimal. The same is true for mixing due to a loss of mechanical integrity in these two wells. It is true that some local degradation of water quality in the valley-fill aquifer might occur but due to the similar chemistry of thermal and non-thermal waters here it would take approximately a 50-50 mixture to raise parameters like arsenic, fluoride or TDS above Drinking Water Standards. Also, such leakage may not be a short cut for geothermal fluids to mix with valley-fill aquifer water near the municipal water wells. Transmissivity, hydraulic gradients and flow path length may make the Kate Peak Andesite a more direct path to the valley-fill aquifer near the municipal wells. Lastly, municipal water supplies are not threatened by these operations because potentially impacted wells are only a fraction of the total water supply wells and the water utility company blends well water with better quality Truckee River water.

Steamboat Hot Springs

Geothermal Development Associates has constructed an electric power generating facility with two injection wells. This facility has only recently been completed and is in an equipment testing mode. Anticipated start up is December, 1986. This should be considered a preliminary assessment because this is new inventory information and some pertinent details of well construction, mechanical integrity testing and operational monitoring have not been collected. Hydrogeology and water use information indicates there are domestic and public water supply wells within about 1 mile of these injection wells. Updated information on public water supply wells in the Steamboat vicinity has been requested and should be included in a final assessment. Based on information presently available the use of these injection wells is believed to have a moderate to high contamination potential. Three major factors lead to this assessment: (1) the injection zone is the geothermal reservoir, (2) the facility utilizes a closed loop geothermal system, and (3) injection occurs in close proximity (400-900') to the production area but there is a direct hydraulic connection to a valley fill aquifer. These points are discussed in the following paragraphs.

The two injection wells will be disposing of heat spent geothermal fluids into the andesite, tuff-breccia at depths of 400 to 600' below ground level. This corresponds closely with the zone in which production wells are completed. Background water quality in this zone around the site should be homogeneous.

Impacts to water quality in this zone should therefore be minimal.

The fact that this facility uses a binary method of electric power generation also minimizes impacts to water quality of the injection zone and othe USDW's. The geothermal fluids are totally contained in a closed loop at this facility which minimizes chemical changes to the waste stream. One aspect of this is that there are no concentrating effects due to evaporation or flashing. Also, pH and Eh changes due to a loss of volatiles or exposure to oxygen in the atmosphere are largely avoided. A closed loop system should therefore have less prblems with well or formation plugging due to precipation of solids or scale formation.

The third point is important because the injection zone is probably in direct hydraulic connection with the other USDW in the area. The valley-fill aquifer, units Qal and Qtg on Figure V-14, is the only identifiable USDW present besides the geothermal reservoir. The valley-fill aquifer is believed to be connected to the geothermal reservoir near Steamboat Hot Springs because in some areas it was deposited directly on the andesite, tuff-breccia. When there are intervening rock units, faults and fractures are conduits connecting the two. The spatial pattern of geothermal fluid withdrawals and injection could therefore have an unknown effect on the pattern of mixing between thermal and non-thermal waters. Some increased mixing of waters may occur to the north and northeast of the injection wells. This

could be detrimental to valley-fill aquifer water in terms of TDS, Arsenic, Boron and temperature.

SECTION 3.1.2

TITLE OF STUDY: (or SOURCE OF INFORMATION)	Injection Well Procedures Manual: A Case Study of the Raft River Geothermal Project, Idaho
AUTHOR: (or INVESTIGATOR)	David Kraus, Gregory Burgdorf, William Zamor
DATE:	December, 1983
FACILITY NAME AND LOCATION:	Raft River Geothermal Project, Idaho, USEPA Region X
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	SMC Martin was requested to prepare an injection well procedures manual to provide EPA Region X with assistance in the evaluation of injection well permit applications. The manual discusses a real-world example of an injection well located in a complex hydrogeologic setting and is written for a technical audience familiar with the UIC program. Due to the manual's length, only the introduction is included here.

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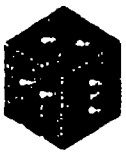

SMC Martin
900 West Valley Forge Road
PO Box 859
Valley Forge, Pennsylvania 19482

INJECTION WELL PROCEDURES MANUAL: A CASE STUDY OF THE RAFT RIVER GEOTHERMAL PROJECT, IDAHO

Office of Drinking Water
Ground Water Protection Branch
U.S. Environmental Protection Agency
Washington, DC 20460

December 1983

INJECTION WELL PROCEDURES MANUAL: A CASE STUDY OF THE RAFT RIVER GEOTHERMAL PROJECT, IDAHO

by

David L. Kraus
Gregory J. Burgdorf
William Zamor

SMC Martin Inc.
900 West Valley Forge Road
P. O. Box 859
Valley Forge, PA 19482

EPA Contract #68-01-6288
Task #8

Project Officer

Mario Salazar

Task Officers

Joseph F. Keely
Harold M. Scott

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I. INTRODUCTION

Background

The Safe Drinking Water Act (SDWA) was adopted in 1974 in an effort to correct deficiencies of the Clean Water Act of 1972. The SDWA incorporated several provisions relating specifically to ground-water protection.

Among these provisions is the requirement that the U.S. Environmental Protection Agency (EPA) develop minimum requirements for state programs regarding the protection of underground sources of drinking water (USDWs) from pollution by subsurface fluid injection. The SDWA also requires that EPA adopt and administer an Underground Injection Control (UIC) program in states failing to meet those requirements or in those states that decline primacy with regards to a UIC program. In administering the UIC program, the responsibilities of each EPA regional office will include reviewing permit applications for injection facilities.

Purpose and Scope

Under EPA Contract #68-01-6288, Task #8, SMC Martin was requested to prepare an injection well procedures manual which would provide EPA Region X with assistance in the evaluation of injection well permit applications. The manual discusses a real world example of an injection well located in a complex hydrogeologic setting and is written for an audience familiar with injection well technology,

hydrogeology and the Underground Injection Control Program (UIC). The case study was to be used as an aid to the Regional staff to review, condition and approve or disapprove a permit application.

The selected case study describes operations at the Raft River Geothermal Field, Idaho. The case study includes detailed discussion and analysis on the site geology and hydrogeology, disposal well siting, construction and completion techniques, geophysical and mechanical integrity testing, area of review calculations, wastewater characteristics and compatibility tests, and design of the monitoring well network. These topics were chosen on their importance in the siting and permitting of an injection facility under the UIC program, and the availability of information to develop suitable evaluations of the injection well system.

Use of Manual

The case study presented in this manual is the Raft River Geothermal Project, Idaho operated by U.S. Department of Energy. The technical investigations were prepared and reported by EG&G, Idaho. In the preparation of this case study, information was extracted from several published EG&G reports. This case study was not intended to represent a precise summary of all facets of the Raft River operation, but only to present selected data relevant to a permit reviewer.

The case study is written in an instructional format. Although the case study wells are Class V geothermal injection wells, the requirements of the UIC program for all five classes of injection wells and additional geologic and engineering factors are discussed. At the conclusion of a section or chapter, critical topics which should be considered in the approval or disapproval of a permit application are noted. A discussion is then presented for each topic considering basic geologic rationale and the UIC program requirements. In addition, the reader is given technical questions to answer or evaluate in several chapters.

Figures in this manual were taken directly from several publications and contain metric and/or English units. Unit conversion procedures were not attempted on the manual's figures. The permit writer must be knowledgeable of both unit systems since permit applications may contain either unit system. Conversion factors are given in Appendix A to aid the permit writer.

SECTION 3.1.3

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	Problems of Utilizing Ground Water in the West-Side Business District of Portland, Oregon
AUTHOR: **(or INVESTIGATOR)**	S.G. Brown
DATE:	1963
STUDY AREA:	Portland, Oregon USEPA Region X
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	The purposes of this study are to present available data on the occurrence and use of groundwater in the Portland area, to point out problems, and to suggest areas for additional studies. A portion of the study examines recharge wells used for heating and/or cooling (heat pump wells) and identifies temperature changes resulting from increased use of these systems as a potential problem.

Problems of Utilizing Ground Water in the West-Side Business District of Portland, Oregon

By S. G. BROWN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-O

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

PROBLEMS OF UTILIZING GROUND WATER IN THE WEST-SIDE BUSINESS DISTRICT OF PORTLAND, OREGON

By S. G. Domenico

ABSTRACT

The withdrawal of ground water for industrial uses and for the heating and cooling of buildings in the west-side business district of Portland has increased greatly since 1955. As a result of this increased withdrawal, ground-water levels apparently are declining progressively, even though some of the water withdrawn is returned to the ground-water bodies by means of artificial recharge. Temperature and chemical quality of the ground water also are changing at places, due to the increased pumping and the practice of artificial recharging with water of different temperature and chemical composition from the natural ground waters.

The west-side business district is underlain, in downward succession, by alluvium of Recent age, fluviolacustrine deposits of late Pleistocene age, the Troutdale formation of early Pliocene age, the Sandy River mudstone, of early(?) Pliocene age, the Columbia River basalt of Miocene and Pliocene(?) age, and marine sedimentary rocks of early Tertiary age. Sand and gravel layers in the Troutdale formation and interflow zones in the Columbia River basalt are water bearing and yield water of good to fair chemical quality to several dozen industrial wells in the area. The underlying marine sedimentary rocks contain saline water, which apparently is migrating upward and mixing with water in the basalt aquifers.

The data presently available indicate that with continued uncoordinated increases in pumped withdrawal and artificial recharge the problems of declining levels and changes in the temperature and chemical quality of the ground water probably will increase. A comprehensive plan for the development and management of the ground-water resources is needed to insure maximum benefits from the ground water and to minimize the effects of the problems now developing. Additional information on the changes in temperature, chemical quality, and levels of the ground water, and on the amounts of ground water pumped and recharged artificially is needed to serve as a basis for such a comprehensive plan.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The withdrawal of ground water for industrial uses and for the heating and cooling of buildings in downtown Portland has increased greatly since 1955. As a result of this increased withdrawal, ground-water levels apparently are declining progressively, even

though some of the water withdrawn is returned to the ground-water bodies by means of artificial recharge. The character of water withdrawn from some wells is changing noticeably. In view of the expected increase in the demand for ground water in the downtown district, it is anticipated that serious interference between wells will occur, and that the suitability of the ground water for some uses may be impaired, unless more orderly procedures are followed in the withdrawal and recharge of the ground water, and in development of additional ground-water supplies.

The purpose of this study is to consolidate and present available geologic and hydrologic information bearing on the occurrence and use of ground water in the area, to point out the developing and anticipated problems, and to suggest additional studies that are needed to form a basis for efficient administration and development of the ground-water resources.

Several classes of data are presented in this report: (1) records of wells in the area; (2) water-level data obtained during 19 years of regular monthly measurements at an index observation well in downtown Portland; (3) records of water withdrawn from the ground and discharged to the city sewers; (4) geologic information obtained from investigations made by the U.S. Geological Survey and from other sources; (5) stage records of the Willamette River; (6) chemical analyses of ground water sampled by the Geological Survey and others; (7) climatological data from the U.S. Weather Bureau. The analysis of these data provided the basis for the conclusions in this report.

The work was accomplished under the direct supervision of R.C. Newcomb, district geologist for Oregon. It was part of the continuing program of studies carried on by the Geological Survey in cooperation with the office of the Oregon State Engineer.

ACKNOWLEDGMENTS

Mr. W. T. Monahan and Mr. R. A. Carlson, engineers of the city of Portland, made available data on metered water discharged from wells to city sewers. The A. M. Jannsen Drilling Co., O. E. Jannsen Drilling Co., Steinman Bros., R. J. Strasser Drilling Co., and Mr. Lance Strayer contributed well logs and other information. The assistance of all is gratefully acknowledged.

LOCATION AND EXTENT OF THE AREA

The area of this study is the main business and industrial district on the west side of the Willamette River in the city of Portland (pl. 1). The area extends from the river across a narrow flood plain, stream-built terraces, and alluvial slopes, to the foot of the West Hills (part of the Tualatin Mountains), and along the Willamette

River downstream from the vicinity of the Ross Island Bridge to about 1 mile northwest of the Broadway Bridge. The area is roughly ovalshaped, about 3 miles long, 1¼ miles in maximum width, and totals slightly more than 3 square miles. Most of the area is built up in multiple-story commercial, warehouse, hotel, apartment, and office buildings.

CLIMATE

Portland has a temperate, moist, marine-type climate that is modified somewhat by the Coast Range which lies between the city and the Pacific Ocean. The area is largely sheltered from the more extreme continental climate of eastern Oregon and eastern Washington by the Cascade Range to the east.

Climatological data have been recorded by the U.S. Weather Bureau at Portland since 1871. The mean monthly temperature and average monthly precipitation computed from those records are shown in figure 1. The mean annual temperature recorded at the Portland Weather Bureau Station is 54.6°F. The highest temperature recorded was 107°F in July 1942, and the lowest was 3°F in December 1919.

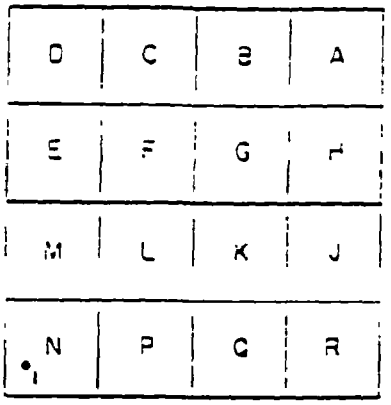
The average annual precipitation at Portland was 39.91 inches for the 88-year period ending in 1958; less than one-tenth of the total fell as snow. Average monthly precipitation ranged from 7.1 inches in December to 0.4 inch in July.

The relative humidity at Portland generally averages 85 to 95 percent in the early mornings. The relative humidity in the afternoons remains about 70 percent from November through February, but is as low as 47 percent during the summer. No evaporation data are available from the Portland station.

WELL-NUMBERING SYSTEM

Wells discussed in this report are designated by symbols that indicate their location according to the Federal rectangular system of land division. In the symbol 1N/1-34N1, for example, the part preceding the hyphen indicates respectively the township and range (T. 1 N., R. 1 E.) north and east of the Willamette base line and meridian. Because most of the State lies south of the Willamette base line and east of the Willamette meridian, the letters indicating the directions south and east are omitted, but the letters W and N are included for wells lying west of the meridian and north of the base line. The first number after the hyphen indicates the section (sec. 34), and the letter (N) indicates a 40-acre subdivision of the section as shown in the accompanying diagram. The final digit is the serial number of the well within that 40-acre tract. Thus, well 1N/1-34N1 is in

SW¼SW¼ sec. 34, T. 1 N., R. 1 E., and is the first well in the tract to be listed.



CHARACTER AND RELATION OF THE ROCK UNITS

The Columbia River basalt, of Miocene and Pliocene(?) age, is the oldest rock unit exposed in the west Portland area. This formation comprises an accordantly layered series of lava flows and a few scattered interflow beds of tuff.

The basalt is exposed at places in the West Hills, where the basalt and underlying rocks have been upfolded in an anticline. The upper surface of the basalt slopes eastward about 200 feet per mile and passes beneath younger sedimentary rocks near the foot of the West Hills. At a well in the vicinity of N.E. 39th Avenue and Glisen Street, about 2 miles east of the Steel Bridge, the top of the basalt is believed to be 1,100 feet below sea level. The eastward inclination of the basalt is shown in the cross section in plate 1, and by contours on the upper surface of the basalt in figure 2.

Where unweathered, the basalt is mostly dense, hard, and dark gray to black. Beneath most of the West Hills, the upper part of the basalt has weathered to a red clayey soil to depths of 20 feet or more (Trimble, 1957). Along the steep eastern slope of the West Hills, where erosion is more active, the basalt is relatively unweathered.

Individual layers of the basalt range in thickness from 5 to about 100 feet and average about 50 feet. The layers commonly consist of a dense central part, moderately jointed as a result of contraction during cooling; a vesicular upper part, which commonly is more broken as a result of weathering and jointing; and a lower part that commonly is strongly jointed and sometimes rubbly.

Records of wells in the area suggest that the Columbia River basalt is at least 700 to 800 feet thick in the west Portland area. Shale and sand of Tertiary age underlie the basalt and have been reached

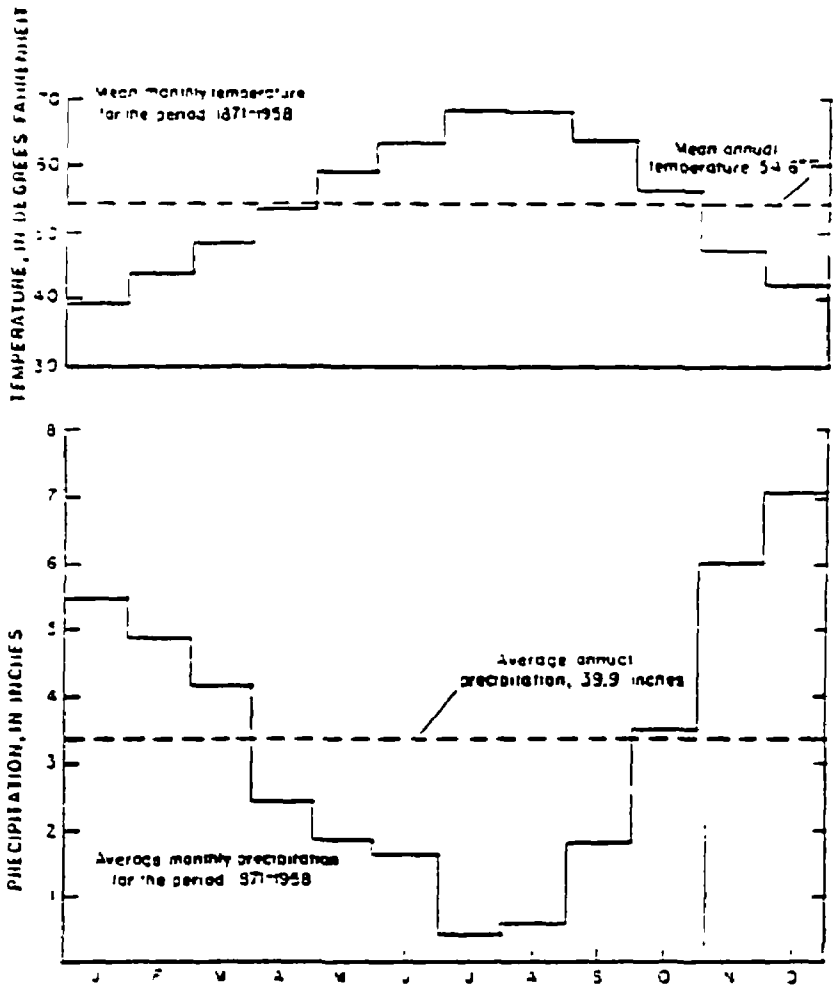


FIGURE 1.—Mean monthly temperature and average monthly precipitation in downtown Portland, Oreg. (from U.S. Weather Bureau data).

by drilling at Gladstone, about 9 miles southeast of this area, at a depth of 685 feet (615 ft below sea level), and in three wells in the West Hills. Of the three wells in West Hills, two are in sec. 23, T. 1 N., R. 1 W., where the basalt is about 700 feet thick, and the top of the older sedimentary material is about 200 feet above sea level. The third well is at the Riverside Cemetery, in sec. 27, T. 1 S., R. 1 E., where the underlying sedimentary rocks are 700 feet below the surface (250 ft below sea level).

Unconformably overlying the basalt is a series of consolidated and partly consolidated beds of mudstone, sandstone, and shale, formerly known as the lower member of the Troutdale formation,

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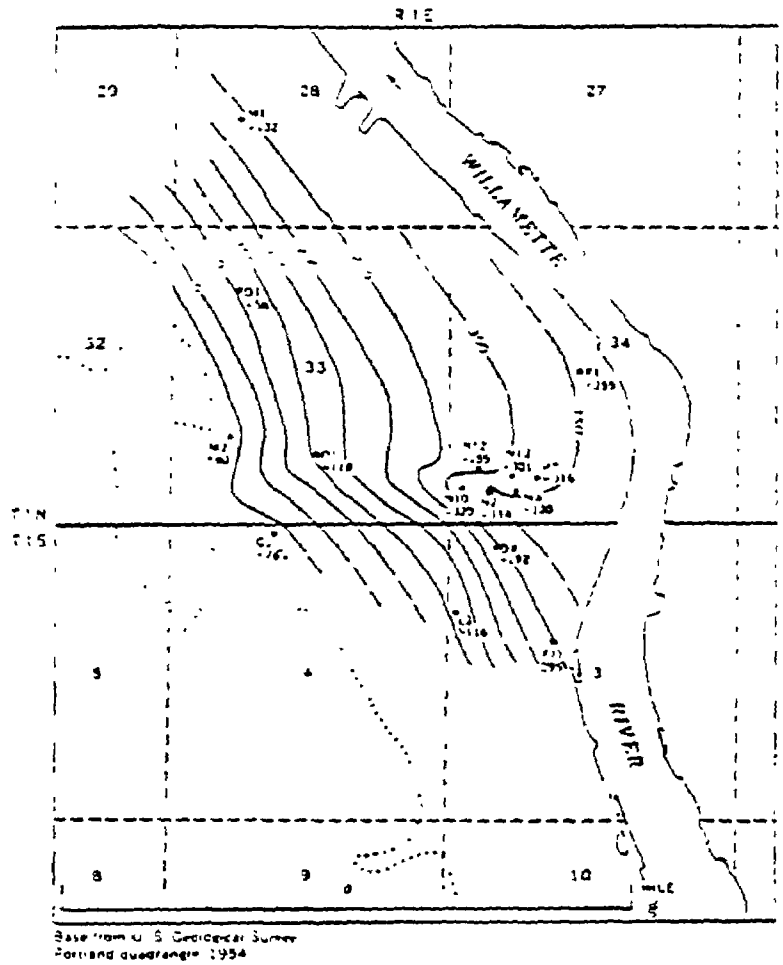

Base from U. S. Geological Survey
Portland quadrangle 1954

EXPLANATION

Well penetrating Columbia River basalt
Number indicates altitude at which well entered the basalt

Contours on the upper surface of the Columbia River basalt
Dashed where approximate or inferred. Contour interval 50 feet, datum is mean sea level

Limit of area in which basalt is at or near the surface

FIGURE 2.—Map showing the altitude of the upper surface of the Columbia River basalt beneath a part of Portland, Oreg.

but recently named the Sandy River mudstone, of early(?) Pliocene age (Trimble, 1962). The Sandy River mudstone does not crop out here, but has been penetrated by wells in the eastern part of the area. Farther west, the Sandy River pinches out against the westward-rising surface of the Columbia River basalt (pl. 1, section A–A'). The maximum thickness penetrated was 228 feet in well 1N/1–34N2.

The Sandy River mudstone where present, and the Columbia River basalt are overlain by the Troutdale formation, of late Pliocene age. The Troutdale formation, which is composed largely of pebble conglomerate and sandstone, underlies the entire west-side business district and extends to the east, north, and south beyond the limits of this area. Its known thickness ranges from a few feet on the slopes of the West Hills, to 235 feet at well 1N/1–33R2.

The gravel-size particles of the conglomerate consist mostly of Columbia River basalt and other volcanic rocks, but also contain much quartzite, granite, and metamorphic rocks typical of the upper Columbia River region. The sandstone is micaceous and is predominantly quartzose. The Troutdale apparently was deposited on an eroded surface of the Sandy River mudstone. Well logs indicate that the contact between the two units in this area ranges in altitude from about 120 to more than 200 feet below sea level (pl. 1, section A–A').

Through most of the area the Troutdale formation is overlain by a relatively thin mantle of unconsolidated terrace deposits of late Pleistocene age, which are part of the deposits called "older alluvium" by Piper (1942, p. 23) and "Portland terrace gravels" by Treasher (1942). The deposits consist mostly of stratified and locally cross-bedded gravel and sand, and contain lesser amounts of silt and clay. The clay and silt, although comprising less than half of the total volume of the unit, occur in sizable bodies at a few places in the area, and indicate that this unit probably was laid down under alternating stream and quiet-water conditions, or by streams discharging into a lake. For that reason, the unit is herein referred to as fluviolacustrine deposits. The fluviolacustrine deposits underlie terraces that rise from an altitude of about 50 feet up to the foot of the West Hills at an altitude of about 200 feet, and generally are less than 100 feet thick.

Along the Willamette River below an altitude of about 50 feet, the terraces and flood plain are underlain by alluvium of Recent age and by artificial fill. These materials are predominantly unconsolidated sand and silt. They are commonly less than 50 feet thick where penetrated by wells in the area, but probably thicken closer to the Willamette River.

OCCURRENCE OF THE GROUND WATER

GENERAL FEATURES OF OCCURRENCE

Ground water may be defined as water that occurs under hydrostatic pressure below the land surface and completely saturates or fills all pore spaces of the rock material in which it occurs. The upper surface of such a zone of saturation, if unconfined, is called the water table, and its position is indicated by the level at which water will stand in a nonpumped well [illegible].

Because ground water occurs in the openings, or interstices, in the rock material, the amount of water contained and the rate at which water can move through the rocks depend largely upon the size and degree of interconnection of the interstices. The interstices differ greatly in size and character; they include minute pore spaces in clays and shales, large well-connected openings in coarse well-sorted gravel, and joints in basalt. The capacity of a rock material to transmit water is referred to as its permeability or transmissibility. A rock unit that is capable of transmitting and yielding appreciable amounts of water to a well is called an aquifer.

In addition to the unconfined, or water-table type of occurrence, at places ground water is confined. Confined ground water occurs where an aquifer is overlain by a less permeable layer that retards the upward movement of the water, and pressure is exerted by the head of water in the aquifer. Thus, the confined water is under pressure greater than that of the atmosphere and it rises above the base of the confining layer in wells. The two principal types of hydraulic conditions in which ground water occurs—confined and unconfined—can be gradational, and an area in which ground water is confined under a small hydrostatic head can occur close to an area of unconfined ground water.

Discharge of ground water in the area is mainly by seepage to the Willamette River and by withdrawal from wells. Under natural conditions, the water table was higher than the level of the river during most of the year and ground water moved toward the river and discharged into its channel. Conversely, during high stages, the river normally reached levels considerably above those of the water table, and water infiltrated from the stream channel to the ground-water body. During recent years, however, the water table has declined at places to the extent that it remains lower than the river level throughout the year (pl. 2).

Recharge, or replenishment of ground water occurs in the west Portland area chiefly by infiltration from precipitation and from streams. This natural recharge is augmented to some extent by artificial injection of water into wells. In addition, the amount

of water available for discharge from a particular aquifer may be increased by water migrating from an adjacent aquifer

WATER-BEARING CHARACTER OF THE ROCK UNITS

The principal aquifers underlying the west Portland business district are in the Columbia River basalt and in the Troutdale formation. Other less important aquifers are the fluviolacustrine deposits of late Pleistocene age and the alluvium of Recent age, where these units extend below the water table. The [illegible] rocks of early Tertiary age beneath the Columbia River basalt are less permeable, and the small amount of water they yield is saline.

GROUND WATER IN THE OLDER SEDIMENTARY ROCKS

At least part of the fine-grained sedimentary rocks of early Tertiary age that underlie the Columbia River basalt in the west Portland area were deposited in a marine environment. In nearby areas where these rocks have been penetrated by wells they contain saline water. This saline water probably is connate—that is, the sediments probably still contain some of the sea water in which they originally were deposited. Where the overlying basalt has been flexed and ruptured by tectonic movement the saline water may migrate upward into the basalt from the marine sedimentary rocks (Hart and Newcomb, 1956, pl. 1S).

GROUND WATER IN THE COLUMBIA RIVER BASALT

In the Columbia River basalt the fractured and scoriaceous zones in the upper parts of many of the flow layers are permeable and serve as aquifers when they are saturated. The dense central parts of the flows are relatively impermeable, except where they are jointed and fractured. In general, ground water can move freely through the tabular interflow zones parallel to the flow layers, but can move across the flows only in minor amounts. Where the basalt layers are tilted, the porous interflow zones farther downdip contain water confined by the dense, less permeable central parts of the lava flows.

The permeable interflow zones are not everywhere continuous. Each lava flow is limited in extent, and its water-bearing zone may be discontinuous or may merge with that of an adjacent flow. Faulting or intense folding of the basalt may have further interrupted the continuity of the permeable zones. Where faulting has occurred, the water-bearing strata may have been crushed to form impermeable material (gouge), or may be offset so that a permeable layer abuts an impermeable stratum. Folding of the basalt caused the layers to shift along the interflow zones, and in places the once-permeable material may have been crushed to form a finer, less permeable material.

Eighteen wells in the west-side business district are known to have been drilled into the Columbia River basalt, and 13 are finished in the basalt and obtain their water exclusively from it (table 1). Three wells draw water from both the basalt and the overlying Troutdale formation. The yields computed from test records for the 13 wells that tap the basalt average about 440 gpm (gallons per minute), and range from 50 to 1,000 gpm. Reported drawdowns of the water levels during pumping of these wells ranged from 25 to 250 feet at pumping rates of 800 and 650 gpm, respectively (table 1, wells 1N/1-34N4 and 34N10). The average [illegible] wells is about 130 feet. The maximum computed specific capacity[1] is about 21 gpm per ft, the minimum is 0.6 gpm per ft, and the average is 4.3 gpm per ft.

GROUND WATER IN THE SANDY RIVER MUDSTONE

The Sandy River mudstone is not important as an aquifer in the area, the fine-grained materials constituting this formation are relatively impermeable and yield little water to wells. Where present, the Sandy River mudstone forms an effective barrier to the vertical movement of water between permeable zones in the underlying basalt and those in the overlying Troutdale formation, and confines ground water in the upper part of the basalt. Most wells that are drilled into the Sandy River mudstone without having obtained a sufficient yield of water are extended through the formation into the underlying basalt.

GROUND WATER IN THE TROUTDALE FORMATION

The Troutdale formation is the most productive source of ground water in the area. Large yields are obtained from wells that tap unconsolidated gravel and coarse sand in the formation. The sand and gravel beds transmit water readily in any direction, but a few layers of clay and mudstone in the Troutdale limit the vertical movement of the water. Many of the sand and gravel layers are compacted, cemented, or have the interstices so filled with fine material that they do not transmit water readily. However, in most parts of the west Portland area the sand and gravel in the Troutdale formation act as a water-table type of aquifer.

In 1958, 14 wells were pumping water from the Troutdale formation for heating, cooling, and industrial use. This water was subsequently metered and discharged to the city sewers. Several other wells, including two at the Equitable Building, are believed to tap the Troutdale formation; however, water from these wells was not discharged to the sewers, but was injected underground through another well. The yields of the Equitable wells have been estimated from

[1] Specific capacity of a well is a ratio of the discharge to the drawdown of water level produced by that discharge, and usually it is given in gallons per minute per foot of drawdown (gpm per ft).

data derived from commercial pumping tests and from the capacity ratings of the installed pumps. The maximum reported yield of a well in the Troutdale formation was 1,100 gpm of water with an 80-foot drawdown of the water level at well 1/1-3E1. The minimum reported yield was 3 gpm with a drawdown of 45 feet at well 1N/1-34P1. The average of the yields of the 14 wells was about 290 gpm. Specific capacities of the wells that tap the Troutdale formation were computed from the results of 14 commercial pumping tests. The maximum specific capacity was 50 gpm per ft of drawdown [illegible] and the average specific capacity was about 7 gpm per ft.

Pumped withdrawal probably constitutes the major form of ground-water discharge from the Troutdale formation in the area; infiltration from the Willamette River probably is the principal source of recharge to the formation. Infiltration of precipitation along the base of the West Hills probably is also an important source of recharge.

An additional source of recharge to the formation was suggested by Hart and Newcomb (1956, p. 66) who state that, along the axis of the anticline that forms the West Hills, the level of the ground water in the Columbia River basalt drops about 160 feet from the Tualatin Valley side on the west to the Portland side on the east, and that at places water probably is moving through the basalt from west to east across the structural divide. At the eastern base of the West Hills, where the basalt has been strongly deformed, it is possible that compression and tension have opened the joints in the basalt, and allowed some water to migrate across the flow layers into the Troutdale formation. To date, no effects of this possible interformational leakage have been recorded in the west Portland area.

THE WITHDRAWAL OF GROUND WATER

When a well that taps an unconfined aquifer is pumped, the water table in the vicinity of the well is drawn down in the shape of an inverted cone, called the cone of depression. Thus, a hydraulic gradient is established, and water from the surrounding parts of the aquifer moves toward the well. As pumping continues, the cone of depression expands, but at a progressively slower rate, until it reaches an impermeable body or a line source of recharge, or until the cone encompasses an area in which the recharge to the aquifer is equal to the discharge. The drawdown of ground-water levels within the cone of depression also increases until equilibrium is reached between recharge and discharge. Figure 3 shows the hydraulic conditions in the vicinity of a well pumping water from an unconfined aquifer.

The conditions in the vicinity of a well that discharges water from a confined aquifer are much the same as described above, except that the pressure surface (piezometric surface) of the confined ground

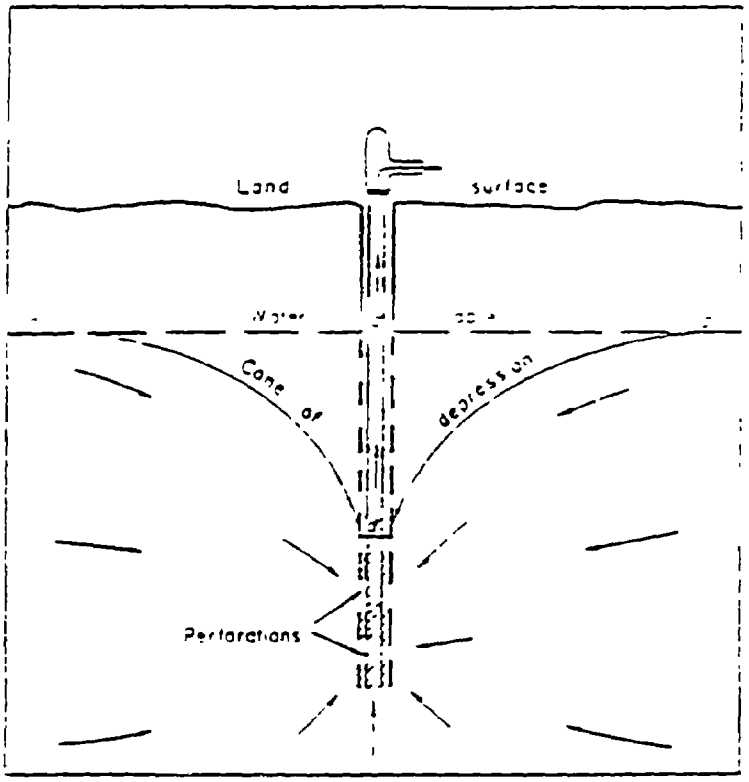

FIGURE 1.—Diagrammatic section through a discharging water-table well. Distance d–d' represents the drawdown from the static (nonpumping) water level. Section a'c' shows the cone of water-table depression. Arrows indicate direction of water movement.

water, rather than the water table, is drawn down to form the cone of depression.

If no recharge occurs in the area of the cone of depression during discharge from a water-table well, the only water available for discharge is water that was previously stored in the aquifer. If the withdrawal from an aquifer exceeds the recharge for an extended period, a general lowering of the ground-water level occurs.

Where the cones of depression of adjacent wells overlap, there is competition for the ground water in that part of the aquifer between the wells. The amount of water moving toward each well is decreased, and the drawdown of water levels for a given discharge is greater than it would be if the cones of depression did not overlap.

The chief source of information on quantities of water withdrawn from wells has been the Water Bureau of the city of Portland. All well water that is wasted to the city sewers is metered by that bureau

for sewer-use charges. The meter records are the source of the pumpage data presented in figure 4 and plate 2, and in table 3.

Between 1954 and 1958, 26 wells in the west-side business district were reported to be wasting water to the city sewers at one time or another. During 1958, 20 wells were metered. In addition, the water from two shallow wells that tap gravel (1N/1-34N3 and 34N5) is injected into a deep well that taps basalt (1N/1-34N4) after the water is used to heat the Equitable Building. Conversely, during periods when the heating wells are unused, the deeper well is pumped as a source of the cooling water and most of the water withdrawn is injected into the two shallow wells. Some water also is recharged interchangeably between wells in gravel and basalt at the Oregonian Building (wells 1/1-3E1, 3E2, and 3E3).

The water that is injected into wells is not metered, and thus the quantity is not known. The amount of ground water withdrawn for cooling or heating and wasted to the sewers from October 1954 to December 1958 is shown in table 3. The values given represent actual metered discharge, except for December 1958; the values for that month were estimated from previous records by use of temperature and relative humidity data.

It will be noted that the metered pumpage increased from about 780 acre-feet in 1955 to about 1,300 acre-feet in 1958, an average increase of about 340 acre-feet per year. If the volume of ground water that is wasted to the sewers continues to increase at the same average rate, it will amount to nearly 2,300 acre-feet in 1960. However, the city authorities of Portland have moved to restrict the disposal to the sewers of waste water from future air-conditioning and heating systems, as that practice has progressively taxed the capacity of the sewer system. This move has imposed upon well owners and those contemplating future installations the necessity to plan other methods of disposal, such as returning the water underground through wells.

Extensive artificial recharge by use of these waste waters may assist in maintaining ground-water levels, but it may also raise problems concerning the temperature of water in a given aquifer, local overpumping and over-recharging, and changes in the chemical quality of the ground waters.

WITHDRAWAL FROM THE TROUTDALE FORMATION

During 1958, the total metered pumpage from the Troutdale formation within this area was about 480 acre-feet. The metered pumpage from that formation has increased steadily every year since 1955 to about 1,300 acre-feet in 1958—an increase of about 170 percent. Although the withdrawal during some months may have been less than that for the same month in preceding years, the overall effect has been one of progressive increase of total yearly withdrawal.

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The discharge from 19 wells was metered at some time during this period, but the records of discharge from some of these wells are incomplete.

WITHDRAWAL FROM THE COLUMBIA RIVER BASALT

Total metered pumpage from the Columbia River basalt was about 300 acre-feet in 1955, and about 510 acre-feet in 1958—an increase of about 70 percent. In early 1959, seven wells were yielding water from the basalt and additional wells were being drilled into it. Some of [illegible] may not be metered as their waste water is planned for recharge to the Troutdale gravel, provided [illegible] wells in the gravel of the Troutdale will accept the desired amounts of water.

FACTORS INFLUENCING WITHDRAWAL

Many of the wells where water is metered are operated for air conditioning. The amount of water withdrawn from these wells is dependent upon many factors, among which are temperature, humidity, incoming solar radiation, length of daylight, and season of the year. Figure 4 shows the general relationship between monthly metered pumpage and the monthly mean temperature. It is apparent from the relationships shown in figure 4 that the total monthly pumpage increases greatly with rising monthly mean temperatures. This is partly because many air-conditioning wells are pumped only during the periods of warmest weather. The water that is withdrawn during months when mean temperature are below about 45°F is used mainly for industrial purposes, for two reverse-cycle heating installations and for one direct-cycle heating system. During the cooler months the rate of ground-water withdrawal apparently approaches constant values (fig. 4) that probably are equivalent to the average industrial and heating demand.

ARTIFICIAL RECHARGE

At least 10 wells[1] in the area reportedly are or have been used for injection of water to recharge the aquifers. Other wells are planned for this use in the future. At present (1959), little information exists on the amount, temperature, or quality of the water injected, and there is no regulation of this artificial recharge. The amount of water recharged depends mostly on the amounts of water needed for air-conditioning and heating installations, as the waste water from these installations constitutes the only water so recharged at the present time.

Some operators of air-conditioning plants withdraw or plan to withdraw water from basalt and recharge the warmed waste water

[1] [illegible], First National Bank; [illegible], 4, and 5, Equitable Building; [illegible], Dierks Medical Center; [illegible], Good Building Co.; [illegible], 2, and 3, Overseas Building, [illegible], Medical-Dental Building.

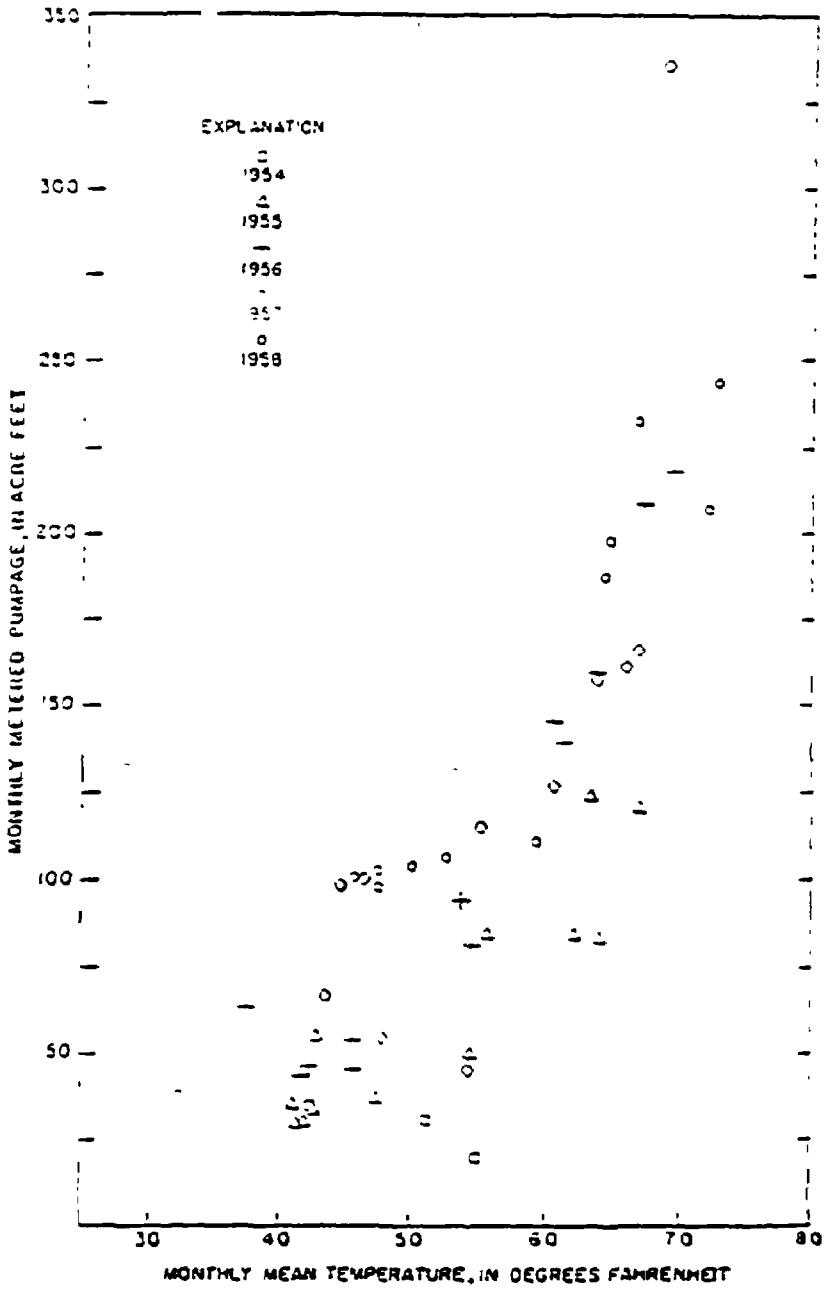

FIGURE 4.—Relationship of monthly metered pumpage to the monthly mean temperature from October 1954 to November 1958.

to the aquifers of the Troutdale formation. Others pump from the Troutdale and recharge to the basalt. Several operators are recharging, or plan to recharge, warmed water to the gravels of the Troutdale within about 100 feet of preexisting wells that withdraw water for cooling from the same aquifer. Thus, as water in the aquifer becomes warmer, many wells, especially those near wells that recharge warm water to the aquifer, will yield warm water that is less suitable for cooling.

GROUND-WATER LEVELS IN THE AREA

Under natural conditions an overall balance exists between the water an aquifer receives and the water it discharges; minor variations occur in the amount of water in storage within an aquifer, due to seasonal and long-term differences in the amount of water recharged and discharged and the rates and times at which these additions and losses take place. The differences in the rates of natural recharge to the aquifer and of natural discharge from the aquifer result in changes in the amount of water in storage, which are indicated by changes in the altitude of the water table or piezometric surface. Other natural changes in ground-water levels are caused principally by barometric pressure changes, tides, and earthquakes. Changes of ground-water levels also are induced artificially by such practices as (1) artificial recharge of the aquifers, (2) paving or artificially draining areas of natural infiltration (which decreases natural recharge), and (3) withdrawal from wells. These practices all affect ground-water levels in the downtown Portland area.

Since September 1940, measurements of the depth to water in well 1N/1-34N1 have been made monthly. The well is 155 feet deep and taps the Troutdale formation. It is at the southeast corner of SW. Sixth Avenue and Washington Street, near the approximate center of pumping from the Troutdale formation in the west-side business district.

Plate 2 shows the hydrograph of well 1N/1-34N1; graphs showing seasonal variations in pumpage from the observation well and from the Troutdale formation and Columbia River basalt; monthly average stage of the Willamette River at Portland; the monthly precipitation in downtown Portland; and the cumulative departure from average monthly precipitation. This assemblage of data allows visual comparison of the water-level variations in the well with some of the factors that influence the variations.

Comparison of the hydrograph of well 1N/1-34N1 and the pumpage graphs shows the effects of pumping on water levels in the well. During the summer months, when pumping is greatest, the water level in the well declines, but as pumping decreases during the fall

and winter the water level recovers to near the level of the preceding spring. It is apparent that the year-to-year increase in the total quantity of water withdrawn from the Troutdale formation in this area is paralleled by a general decline in the summer month-end water levels in the index well. In every year that pumping from the Troutdale formation is known to have increased, the summer low water levels in the well have been lower than during the preceding years. From 1937 through the spring of 1959 an almost steady general decline of water levels occurred. The decline from 1956 to 1959 was about 4 feet in the winter high levels and 9 feet in the summer low levels in the observation well. Particularly notable is the drop in water levels from May through September 1958, when a large increase occurred in pumping from the Troutdale formation.

Comparison of the well and stream hydrographs show that from the beginning of the record, and especially before 1953, water levels in this well rose or fell more or less synchronously with the stage of the Willamette River at Portland. The highest stages in the Willamette River at Portland commonly occur as backwater from the annual high stage of the Columbia River in May, June, or July; secondary high stages occur in the winter due to precipitation in the Willamette basin. At times of low river stage the ground-water level formerly stood at or above the altitude of the river, whereas only at high or rising river stages was the altitude of water level in the index well below the monthly average river stage. Since the early part of 1957, this synchronism has in part persisted, but the level in the well has been consistently lower than the stage of the river. Thus, a greater than normal hydraulic gradient has been established from the Willamette River to the vicinity of the well, and the direction of this gradient is maintained throughout the year. As a result, recharge from the Willamette River to the aquifers in the Troutdale formation probably has increased substantially.

At the bottom of plate 2 is a bar graph showing the monthly precipitation measured at the U.S. Weather Bureau Portland (city) station; just above the bar graph is a line graph showing the cumulative departure of the monthly precipitation from the averages for 1940–58. Comparison of the month-end ground-water levels and the precipitation graphs indicates that precipitation has little direct or immediate effect upon the ground-water level in this well, and the long-term trends in precipitation bear no relation to the year-to-year decline in levels in the well from 1956 to 1959.

From 1940 to about November 1947 the cumulative departure curve for the precipitation and the curve for ground-water levels show a general similarity. However, the latter curve shows sharp declines that reflect the heavy pumping during the summer months,

and rising trends that apparently coincided with the onset of the autumn rains, but doubtless were partly due to local recovery of the water table as pumping of water for air conditioning was reduced.

From 1948 to 1955 cumulative departure from the average precipitation showed an upward trend, whereas the month-end water levels remained near or slightly below average. From the autumn months of 1955 to January 1956 the cumulative precipitation curve shows a sharp upward trend and, except for minor variations, levels off after January 1956 and continues at a high level to December 1958. In contrast, the water-level curve has an overall downward trend, beginning in 1956 and continuing to the present (1959). Thus there are two unnatural declining trends in the water level in the well—one beginning in 1948 and the other in 1956—despite an increase in precipitation and a resultant increase in potential ground-water recharge.

The indicated lack of relationship between precipitation and ground-water levels agrees qualitatively with the factors governing the direct recharge to the Troutdale formation from precipitation. The west-side business district is largely paved or occupied by buildings, so that opportunity for surface infiltration is practically non-existent in the area around well 1N/1-34N1.

Effective recharge from precipitation probably can occur only in a few distant places, such as at the base of the east slope of the West Hills. The interception of most of the precipitation by the pavement and buildings probably explains the lack of rise in water level in well 1N/1-34N1 after periods of heavy rainfall. However, it is difficult to identify any recharge from rain because changes in the pumping regimen and recharge from the river tend to mask other increments of recharge.

Within a radius of 1,000 feet of well 1N/1-34N1 are six wells that tap the Troutdale formation. Two are used for the heating phase of a reverse-cycle heating and cooling system, and although seldom pumped, frequently receive recharge water during the summer months. Together they accept as much as 250 gpm of water, which is recharged to the Troutdale formation. The other four nearby wells are capable of a combined yield as great as 1,200 gpm from the Troutdale formation during periods of peak demand.

Plate 2 indicates that the periods of low water levels in well 1N/1-34N1 are more directly related to periods of large withdrawal from the Troutdale formation than to any other factor. The periods of low level in the well are more closely related to total pumpage from the Troutdale formation than to pumping from the well itself. Therefore, it is concluded that the general downward trend in levels in the index well has been caused mostly by the year-to-year increase in

pumpage from the aquifers of the Troutdale, and that the sharp declines in ground-water levels during recent summers are due mostly to the increasing use of ground water for air conditioning.

TEMPERATURE OF THE GROUND WATER

Water from the Troutdale formation normally is at temperatures ranging from 55° to 69°F, and water from the Columbia River basalt ranges from 54° to 70°F. Temperatures of water in both aquifers are [illegible]. Wells utilizing these two aquifers have been installed in the Equitable and Oregonian Buildings and are planned for other buildings.

When the shallow wells that supply the Equitable Building system (1N/1-34N3 and 34N5) were drilled, the temperature of the water in the Troutdale formation was 63° to 66°F. Heated exhaust water from the system is recharged to these wells at temperatures of 75° to 85°F during the cooling phase of the operation. At the beginning of the heating phase each winter, the temperature of the water from the wells is at or near the temperature of the exhaust water that was recharged during the cooling phase. After about the first week of pumping, during the heating phase, the temperature of the water in the shallow wells is about 65°F. The chilled water exhausted during the heating phase is artificially recharged to the basalt through the deep well (1N/1-34N4) at a temperature of about 48°F. The water-bearing zone tapped by that well apparently is so permeable that this chilled water moves outward and mixes freely with the natural water in the aquifer. The chilled recharge water reportedly does not build up to form a substantial cone of elevation (the counterpart of the cone of depression of a discharging well) nor does its lower heat content appreciably lower the normal 54°F temperature of the natural water in the basalt aquifer.

The heating and cooling system used by the Oregonian Building is a three-well system consisting of two wells for cooling (1/1-3E1 and 3E2), which draw water at 55°F from the Troutdale formation and a deeper well for heating (1/1-3E3), which obtains water at 58°F from the Columbia River basalt. After the operation of the system had begun, it was found that water from the deeper well, 1/1-3E3, was less desirable because of its higher mineral content, and for this reason the well is largely unused. Also, the deeper well has a limited capacity for pumping and recharge. The two wells that tap the Troutdale formation are used for both the heating and cooling cycles, but a part of the exhaust water from the cooling system is injected at temperatures as high as 120°F into the deep well. When the deep well was pumped in January 1956, for the first time in 3 years, the water temperature was reported to be 96°F. This high temperature

indicates that there is only limited movement of the water outward from the well into the basalt aquifer. Reportedly, the temperature of the water in the deep well normally is about 80 °F after the warmed water from the cooling system has been injected throughout the summer, but the temperature drops to about 60 °F after the well is pumped for 3 months.

Heated or cooled water that is recharged to an aquifer may move down the hydraulic gradient and adversely affect the temperature of water from down-gradient wells. If the warmed waste waters from several cooling systems are injected into the same aquifer, it is probable that the overall temperature of the ground water in that aquifer eventually will rise. Such a temperature rise would, of course, decrease the value of the ground water as a cooling supply and might limit its usefulness for other purposes as well.

In other parts of the country a general rise in the temperature of ground water in certain aquifers has been caused by using warmed water for artificial recharge. Concerning the use of warmed water for artificial recharge by one air-conditioning plant on Long Island, N.Y., Brashears (1941, p. 317–318) stated:

> • • • at an industrial plant in Kings County, which continuously recharges about 1 million gallons daily, the temperature of the water pumped from the supply well increased about 20 degrees after a few months of operation. The supply well and recharge well both end in the same formation and are about 200 feet apart. It is reported that this rise in temperature increased operating costs about 300 to 500 dollars a month.

A similar warming of the water withdrawn from a supply well at the Snohomish, Wash., substation of the Bonneville Power Administration was due to nearby artificial recharge with warmed water (Hart, 1958, p. 37).

CHEMICAL QUALITY OF THE GROUND WATER

Table 4 presents chemical analyses of water from three wells that tap the Troutdale formation, four wells that tap the Columbia River basalt, and one well that is reported to draw water from both formations. More than one analysis is listed for four of the wells that draw their supply solely from the Columbia River basalt. Samples from those wells were taken at different times and the analyses show that the chemical quality varies with time of sampling. The analysis of one sample from well 1/1–3E2, which taps the Troutdale formation, doubtless represents a mixture of the natural water in that formation with water that previously had been pumped from the basalt and injected into the well.

Water from the Troutdale formation is predominantly high in calcium bicarbonate and is generally of good quality. Its pH ranges

from 6.5 to 6.7. This water is considered moderately hard or hard; the hardness, as $CaCO_3$, averaged 147 ppm (parts per million) for the 3 samples analyzed. Chloride content is low, the average was 23 ppm for 3 samples.

Analyses of two samples from each of four wells that tap the Columbia River basalt (1N/1-34N4 and N13, 34P2, and 1/1-3E3) are given in table 4. The analyses show that the water in the basalt contains [illegible] and chloride and is of generally poorer quality than water from the Troutdale formation. The hardness ranged from 110 ppm (moderately hard) to 650 ppm (very hard.) Chloride content ranged from 90 to 790 ppm. Comparison of the different analyses for each of the wells indicates that the chloride content increased consistently with time in all wells but 1/1-3E3, which received much recharge water pumped from the Troutdale formation. The most recent analysis for well 1 1-3E3 shows a decrease of 123 ppm in the chloride content since the previous analysis 7 years earlier. This decrease probably was caused by the injection into this well of water of lower chloride content from the Troutdale formation. The hardness also decreased by 12 ppm during the same time, and the pH dropped from 8.2 to 7.2. The injection of water from the Troutdale formation into this well, and the improvement in chemical quality that apparently resulted, reportedly were not accompanied by any noticeable change in temperature of the water in the aquifers recharged.

In well 1N/1-34N12, which taps aquifers in both the Troutdale formation and the Columbia River basalt, dissolved constituents increased between November 16, 1953, when the first sample was taken, and March 1, 1955, when the second sample was taken. The chloride content increased from 695 to 840 ppm, and the hardness from 540 to 665 ppm. Presumably, the increase in the mineral content of the water from that well is due principally to an increase in the salinity of water from the basalt aquifers tapped by the well. If so, the change in water quality in the basalt aquifers doubtless is even greater than indicated, because the water from those aquifers is diluted, to some extent, by water from the Troutdale formation before it is discharged from the well. Other possible conditions that may have influenced the measured increase in mineral content of the well water are: the water in the basalt aquifers may be under sufficient pressure to cause it to rise in the well and move outward into the Troutdale adjacent to the well, and thus to decrease the effectiveness of dilution by water from the Troutdale formation; or the basalt aquifers may be the more productive aquifers and may supply a progressively greater part of the water pumped from this well.

As previously stated, the mineral content of water from the basalt wells apparently is increasing as the wells are pumped. The increase in the calcium content (reflected by the hardness) and the chloride content of the water suggests that a different type of water is migrating upward from the underlying marine sedimentary rocks.

The saline water in the sedimentary rocks underlying the basalt is an unusual type referred to as a calcium-sodium chloride water. Where the overlying basalt has been fractured or stretched during folding it possibly has more abundant and more open joints and fractures which allow this water of poorer quality to migrate upward (Hart and Newcomb, 1956, pl. 18). Where the basalt aquifer is tapped by a well in or near such a fractured zone, drawdown of the water table or reduction of artesian pressures due to pumping may cause larger amounts of the saline water to migrate upward into the basalt aquifer and thence to the well.

The belt of strongly folded basalt at the foot of the West Hills has always contained some saline water of this type. Well 1N/1-20N1, about 2 miles north of the area studied and owned by the Northern Pacific Terminal Co., yielded such a hard and mildly saline water as soon as it entered the basalt. The water from another well, 6 miles north of the west-side business district at the Pennsylvania Salt Co. plant, was too saline for plant use. Most of the wells in basalt beneath the west-side business district obtain water of this type, which has varying degrees of hardness and salinity. The mineral content was particularly troublesome in the deepest well, 1/1-3E3, at the Oregonian Building, and suggests that the salinity of water in the basalt may increase with depth.

The chemical quality of the water in an aquifer can be altered by recharge with water of a different type from another aquifer. For example, if aquifers in the Troutdale formation were recharged with the more saline water of the Columbia River basalt, the water in the Troutdale, especially near the recharge well, probably would have some of the undesirable characteristics of water from the basalt. Conversely, recharging the basalt aquifers with water from the Troutdale formation, or with other water of good quality, might improve the quality of the water in the basalt aquifers near the recharge well. The chemistry of the waters must be considered carefully in planning for the ultimate maximum utilization of the two main ground-water bodies beneath the downtown Portland area. It is reiterated that the water of good quality in the Troutdale formation, the upper aquifer, can be impaired or rendered unfit for certain industrial uses if water of poor quality is injected into the Troutdale in substantial amounts.

SUMMARY OF PROBLEMS

In view of the rapid and continuing increase in withdrawal of water from the Troutdale formation and the Columbia River basalt, the following problems in the west Portland area may be expected to increase unless a comprehensive plan is established to control withdrawal, artificial recharge, and the temperature and quality of the ground water.

Declining water levels.—The continuing increase in withdrawal for heating and cooling purposes probably will cause continuing declines in ground-water levels, both in wells that tap the Troutdale formation and in those that tap the Columbia River basalt. The declining trends will be offset to some extent by the current practice of artificially recharging in some of the wells. As previously stated, the decline of the water table in the Troutdale formation has established a steeper than normal hydraulic gradient from the Willamette River to aquifers in that formation, and may have induced substantially greater recharge from the river to those aquifers. This induced recharge also would tend to offset the continuing decline in levels in those aquifers. The degree of hydraulic connection between the Willamette River and aquifers in the basalt is not known; however, because the basalt aquifers are at considerable depths beneath the river, and are overlain by much material of low permeability, there appears to be little possibility of artificially inducing substantial recharge from the river to those aquifers.

Deterioration of chemical quality.—A lowering of artesian pressure in the basalt aquifers apparently has allowed the upward migration of saline water from the underlying marine sedimentary rocks. If these artesian pressures decline further because of continued intensive pumping, further deterioration in quality of the water in the basalt can be expected, at least locally. The saline water might also, contaminate aquifers in the Troutdale formation if the saline water is used to recharge those aquifers artificially, or if a well taps aquifers in both the Troutdale formation and the basalt and saline water in the basalt is under sufficient pressure to cause it to move upward in the well and outward into higher aquifers. Conversely, the quality of the water in the basalt aquifers might be improved substantially by increased artificial recharge with water of better quality, either from the Troutdale formation or from some other source.

Temperature changes.—The use of water in air-conditioning or heating systems produces radical changes in the water temperature—as much as 30°F or more. If the heated or cooled exhaust water from these systems is injected into wells, it will tend to change the temperatures of the natural water in aquifers tapped by those wells. The temperature changes produced by artificial recharge to aquifers with

such water depends largely on the transmissibility of the aquifers—that is, the capacity of the aquifers to carry the water away from the well—and on the amount of heated or cooled water that is injected.

Any change in the temperature of ground water may radically effect the usefulness of the water for some purposes. For example, the warming produced by artificial recharge of an aquifer with warmed exhaust water from an air-conditioning plant may impair the value of the water [illegible] a lower temperature, and improve it for those that want higher temperature water for heating.

Artificial recharge of the ground-water bodies in the west-side business district is likely to increase in the future, especially because of the reluctance of the city authorities to permit disposal of more heating and cooling water to the sewer system. There is, at present, little coordination between well operators in the withdrawal and recharge of ground water. Because of this lack of coordination, some well operators may, through artificial recharge, cause temperature changes in the ground water that are incompatible with the needs of other ground-water users.

Other problems.—The aforementioned changes in the character of the ground water and the lowering of levels in wells in the west Portland area, probably will cause economic or legal problems. For example, the lowering of ground-water levels that would accompany the expected increases in withdrawal would increase the costs of pumping the ground water. Likewise, the operation of heating and cooling plants with water of unsuitable temperature would decrease the efficiency and increase the costs of such operations.

An unusual legal question not previously encountered in Oregon may arise as a result of the temperature changes induced by artificial recharge. That question is whether such temperature changes, which might impair the usefulness of the water for certain purposes, "adversely affect the public interest" should be considered a problem for administration under the water laws of Oregon (Office of the State Engineer, 1955, Chap 537.170, p. 25).

An additional problem may develop at those buildings in the area that are founded on wooden pilings, if the water table declines below the tops of the pilings. Pilings thus exposed to aeration, or to repeated submergence and aeration probably would decay rapidly, especially if untreated.

ADDITIONAL STUDIES NEEDED

A comprehensive plan for the development and management of ground-water resources in the west Portland district would aid in insuring optimum use of this valuable resource and in minimizing the

effects of the problems that are now developing. As a basis for such a comprehensive plan, the data now available allow only partial understanding of the hydrologic factors involved. Additional studies, outlined below, are needed to provide the information necessary for a better understanding of the changing hydrologic regimen of the area.

Measurement of ground-water levels.—The water levels in a large percentage of the wells in the west-side district should be measured periodically on a continuing basis to provide data for relating water-level changes to pumpage, changes in chemical quality, and to temperature, and possible changes in recharge from the Willamette River. In order to obtain the needed water-level data, it will be necessary to make an opening in the base of the pump or in the casing at many of the wells to permit the insertion of a steel tape or other measuring device.

Measurement of ground-water temperatures.—Periodic measurement of the temperature of water should be made at all wells during periods of pumping and artificial recharge. The temperature data thus obtained would allow evaluation of the seasonal and long-term effects of recharging the aquifers with waters of unnatural temperatures, and the areal extent of such effects. In order to obtain the temperature data, it would be necessary to provide a sampling tap in the discharge and injection pipes at the wells where such taps are not already installed. The sampling taps also would allow the collection of water samples for chemical analyses, discussed below.

Analysis of ground-water samples.—Systematic sampling and chemical analysis of the natural water in the aquifers, and the water introduced into the aquifers by artificial recharge, should be started as soon as possible. More data on the chemical composition of the waters are needed to predict any possible deleterious effects of the mixing of waters of different chemical composition, and to determine changes in the salinity of water in the aquifers. The quality-of-water data would serve to guide decisions concerning the areal distribution and intensity of withdrawal from the basalt aquifers. Those data also would provide a check on the effectiveness of any future program of artificial recharge aimed at improving the quality of water in the basalt.

Records of pumpage and artificial recharge.—To evaluate properly the effects of pumpage and artificial recharge, better records of the amounts of water withdrawn and injected are needed. At present, only incomplete records of pumpage exist, and very little information is available on the amounts of water recharged through wells. Adequate and reliable quantitative data probably could be obtained by the installation and periodic reading of totalizing water meters on the discharge and injection pipes at all large-capacity wells.

Possible improvement of water quality by artificial recharge.—The injection of water from the Troutdale formation into well 1/1-3E3 apparently improved, at least temporarily, the quality of water in the basalt aquifers in the vicinity of that well. This fact suggests the possibility of improving the quality of the water in the basalt aquifers throughout the area by a planned program of artificial recharge. However, before such a program could be undertaken, a preliminary appraisal would be needed to determine the feasibility and probable effectiveness of a recharge program. Such a study would involve the collection and interpretation of geochemical data obtained either during present recharge operations or by means of a recharge experiment.

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TABLES

TABLE 1.—*Records of representative wells in the west side business district of Portland, Oreg.*

Altitude. Altitude of land surface datum at well in feet above mean sea level, interpolated from topographic life maps and shown in round figures; one altitude, obtained by leveling, is given to nearest tenth of foot.
Type of well: Dg, dug; Dr, drilled.
Ground-water occurrence: C, confined or partly confined; U, unconfined.
Type of pump: C, centrifugal; S, submersible turbine; T, turbine.
Use of the water or the well: A, air conditioning (mostly cooling); H, heating; Ind, industrial; N, not used; R, disposal or recharge.
Remarks: C, chemical analysis in table 4; d, drawdown, gpm, gallons per minute; hr, hours; hr, hours; L, log in table 3; pf, perforated or perforations; ppm, parts per million; Temp, temperature of water in degrees Fahrenheit. Remarks on the general quality of the water and the materials penetrated were supplied by owners, tenants, drillers, and others.

Well	Owner or tenant	Approximate altitude (ft)	Type of well (fig.)	Depth of well (ft)	Diameter (in.)	Depth of casing (ft)	Water-bearing materials: Depth to top (ft)	Water-bearing materials: Thickness (ft)	Water-bearing materials: Character of material	Ground-water occurrence	Water level: Feet below datum	Water level: Date	Type of pump	Yield (gpm)	Use	Remarks
T 1 N R 1 E																
2S/1E-	Young & Son Iron Works	48	Dr	77	4				Gravel					10	N	Water was formerly used for tempering steel
2S/1E-	Zehrung Chemicals	55	Dr	150	10	124	124	4	do	U	25	1957			Ind	Pumped 45 gpm, did not penetrate small fl.
2S/1E-	Griffith Rubber Mills	53	Dr	370	8	368			Basalt	C	32	August 1916	T		Ind	Pumped 50 gpm, did not penetrate small fl.
2S/1E-	Ellis Weinhard	47			6	305			Gravel					15	Ind	Chloride 250 ppm, hardness 87 ppm. Temp 55°
2S/1E-	Portland Ice and Cold Storage Co	48	Dr		8				do				T	100	Ind	
2S/1E-	Portland Commission of Public Docks	32	Dr	142	8				do				T	150	Ind	Temp 58°
2S/1E-	Ice Co.								do					75	N	
2S/1E-	Good Samaritan Hospital	100	Dr	600	10	569	351	49	Basalt	C	95	July 17, 1953		350	N	Pumps 1 355 gpm for 2 hr, ds 320 ft. Temp 55° f
2S/1E-	Fred Meyer Inc	110	Dr	105	12				Gravel				T	300	A	Temp 54°
2S/1E-	Henry Thiele	135	Dr	350	6	335?	325	326	Basalt	U	30	May 1951		15	N	Pumped 25 gpm for 1 hr, ds 10 ft. f
3S/1E-	U S National Bank, Stadium Branch	110	Dr	500	8 6	301 478	455	105	do	C	100	July 1946	T	600	A	Pumped 475 gpm with 25 ft d and 550 gpm with 100 ft d. f
3S/1E-	First National Bank, 6th and Morrison Branch	100	Dr	600	10 8	300 600			Gravel(?) and basalt		85	November 1955	T	500		Pumps 1 600 gpm for 6 hr, ds 10 ft with cooling f

3383 ...	... do	100	Dg	300	10	300	105	195	Gravel ...	U	91	1950 .				R	Used for disposal of water from air conditioning plant.
3383	Pacific Telephone & Telegraph Co	105	Dg	255	8	245	210	45	. do	U	..		T	300	A	Pumped 500 gpm, dd 300 ft.
3384	Spokane, Portland & Seattle Railway Co	30	Dg	165	18	.	.	.	.. do	.	.				R	Water for boiler for use in boilers. Yield "high."
3385 .	Terminal Ice & Cold Storage Co	30	Dg	552	10 8	424 552	405	87	Basalt	U			T	125	Ind	Pumped 500 gpm, dd to 70 ft, 15 ft below top of casing. Temp 60°.
3386 .	Swift & Co., Dairy & Poultry Plant	30	Dg	60	3	.			Gravel				I	12?	R	Temp 52°.
3387	Portland Lafferndo Creamery	25	Dg	61	6?		50	11	do	U	.	. .			R	Quicksand to 30 ft, and cemented gravel and sand to 50 ft. Water 15 ft from stem. Temp 52°.
3388 . . .	Bay Elle Meat Market	30	Dg	160	6	.	.		. do				C	15	R	Temp 50°.
3389	Portland Dish Co .	30	Dg	85	8				Gravel		..				R	
3390 .	Portland (Atlantic) Fish Co	30	Dg	78	8	.	60	8	. do .	U	21	December 1911.	T	300	Ind	Pumped 300 gpm, dd 5 ft.
3391	Weisfield & Gold Bag	47.2	Dg	155	8	142	75	70	do	U	32	Sept 28 1940	T		A	Hydrograph on pt 2 bailed 50 gpm for 15 min, dd 27 ft. Temp 52°.
3392	U S National Bank formerly United Artists' Theater	48	Dg	601	10 8 6	515 570 601	180	19	Gravel and sand	U		.	T	200	R	Pumped 250 gpm for 10 days dd 520 ft. Furnished by supplied air on ft flooding water to theater. Temp 58°.
3393 ...	Equitable Bldg .	40	Dg	173	16	155	67	66	Gravel sheet by cemented	U	30	October 1916	I	225	R	With casing pt from 60 ft to 100 ft pumped 150 gpm, dd about 30 ft. Then pt to 140 ft and pumped 225 gpm, dd about 110 ft. Temp 56° F.
3394	. do	40	Dg	203	16 12	161 200	140	138	Basalt . .	U	36	December 1910	T	600	A	Pumps 1100 gpm for 8 hr, dd 28 ft. Temp 57° F.
3395	. do	40	Dg	180	12	165	55	107	Sand and gravel	U	30	February 1917	T	300	R	Pumps 300 gpm. Temp 60°.
3396	Northwest Electric Co	55	Dg	97	12			. .	Gravel			.	I	100	R	Temp 56°.
3397 .	Benson Hotel . ..	28	Dg	46	60				Sand and gravel	U					R	Formerly used for air conditioning.
3398 . .	Ilgman Wolfe & Co	40	Dg	40	12	.		.	Gravel				I	30	Ind	Supplies water for sand duty facilities. Temp 56°.

TABLE 1 — *Records of representative wells in the west side business district of Portland, Oreg* — Continued

Well	Owner or tenant	Approximate altitude (ft)	Type of well (D)	Depth of well (ft)	Diameter (in.)	Depth of casing (ft)	Water-bearing zone(s)			Ground-water reservoir	Water level		Type of pump	Yield (gpm)	Use	Remarks
							Depth to top (ft)	Thickness (ft)	Character of material		Feet above datum	Date				
1 1 N., R 3 E. — Continued																
3s1E9 .	Former Oregonian Bldg (razed)	45	Dr	167	7	.		. .	Gravel .		.	. . . .	.		U	Abandoned and approximately destroyed Formerly supplied 600 gpm to air conditioning system Temp 58°
✓3s1E10. . .	Dierks Medical Center	45	Dr	601	12	360	385	200	Basalt .	C	50	Apr 14, 1950	. . . .	.	A	Well will supply reverse-cycle heating and cooling plant Pumped 650 gpm for 12 hrs, dd 200 ft L
3s1E11.	. . . do	45	Dr	618	12	327	430	436	Gravel cemented	U	. . .	. . . . .	. . .	.	U	To be used as disposal well for reverse-cycle heating and cooling plant L
3s1E12 .	Federal Reserve Bank of San Francisco	40	Dr	788	14	605	300	96	Sand, gravel and clay	.	40	Feb 22, 1952	T	600	A	Pumped 800 gpm, dd 11 ft, 600 gpm, dd 46 ft C L
3s1E13 .	U S National Bank, Main Branch	38	Dr	610	40 12 10 8	615 550 685 633	605 550 710	160 210 21	Basalt do Gravel	C	25	November 1951	T		A U	Pumped 300 gpm, dd 58 ft, 450 gpm dd 105 ft Temp initially 70°, after pumping 350 gpm for several hr temp drops to 53° C L
3s1E14 . .	First National Bank	38	Dr	644	18	358	356	270	Basalt . .	. .	43	Apr 9, 1929 .	. . . .	. . .	A	Pumped 1 000 gpm for 12 hr, dd 253 ft Temp 64° L
3s1E15 . .	. . . do	37	Dr	161	14	148	65	95	Gravel . . .	. .	18	May 1, 1939 .	. . . .	.	U	Pumped about 100 gpm Temp 63°
3s1E .	Pacific Telephone & Telegraph Co	38	Dr	92	8	38	. .	. . . .	Sand and gravel(?)	U	37	September 1913	. . .	.	U	Pumped 3 gpm for 1 hr, dd 48 ft
3s1E3 . .	. . . do	38	Dr	607	14	328	368	340	Basalt .	C.	38	December 1910	T		A	Pumped 700 gpm, dd 78 ft, 376 gpm, dd 136 ft C L
3s1E3 . .	Alder Market	38	Dr	38	3	. . .	.	. . . .	Gravel . .	.	. .	. . . .	C	.	Ind	Temp 54°

TABLE 11

	3111	Fox Theatre	70	12x	225	8	-	--	-	Sand(?) and gravel	U	--	- -	--	350	A	Temp 56° F
	3112	Paramount Theatre	68	12x	142	-		--	---	Sand and gravel		-	- ---	?	300	A	Pumped 350 gpm for 10 hr each day for 6 months
	3113	Pacific Power & Light Co	65	12x	100	10	-	--	--	-- do -	-	--	-	T	25	A	Temp 56°
	3114	Pacific Mut Bdg and Savings & Loan Association	60	12x	308	14	204	240	1	-- do -	U	58	1925 -	T	350	A	Pumped 350 gpm, dd 96 ft, 700 gpm, dd 140 ft
	3115	Ladd Building Co	60	12x	220	14	178	178 198	15 9	Sand and gravel	U	63	May 16, 1930			A	Pumped 650 gpm for 20 hr, dd 63 ft, 765 gpm for 20 hr, dd 93 ft, temp 60° F
✓	3116	Pacific Bldg	60	12x	165	16	320	403	362	Basalt		63	1930			A	Pumped 750 gpm, dd 306 ft, temp 60° F, chloride 370 ppm, hardness 340 ppm
	3117	do	62	12x	220	14	220	130 198	10 9	Gravel do		63	1930		-	A	Pumped 765 gpm, dd 93 ft, temp 60°
✓	3118	Oregonian Bldg Co	110	12x	203	16	193	322 378	15 15	Sand and gravel do	U	68	June 1912	T		A	Pumped 1 250 gpm for 24 hr, dd 69 ft, 1 500 gpm for 24 hr, dd 80 ft, temp 55° F
✓	3119	do	110	12x	210	14 10	150 210	178 191	23 10	do do	U	101	June 1917			A	Pumped 600 gpm for 24 hr, dd 80 ft, 1 000 gpm for 24 hr, dd 90 ft, temp 61° F
✓	3120	do	110	12x	230	10 12	198 240	220	700	Basalt	C	80	January 1918	--		A	Used only intermittently. Pumped 250 gpm for 1 hr, dd 674 ft, 500 gpm for 1 hr, dd 700 ft, temp 56° F
	3121	Boilermakers Union	60	12x	151	10	-	130	20	Sand and gravel	U	56	July 1912 -	...	200	A	Pumped 200 gpm for 10 hr, dd 47 ft, temp 57° F
	3122	Portland General Electric Co	65	12x	240	8	173	210 215	20 25	Basalt Gravel do	C		-	T	130	A	Pumped 130 gpm, dd 146 ft, temp 56° F
	3123	Western Condensing Co	70	12x	191	8	-						- - -	?	650	A	Temp 54°
	3124	Portland Art Museum	110	12x	235	10	235	265 285	10 20	Sand, green and lava gravel	U	100	October 1938	4	676	A	Pumped 350 gpm for 4 hr, dd 169 ft, temp 53° (Water softened)
✓	3125	Medical Dental Bldg	110	12x	372	12 10	328	378	218	Basalt	C	100	1929			A	Pumped 700 gpm, dd 91 ft, temp 56°
	3126	do	105	12x	193	12	193	170	25	Gravel	U	101	1929			A	Pumped 1 050 gpm, dd 32 ft, temp 56°
	3127	Rose City Bowl, Inc	110	12x	265	8 6	65 193	172	23	Basalt	C	51	June 10-3		-	A	Pumped 150 gpm for 1 hr, dd 160 ft

TABLE 2.—*Drillers' logs of representative wells*

[Tentative stratigraphic headings by J. O. Brown; word order changed to conform with U. S. Geol. Survey style]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1N/1-2L1. Zehrung Chemical Co. [Drilled by A. M. Jansson Drilling Co., 1957]					
Alluvium and Troutdale formation:			Alluvium and Troutdale formation—Continued		
Clay, dry	10	10	Sand, dry	9	111
Sand, dry	10	20	Clay and gravel	59	124
Gravel, dry	41	61	Gravel, water-bearing	2	126
1N/1-2M1. Griffin Rubber Mills [Drilled by A. M. Jansson Drilling Co., 1941]					
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation:		
Rock, sandy	22	22	Gravel, cemented	4	145
Gravel, large	10	32	Gravel, loose	22	165
Gravel	13	45	Sand and gravel	20	185
Sand and gravel	20	65	Sandy River mudstone:		
Gravel	29	94	Sand	10	195
Gravel, muddy	17	111	"Sand rock"	3	198
Gravel	9	120	Clay, red	97	295
Gravel, loose	21	141	Columbia River basalt:		
			"Sand rock" (basalt?)	3	298
			"Lava rock"	3	301
			Rock, hard	104	395
1N/1-2D1. Good Samaritan Hospital [Drilled by Steinmas Bros., 1955]					
Fluviolacustrine deposits and artificial fill:			Columbia River basalt:		
"Fill"	6	6	Rock, decomposed	57	213
Sand and silt, yellow	64	70	Rock, gray, hard	31	244
Troutdale formation:			Rock, black	49	293
Gravel, brown, cemented	18	88	Basalt, hard, gray	58	351
Gravel, loose	4	92	Rock, "seamy," gray	5	356
Gravel, gray, cemented	54	146	Rock, black and gray, honeycombed	6	362
Silt, yellow	10	156	Rock, black, "seamy"	38	400
1N/1-2M2. Henry Thorle [Drilled by A. M. Jansson Drilling Co., 1941]					
Slope wash, fluviolacustrine deposits, and Troutdale(?) formation:			Columbia River basalt:		
Rock, broken, and clay	110	110	Rock, lava	15	125
			Rock, brown and black	156	281

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1N/1-33D1. U.S. National Bank, Stadium Branch (Drilled by A. M. Jannsen Drilling Co., 1946)					
Fluviolacustrine deposits and Troutdale formation			Columbia River basalt		
Sand	40	40	Rock, lava	72	300
Gravel, loose	76	116	[illegible]	7	307
Troutdale formation			Rock, black, hard	57	364
Gravel, cemented	12	128	Rock, broken	36	400
Sand and gravel	20	148	Rock, some water	13	413
Gravel, cemented	29	177	Sand, black	22	435
Sand	4	181	Rock and clay	30	465
Gravel, cemented	47	228	Rock	108	573
1N/1-33R2. First National Bank, 14th and Morrison Streets (Drilled by R. J. Strasser Drilling Co., 1934. Casing perforated, 150 to 200 ft.)					
Fluviolacustrine deposits			Troutdale formation—Continued		
Silt and sand	10	10	Gravel, large, cemented	61	214
Sand, yellow	55	65	Gravel and boulders, cemented	11	225
Troutdale formation:			Gravel, cemented	21	246
Gravel, cemented	41	106	Gravel, water-bearing	12	258
Gravel, cemented, and sand, water-bearing	14	120	Gravel, cemented	9	267
Gravel, cemented	18	138	"Conglomerate"	33	300
Gravel and sand, water-bearing	15	153			
1N/1-33R3. Pacific Telephone & Telegraph Co. (Drilled by A. M. Jannsen Drilling Co., 1947. Casing perforated, 200 to 225 ft.)					
Fluviolacustrine deposits and Troutdale formation.					
Gravel	210	210			
Gravel, water-bearing	45	255			
1N/1-34P1. Terminal Ice & Cold Storage Co. (Drilled by Green[illegible] 1911[illegible] Log furnished by O. E. Jannsen)					
Unrecorded	31	31	Sandy River mudstone.		
Alluvium(?), Troutdale(?) Formation, and Sandy River mudstone:			Clay, yellow; overlying clay, red, blue, soft	61	385
Gravel, cemented	149	180	Columbia River basalt:		
Sand, hard, and clay, blue	65	245	Basalt, hard	31½	416½
Gravel and sand, cemented	64	309	Basalt, alternate layers hard and soft, some water-bearing	135½	552
Gravel, cemented, and clay, blue	15	324			

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1N/1-34L1. Portland (Atlantic Fish Co. [Drilled by R. J. Strasser Drilling Co., 1942. Casing perforated, 40 to 70 ft.]					
Alluvium			Troutdale(?) formation:		
Clay	30	30	Gravel, cemented	13	73
Gravel, cemented	30	60			
Gravel, coarse, water-bearing	5	65			
1N/1-34N1. Weinhard — Goldberg [Drilled by A. M. Jannsen Drilling Co., 1940]					
Excavation		10	Troutdale formation—Con.		
Alluvium and fluviolacustrine deposits.			Gravel, loose, water-bearing	20	105
Sand and gravel	26	36	Gravel	3	108
Gravel	9	45	Sand	3	111
Sand and gravel, water-bearing	15	60	Gravel	2	113
Gravel	20	80	Sand and gravel, water-bearing	24	137
Troutdale formation:			Sand, black, and rock,		
Gravel, cemented	5	85	water-bearing	22	159
1N/1-34N2. U.S. National Bank [Formerly Called Artists' Theater. Drilled by A. M. Jannsen Drilling Co., 1943]					
Fluviolacustrine deposits and Troutdale formation:			Sandy River mudstone:		
			Clay	60	234
No record, old well	130	130	"Sand rock"	2	236
Sand and gravel	7	137	Clay	166	402
Gravel	17	174	Columbia River basalt:		
			Rock	1	403
1N/1-34N3. Equitable Building [Drilled by A. M. Jannsen Drilling Co., 1946. Casing perforated, 50 to 140 ft.]					
Alluvium, fluviolacustrine deposits, and Troutdale(?) formation:			Troutdale formation.		
			Gravel, slightly cemented, water-bearing	58	155
Silt and sand with gravel lenses (excavation)	15	15	Sandy River mudstone.		
Gravel and boulders	30	45	Clay, blue	18	173
Gravel	10	55			
Sand and gravel	12	67			

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)

1N/1-34N4. Equitable Building

(Drilled by A. M. Jansen Drilling Co., 1946)

Alluvium, fluviolacustrine deposits, and Troutdale formation:			Columbia River basalt:		
Gravel	107	107	Rock	100	470
Sandy River mudstone:			Rock, porous	30	500
Clay	56	213	"Sand," coarse water-bearing	8	508
Clay with sand	31	250			
Clay	120	370			

1N/1-34N5. Equitable Building

(Drilled by A. M. Jansen Drilling Co., 1947. Casing perforated from 30 to 117 ft and from 132 to 168 ft.)

Alluvium, fluviolacustrine deposits, and Troutdale formation:			Sandy River mudstone:		
Gravel and boulders	33	33	Clay, blue	3	165
Gravel, cemented	20	53			
Sand and gravel, water-bearing	107	162			

1N/1-34N10. Diuras Medical Center

(Drilled by Lance Strayer, 1954)

Fluviolacustrine deposits:			Sandy River mudstone:		
Clay, sandy	20	20	Clay, yellow	132	255
Gravel	55	75	Columbia River basalt:		
Troutdale formation:			Rock, black	15	400
Gravel, cemented	75	150	Rock, hard, black	25	425
Gravel, bouldery	50	200	Basalt, softer	166	591
Gravel, cemented	55	254			

1N/1-34N11. Diuras Medical Center

(Drilled by Lance Strayer, 1953. Casing perforated, 23 to 320 ft.)

Fluviolacustrine deposits and Troutdale formation:			Sandy River mudstone:		
Sand, yellow	15	15	Clay, yellow, and rock	59	327
Gravel, cemented	110	125	Columbia River basalt:		
Sand	5	130	Basalt	91	418
Gravel, cemented	138	268			

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
(N/I-34N1). Federal Reserve Bank of San Francisco					
(Drilled by R. J. Strasser Drilling Co., 1932. Casing perforated 200 to 235 ft.)					
Fluviolacustrine deposits and Troutdale(?) formation:			Sandy River mudstone—Continued		
No record (open shaft)	7	7	Clay, blue	13	305
Sand, "packed"	7	14	Columbia River basalt (decomposed)		
Gravel and boulders	15	29	Gravel and clay	97	402
Gravel and clay	21	50	Columbia River basalt:		
Troutdale formation:			Rock, hard, green	10	412
Gravel and sand with "binder" (clay), some water	12	62	"Conglomerate," hard	20	432
Gravel with "binder" (clay)	47	109	Rock, green	14	446
Sand and gravel, loose, water-bearing	2	111	Rock, soft, black	40	486
Gravel and clay	60	171	Clay, yellow	9	495
Sandy River mudstone:			Rock, black, hard and soft	139	634
Clay, blue	2	173	Rock, gray, with seams	14	648
Sand, "packed"	17	190	Rock, gray and red	6	654
Gravel and clay	68	258	Rock, soft, red and gray water-bearing	14	668
"Shale," green	40	298	Rock, gray and black	57	725
Sand, water-bearing	15	313	Rock, black, water-bearing	13	738
			Rock, hard, gray	17	755
(N/I-34N2). U.S. National Bank, Main Branch					
(Drilled by R. J. Strasser Drilling Co., 1947)					
Alluvium and fluviolacustrine deposits:			Sandy River mudstone—Continued		
No record (open shaft)	17	17	Clay, brown	8½	305
Gravel and boulders, cemented	22	39	Silt and sand	22	327
Silt, yellow	3	42	Clay, brown	18	345
Troutdale formation:			Columbia River basalt (decomposed?)		
Gravel and boulders, cemented	20	62	Rock ledges in brown clay	48	393
Gravel and sand, clayey, some water	8	70	Columbia River basalt:		
Gravel, cemented	5	75	Rock, hard, gray	6	399
Gravel and sand, loose, some water	22	97	Rock, porous, black	3	402
Gravel, cemented	22	119	Clay, brown	7	409
Gravel and sand	21	140	Rock, hard, black and gray	26	435
Gravel and sand with clay, blue	15	155	Rock, black, softer	15	450
Sandy River mudstone:			Rock, black with clay in crevices	4	454
Clay, blue	52	207	Rock, porous, black, no water	38	492
Silt, fine, brown	6	213	Rock, hard and creviced, black	41	533
Shale, brown	6	219	Rock, porous, black water-bearing	12	545
Sandstone, hard, gray	23	242	Rock, hard, black	4	549
Shale, brown	17	259			
Clay, reddish-brown	36	295			
Rock, gray	11½	306½			

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1N/1-34N1 First National Bank (Drilled by Barron and Strayer, 1921)					
Alluvium, fluviolacustrine deposits and Troutdale(?) formation:			Sand and clay, blue—Continued		
Gravel	85	85	Clay, layered brown, black, blue and yellow	73	325
Gravel and sand	35	120	Columbia River basalt:		
Troutdale formation:			Rock, brown and black	15	340
Gravel, coarse	45	165	Rock, porous, some water	53	393
Gravel, with cobbles and boulders	20	185	Rock, hard, black, water level dropped 20 ft	15	508
Clay, blue and green	5	190	Rock, black, "coarse cuttings"	20	528
Gravel, hard	30	220	Rock, porous, black	15	543
Sandy River mudstone:			Rock, hard	1	544
Sand, hard	25	245			
Sand and clay, blue	5	250			
"Hard shell" (sandy bed, cemented?)	2	252			
1N/1-34P1 Pacific Telephone & Telegraph Co. (Drilled by L. M. Jaansen Drilling Co., 1951)					
Alluvium and Troutdale(?) formation:			Sandy River mudstone:		
Clay	4	4	Clay, brown and blue	5	77
Boulders and gravel	31	35	Sand	1	78
"Rock" (gravel?)	37	72	"Rock" (sandstone?)	14	92
1N/1-34P2 Pacific Telephone & Telegraph Co. (Drilled by R. J. Strasser Drilling Co., 1950)					
Alluvium:			Columbia River basalt—Continued		
Sand, yellow	15	15	"Conglomerate," hard	16	391
Gravel, boulders and clay	14	29	Rock, hard, black	37	428
Gravel and boulders, loose	4	33	"Conglomerate," hard	12	440
Troutdale formation:			Basalt, hard, black	5	445
Gravel and clay	92	125	Rock, yellow	17	462
Gravel, cemented	44	169	"Conglomerate"	31	493
Clay, blue	3	172	"Shale," hard, brown	30	523
Gravel and clay	11	183	Basalt, gray and black	31	554
Sandy River mudstone:			Rock, porous, black, water-bearing	13	567
Sand, silt, some gravel, dark	57	240	Basalt, hard, black and gray	55	622
Clay, brown	86	326	"Shale," hard, dark	21	643
Sand, green	2	328	Rock, porous, black, water-bearing	32	675
Sandstone	23	351	Basalt, very hard, black	19	694
Columbia River basalt:					
Basalt, black	21	372			
Rock, gray	3	375			

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1/1-3D1. Fox Theater					
[Drilled by L. M. Jansen Drilling Co., 1941]					
Fluviolacustrine deposits and Troutdale(?) formation			Fluviolacustrine deposits, etc.—Continued		
Sand [illegible]	47	47	Gravel, coarse, considerable water	12	137
Sand, coarse, and gravel	38	85	Gravel, cemented	21	158
Gravel, some water at 95 ft	20	105	Sand, coarse and gravel	20	178
Sand, coarse, and gravel, slightly cemented	20	125	Gravel, coarse	33	211
			Gravel, water-bearing		220
1/1-3D4. Pacific First Federal Savings & Loan					
[Drilled by R. J. Strasser Drilling Co., 1955. Casing perforated, 220 to 227 ft]					
Fluviolacustrine deposits:			Sandy River mudstone:		
Soil and silt	10	10	Clay, blue, some gravel	30	247
Sand, brown	26	36	Clay, brown	33	300
Troutdale(?) formation.			Shale, hard, green	2	302
Gravel, cemented	26	62	Clay, brown, and some shale, green	28	330
Sand and gravel, water-bearing	21	83	Shale, hard, brown	3	333
Troutdale formation			Clay, brown	13	346
Gravel, cemented	18	101	Sandstone, brown and gray	6	352
Clay, sandy, brown	12	113	Columbia River basalt (decomposed?):		
Sand, gravel and clay, blue, some water	27	140	Clay, brown, and some basalt	15	367
Gravel, cemented	15	155	Columbia River basalt:		
Sand, gravel and clay, blue	75	230	Basalt, gray	1	368
Sand and gravel, loose, water-bearing	7	237			
1/1-3D5. Lead Building Co.					
[Drilled by R. J. Strasser Drilling Co., 1950. Casing perforated from 20 to 140 ft and from 198 to 207 ft]					
Fluviolacustrine deposits:			Troutdale formation—Con.		
No record, excavation	12	12	Gravel and sand, loose, water-bearing	15	140
Sand	7	19	Gravel, cemented	58	198
Sand and boulders, large	7	26	Gravel, loose, and sand	9	207
Troutdale(?) formation.			Sandy River(?) mudstone:		
Gravel, cemented, large	57	83	Clay, blue	21	228
Troutdale formation:					
Clay, sand, and gravel	42	125			

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1/1-3EL. Oregonian Building Co.					
[Drilled by R. J. Strasser Drilling Co., 1947. Casing perforated from 127 to 142 ft and from 171 to 188 ft]					
Fluviolacustrine deposits and artificial fill			Troutdale formation—Con.		
Fill	9	9	Sand and gravel, loose, water-bearing	15	142
Sand, silty	63	72	Gravel, cemented, [illegible]	29	[illegible]
Troutdale formation			Sand and gravel, loose,		
Gravel, cemented	41	113	water-bearing	18	150
Gravel, sand and clay	14	127	Gravel, cemented	14	203
1/1-3EL. Oregonian Building Co.					
[Drilled by R. J. Strasser Drilling Co., 1947. Casing perforated from 123 to 143 ft, 146 to 164 ft, 169 to 179 ft, 180 to 190 ft, and 191 to 204 ft. Gravel filled to 216 ft]					
Fluviolacustrine deposits:			Troutdale formation—Con.		
Sand, brown	91	91	Sand and gravel, water-bearing	19	210
Troutdale formation			Gravel, cemented	18	228
Gravel, cemented	37	128	Clay, greenish-blue	3	231
Sand and gravel, loose, water-bearing	12	140	Columbia River basalt.		
Sand, gravel and clay	19	159	Rock, hard, black	4	235
Gravel, cemented	32	191			
1/1-3EL. Oregonian Building Co.					
[Drilled by R. J. Strasser Drilling Co., 1947]					
Fluviolacustrine deposits:			Columbia River basalt—Continued		
Silt and clay, dry	83	83	Rock, soft, gray	28	503
Troutdale formation.			"Conglomerate," gray	6	509
Gravel, cemented	41	124	Rock, soft, gray	15	524
Sand, gravel, some water	13	137	Rock, hard, gray	16	540
Gravel, cemented	33	170	Rock, soft, porous, gray	36	576
Sand and gravel, variicolored, water-bearing	21	191	Rock, hard, gray	33	609
Sand, black	2	193	Rock, soft, black	16	625
Gravel, cemented	5	198	Rock, hard, gray	95	720
Sand and gravel, water-bearing	25	223	Rock, soft, black	65	785
Gravel and clay	3	226	Rock, hard, black	7	792
Columbia River basalt.			Rock, soft, black	12	804
Rock, hard, gray	34	260	Rock, hard, gray	8	812
Rock, soft, yellow	27	287	Rock, soft, black	1	813
Rock, hard, gray	19	306	Rock, hard, gray	5	818
Rock, soft, green	41	347	Rock, soft, red and black	17	835
Rock, hard, black	40	387	Rock, hard, red	13	848
"Conglomerate," some water	3	390	Rock, black, caving, with red deposits, water-bearing	27	875
Rock, hard, gray	85	475	Rock, hard, gray	5	880

TABLE 2.—*Drillers' logs of representative wells*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1N/1E-4L. Bailey Makers Union					
(Drilled by R. J. Strasser Drilling Co., 1942. Casing perforated from 120 to 130 ft and from 138 to 140 ft)					
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation		
			[illegible]	40	100
			Sand and gravel, water-bearing	20	140
Clay, sandy	43	43	Gravel and sand, very fine	11	151
Gravel, cemented	18	61			
Sand, some water	5	66			
Clay and gravel	14	80			
1N/1E-5F1. Portland General Electric Co.					
(Drilled by A. M. Janssen Drilling Co., 1947)					
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation—Con.		
			Sand and some gravel	40	137
			Gravel, water-bearing	18	175
Sand	10	10	Sand and gravel	45	220
Gravel and boulders	30	40	Sandy River mudstone:		
Shale	2	42	Clay, blue	53	275
Sand and gravel	18	60	Clay, yellow	40	315
Clay, yellow	5	65	Sand and gravel, water-bearing	25	340
Troutdale formation:			Columbia River basalt:		
Gravel, cemented	30	95	Rock	220	560
Gravel, loose	22	117			
1N/1E-4AL. Portland Art Museum					
(Drilled by A. M. Janssen Drilling Co., 1938. Casing perforated, 218 to 223 ft)					
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation—Con.		
			Gravel, loose, water-bearing	4	170
Sand, loose, and clay	90	90	Sand and gravel, cemented	30	200
Troutdale formation:			Sand, loose, and gravel	5	205
Sand and gravel, cemented	34	124	Sand, loose, green	10	215
Gravel, cemented, and clay	42	166	Sand, green, and rock, loose, water-bearing	20	235
1N/1E-4CL. Rose City Bowl, Inc.					
(Drilled by A. M. Janssen Drilling Co., 1958)					
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale(?) formation—Continued		
			Clay and "rock"	25	98
Gravel	28	28	Gravel and clay	64	162
Boulder	9	37	Clay and "rock"	10	172
Gravel	29	66	Columbia River basalt:		
Troutdale(?) formation:			Rock	73	245
"Rock"	9	75			

TABLE 3 — *Monthly metered pumpage for heating and cooling, in acre feet, discharged to the city of Portland sewers from wells in the west side business district*

[Tt, Troutdale formation, Tc, Columbia River basalt, e, estimated data, p, partial data only, totals rounded]

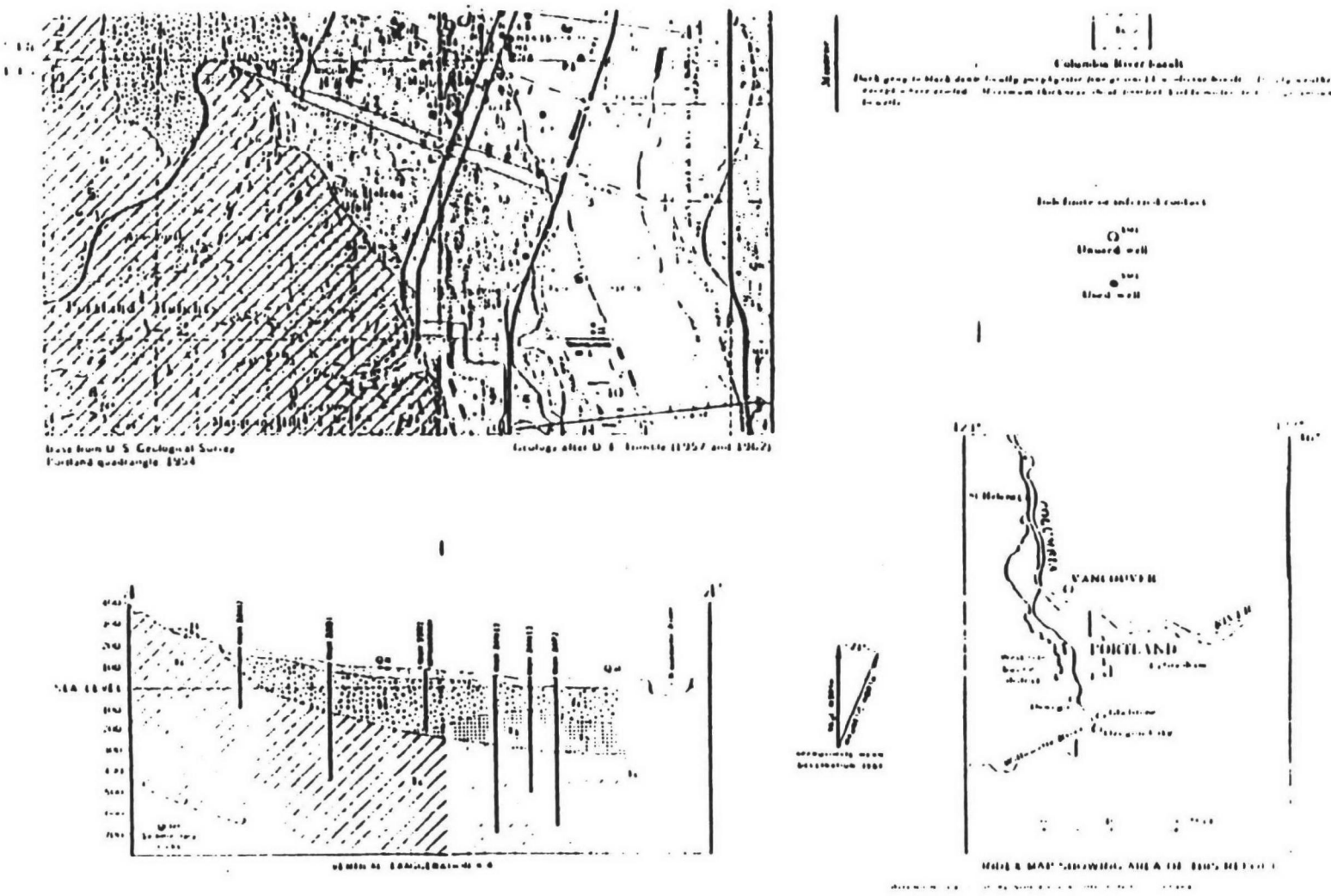
Year	Pumpage from	January	February	March	April	May	June	July	August	September	October	November	December	Totals
1951	Tt	.....	.....	.....	.....	.....	.....	.....	.....	.....	21.2	21.0	27.7	.....
	Tc	.....	.....	.....	.....	.....	.....	.....	.....	.....	18.6	8.4	8.0	.....
	Totals	.....	.....	.....	.....	.....	.....	.....	.....	.....	20	31	36	.....
1955	Tt	27.8	20.1	20.3	25.3	27.6	19.0	47.0	57.4	75.9	57.1	41.7	26.0	180
	Tc	8.9	10.6	9.1	12.2	22.6	35.0	37.1	61.7	19.2	28.0	14.1	4.1	300
	Totals	37	31	35	38	60	85	84	120	130	85	56	30	780
1950	Tt	37.4	60.5	11.8	65.5	108.0	100.6	128.6	121.4	94.0	71.1	48.8	39.7	920
	Tc	9.2	3.5	1.6	15.7	31.2	46.0	90.8	85.8	67.3	21.1	5.5	4.5	390
	Totals	47	64	16	81	140	150	220	210	160	94	54	44	1,300
1957	Tt	31.0	60.8	48.7	32.8	98.8	108.1	110.4	120.0	258.1	97.3	88.7	92.2	1,200
	Tc	4.5	6.6	8.8	13.6	28.4	50.7	52.0	42.1	78.2	18.0	11.7	7.0	300
	Totals	38	67	56	46	130	160	170	160	340	120	100	100	1,500
1958	Tt	92.2	91.9	94.0	85.2	138.0	166.2	148.0	138.5	144.3	80.9	57.8	*57	1,300
	Tc	8.0	11.0	6.5	10.0	50.1	66.1	97.0	70.4	61.7	31.3	10.0	*10	510
	Totals	100	100	100	110	190	230	250	210	200	110	100	100	1,800

TABLE 4.—*Chemical analyses of water from wells of the west side business district, Portland, Oregon*

[In parts per million except the last 2 items. Tt, Troutdale formation, Tc, Columbia River basalt]

Well	1S/1 34N3	1N/1 34N4		1N/1 34N12		1N/1 34N13		1N/1 34N2		1/1 3E1	1/1 3E2		1/1 3E3	
Date of collection	Oct. 23, 1950[1]	Jan. 9, 1947[2]	Mar. 9, 1953[3]	Nov. 18, 1953[3]	Mar. 1, 1955[3]	Nov. 18, 1953[3]	Mar. 1, 1955[3]	Apr. 3, 1951[3]	Mar. 1, 1955[3]	June 11, 1947[2]	July 1, 1947[2]	July 14, 1950[1]	Jan. 7 1946[1]	Mar. 1, 1955[3]
Aquifer (formation)	Tt	Tc	Tc	Tt & Tc	Tt & Tc	Tc	Tc	Tc	Tc	Tt	Tt	Tt & Tc[4]	Tc	Tc
Silica (SiO_2)	62	33		65				63		62	49	64	58	
Iron (Fe) (total)	0.16	.2		2.9						.01	.03	2	4	
Manganese (Mn)				.03				.08		.05	.27	.6		
Calcium (Ca)	31	45		197		84		64		30	39	61	115	
Magnesium (Mg)	10	8		12				3.7		16	17	6	6	
Sodium (Na)														
Potassium (K)	174			218				160		6.7	8.3	62	174	
Bicarbonate (HCO_3)			116	33	107	98	85	117	116			169	135	154
Carbonate (CO_3)				53(?)				0				0	12	
Sulfate (SO_4)	18	13		12				0.8		0.1	14	15	7.1	
Chloride (Cl)	29	308	400	658	610	60	360	5.8	430	18	22	82	34	233
Fluoride (F)				.3				0		.2	.05	.2		
Nitrate (NO_3)				6.8						1.8	2.3			
Dissolved solids														
Sum				1 230				607				287		
Residue on evaporation	312													
Hardness as $CaCO_3$	117	118	200	610	0.5	164	650	176	765	150	165	338	516	618
Noncarbonate	0	0								0	0		317	0.0
Free CO_2	60	8						3		63	66	31	0	
Specific conductance			1 310		2 610		2 310		1 910					1 970
pH	8.1	7.8	7.1	7.8	7.6		8.8	7.8	7.8	8.3	8.1	7.3	8.3	7.2

[1] Analysis by Charlton Laboratories, Portland
[2] Analysis by U. S. Geol. Survey
[3] Analysis by the Hoss Co., Inc.
[4] Water from Tc introduced by artificial recharge
[5] Iron and aluminum oxide



GEOLOGIC MAP OF A PART OF PORTLAND, OREGON, SHOWING THE LOCATION OF REPRESENTATIVE WELLS

EXPLANATION

Qal

Alluvium and artificial fill

Predominantly sand and silt deposited on the flood plain of the Willamette River. Generally less than 50 feet thick. Includes areas of artificial fill, largely derived from Recent alluvium, especially along the Portland water front. Coarser sand and gravel yields moderate quantities of water to wells.

Recent

Qfl

Fluviolacustrine deposits

Unconsolidated gravel, sand, clay, and silt, mostly stratified and locally cross-bedded. As much as 100 feet thick. Exposed at altitudes above 50 feet. Yields small to moderate quantities of water to wells.

Pleistocene

QUATERNARY

Tt

Troutdale formation

Conglomerate, sandstone, shale, and mudstone, tuffaceous in part. Conglomerate mostly Columbia River basalt, lesser amounts of other volcanic rocks and quartzite. Sandstone predominantly quartzose and micaceous. Yields moderate to large quantities of water to wells.

Pliocene

Ts

Sandy River mudstone

Mudstone, shale, and sandstone; not exposed but occurs at depth in part of the area. (shown in cross section only). Yields little water to wells.

TERTIARY

Tc

Columbia River basalt

Dark-gray to black dense locally porphyritic fine-grained low-olivine basalt. Deeply weathered surface except where eroded. Maximum thickness about 1,000 feet. Yields moderate to large amounts of water to wells.

Miocene

Indefinite or inferred contact

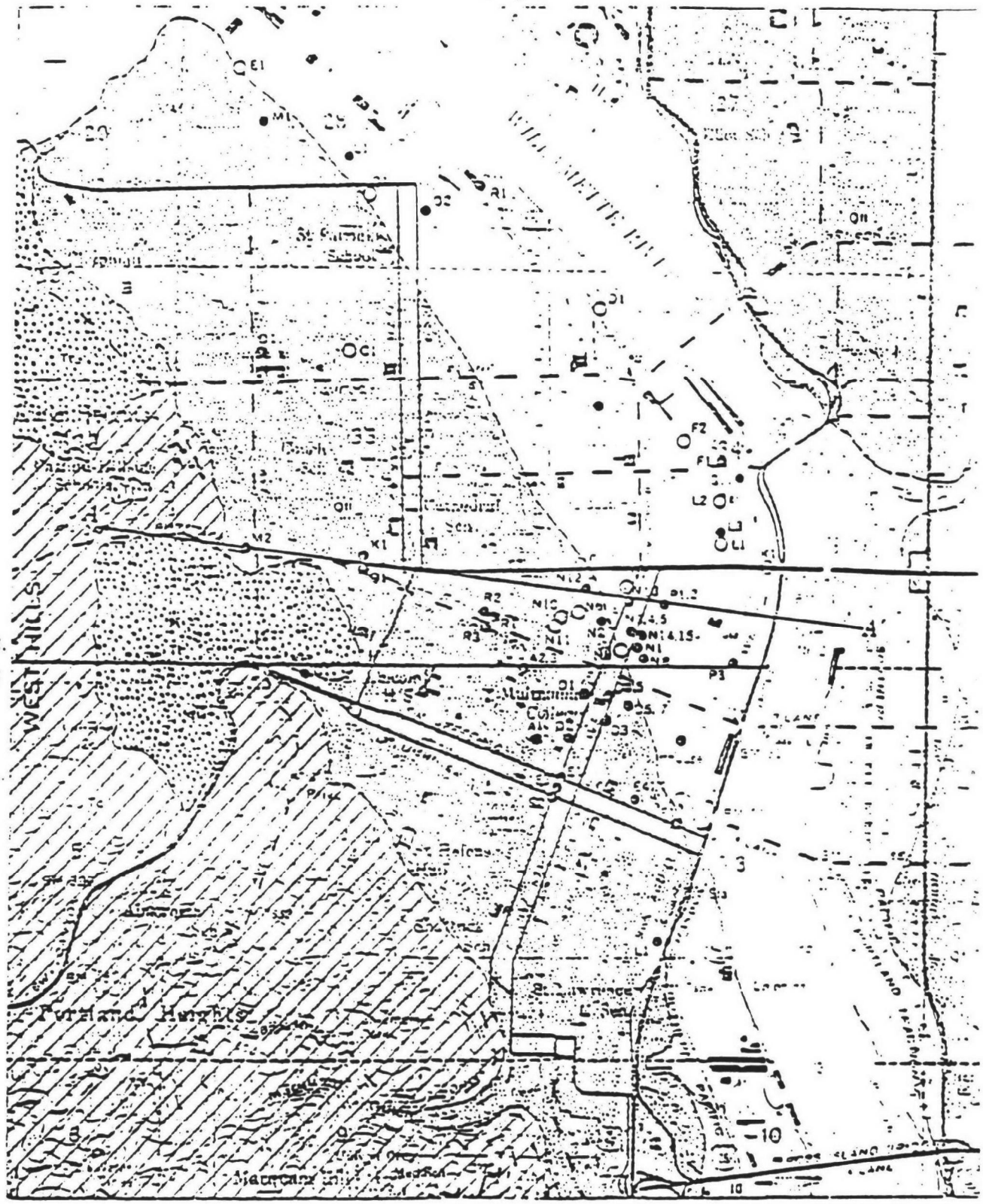
○ 5N1

Unused well

● 5N1

Used well

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY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Portland Heights
Balch
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Miocene
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Pliocene
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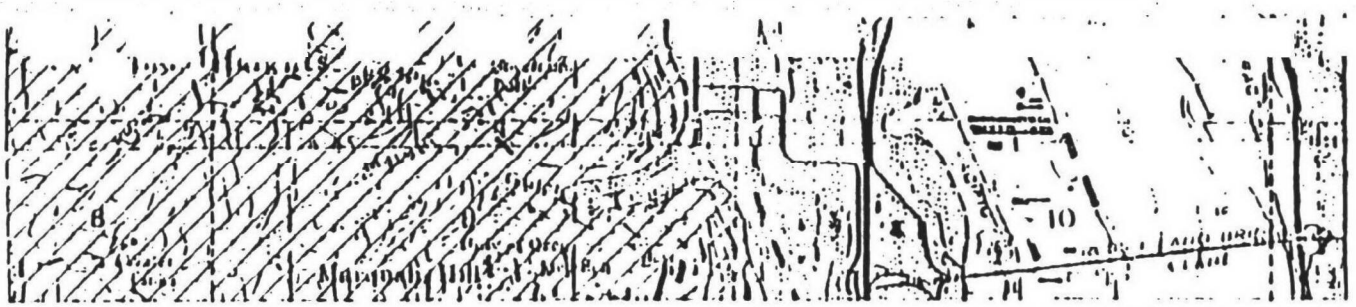
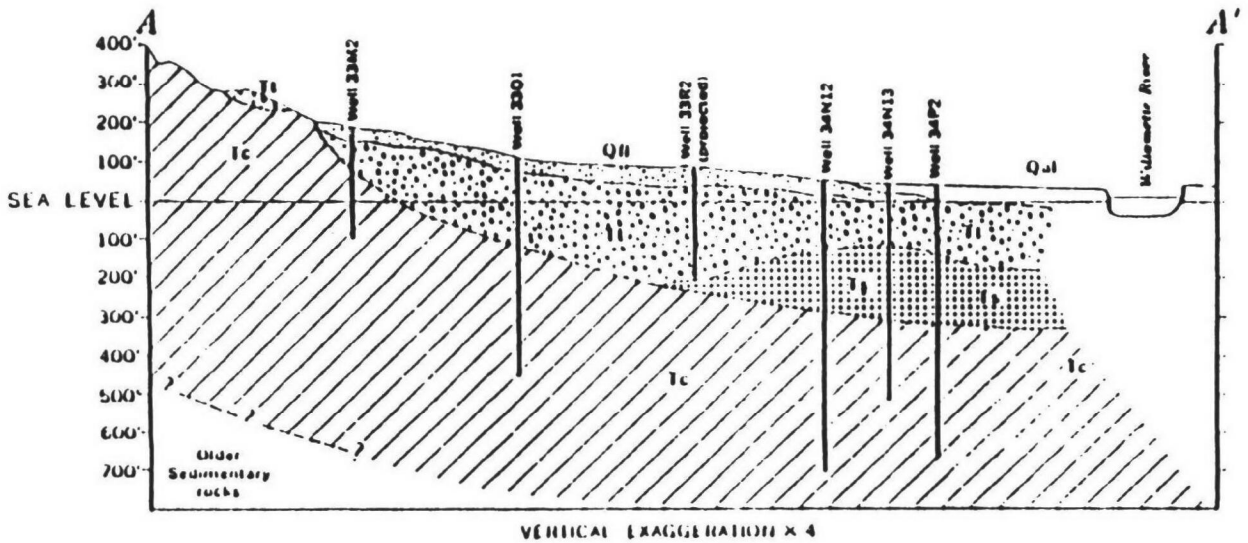
Pli

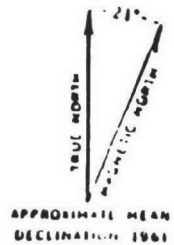


Base from U. S. Geological Survey
Portland quadrangle, 1954

Geology after D. T. Trimble (1957 and 1962)



VERTICAL EXAGGERATION × 4



INDEX MAP SHOWI

INTERIOR—GEOLOGICAL SURVEY, WASHIN

GEOLOGIC MAP OF A PART OF PORTLAND, OREGON, SHOWING THE LOCATION OF RF

SCALE 1:24 000

0 1 MILE

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

QUATERNARY

Recent

Qal

Alluvium and artificial fill

Predominantly sand and silt deposited on the flood plain of the Willamette River. Generally less than 50 feet thick. Includes areas of artificial fill, largely derived from Recent alluvium, especially along the Portland water front. Coarser sand and gravel yields moderate quantities of water to wells

Pleistocene

Qfl

Fluviolacustrine deposits

Unconsolidated gravel, sand, clay, and silt, mostly stratified and locally crossbedded. As much as 100 feet thick. Exposed at altitudes above 50 feet. Yields small to moderate quantities of water to wells

TERTIARY

Pliocene

Tt

Troutdale formation

Conglomerate, sandstone, shale, and mudstone; tuffaceous in part. Conglomerate mostly Columbia River basalt, lesser amounts of other volcanic rocks and quartzite. Sandstone predominantly quartzose and micaceous. Yields moderate to large quantities of water to wells

Ts

Sandy River mudstone

Mudstone, shale, and sandstone; not exposed but occurs at depth in part of the area (shown in cross section only). Yields little water to wells

Miocene

Tc

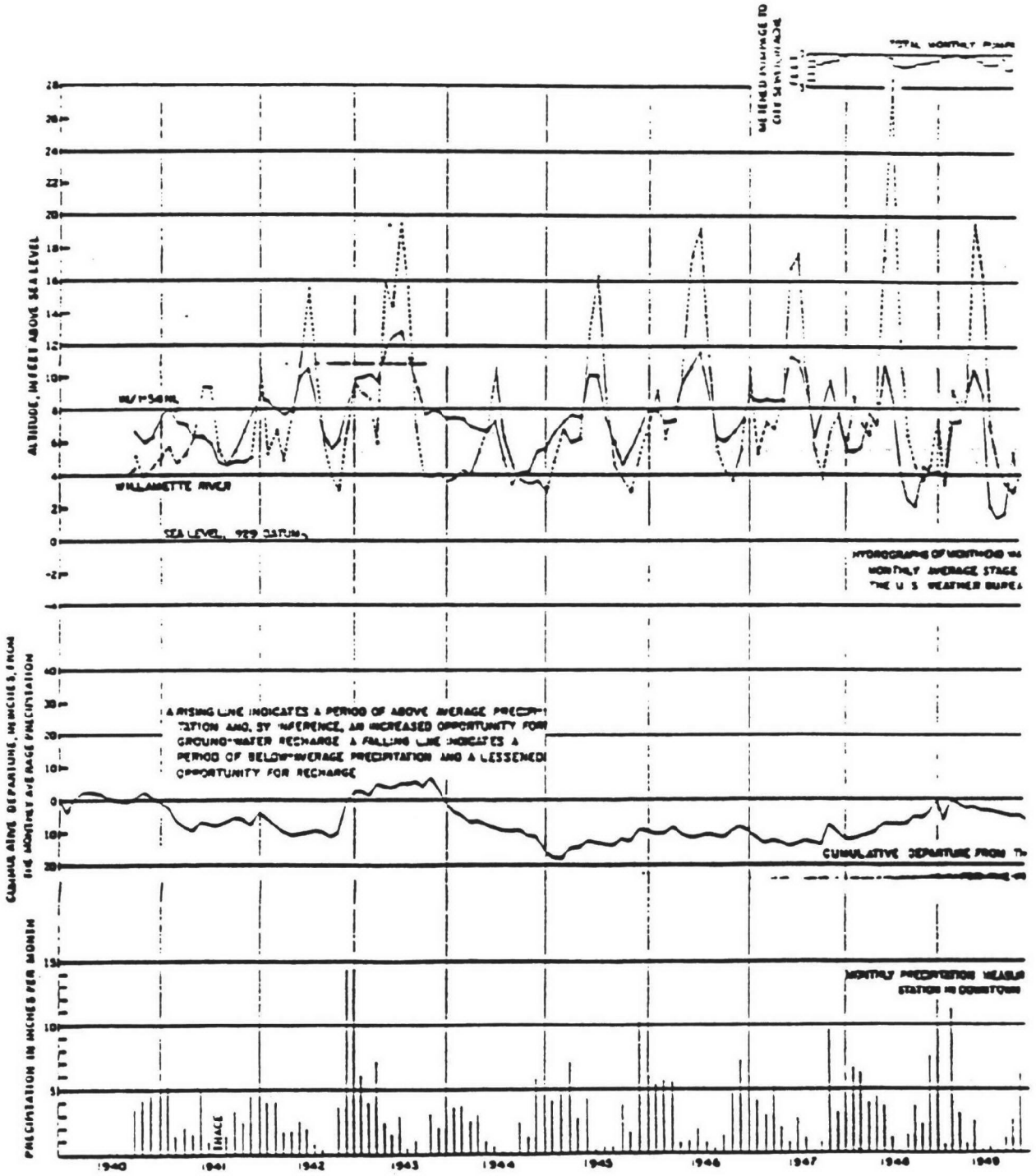
Columbia River basalt

Dark-gray to black dense locally porphyritic fine-grained low-olivine basalt. Deeply weathered surface except where eroded. Maximum thickness about 1000 feet. Yields moderate to large amounts of water to wells

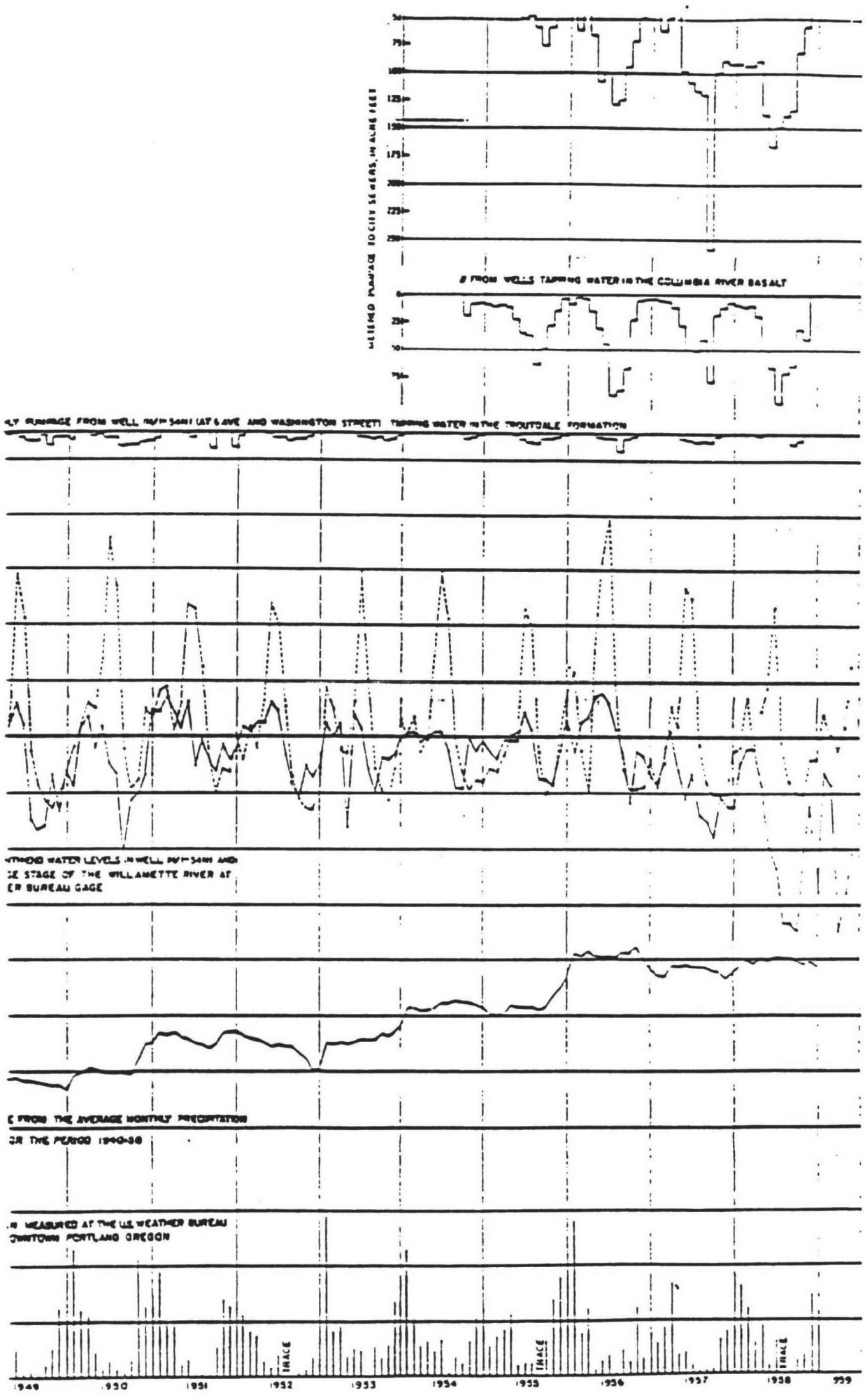
Indefinite or inferred contact

5M1
Unused well

5M1
Used well



GRAPHS SHOWING WATER LEVELS IN WELL 1N/1-24N1, METERED PUMPAGE FROM THA
MONTHLY AVERAGE STAGE OF THE WILLAMETTE RIVER
AND CUMULATIVE DEPARTURE FROM AVERAGE



M THAT WELL AND FROM THE TROUTDALE FORMATION AND COLUMBIA RIVER BASALT
RIVER AT PORTLAND, OREGON MONTHLY PRECIPITATION

SECTION 3.1.4

TITLE OF STUDY: (or SOURCE OF INFORMATION)	Low Temperature Geothermal Resource Management
AUTHOR: (or INVESTIGATOR)	Lauren S. Forcella
DATE:	February, 1984
STUDY AREA:	Oregon USEPA Region X
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	This document was prepared by the Oregon Water Resources Department for the Oregon Department of Energy. Basic descriptions of the use of geothermal resources are provided along with discussions of effluent disposal and associated thermal degradation. Current regulatory status is discussed and recommendations concerning future statute changes are provided.

LOW TEMPERATURE GEOTHERMAL RESOURCE MANAGEMENT

* *

by

Lauren S. Forcella

OREGON WATER RESOURCES DEPARTMENT

for

OREGON DEPARTMENT OF ENERGY

FEBRUARY 1984

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NOTICE

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ABBREVIATIONS

AEDC	Alternate Energy Development Commission
Btu	British Thermal Unit
COP	Coefficient of Performance
CRGD	Citizens for Responsible Geothermal Development
DEQ	Department of Environmental Quality
DOGAMI	Department of Geology and Mineral Industries
LBL	Lawrence Berkeley Laboratory
NCSL	National Conference of State Legislatures
NPDES	National Pollutant Discharge Elimination Systems
OAR	Oregon Administrative Rules
ODOE	Oregon Department of Energy
OIT	Oregon Institute of Technology
ORS	Oregon Revised Statutes
USDOE	United States Department of Energy
USGS	United States Geological Survey
WPCFP	Water Pollution Control Facilities Permit
WRD	Water Resources Department

INTRODUCTION

Low temperature geothermal fluid is defined in OAR Chapter 690, Division 65 as any ground water used for its thermal characteristics that is encountered in a well with a bottom hole temperature less than 250°F (121°C). As such, low temperature geothermal resources are considered part of Oregon's ground water resources and are managed by the Oregon Water Resources Department (WRD). Use of ground water for its thermal properties is considered a beneficial use. With current interest in renewable resources and improved technology in heat extraction, the thermal value of ground water at all temperatures has increased dramatically adding to the complexity of ground water management.

Higher than normal terrestrial heat flow in the Cascade Mountains, the Basin and Range, Columbia Plateau, Oregon Plateaus and the Snake River Plain Provinces give Oregon outstanding potential for use of geothermal resources. Geothermal energy in Oregon potentially is capable of displacing seven million barrels of fuel oil annually, comprising 27 trillion Btus/year (903 MWe) of electrical energy and 66 trillion Btus/year (2208 MWt) of thermal energy. This is equivalent to the energy produced by six Boardman coal-fired plants (Geothermal Task Force, 1980). In a report for the Pacific Northwest Utilities Conference Committee and the Oregon Energy Facility Siting Council by the Oregon Department of Energy (ODOE), these figures have been updated to 6236 MW of total electrical and thermal power or 12 Boardman coal-fired plants (Brown, 1982).

Geothermal resources most commonly are confined to intensely faulted areas where hydrogeologic conditions are favorable for deeply circulated thermal water to rise to land surface. Klamath Falls, Lakeview and Vale are examples of population centers built around active hydrothermal discharge areas. The direct use of geothermal energy for space and process heating in Klamath Falls is the largest application of its kind in the United States. Other areas with potential are the urban areas near the Cascade Mountains such as Portland, Salem, Eugene, Springfield, Oakridge and Hood River, or those of the Oregon Plateau such as Bend, Prineville, Madras and Burns. Other population centers near hydrothermal anomalies are The Dalles, Ontario and La Grande and many rural areas of southeastern Oregon. All these areas have the potential to implement district heating plans that could supply the locale with heat and/or electrical energy. Figure 1 and Table 1 show the geological provinces of the state and the estimated heat available for different areas as determined by the U.S. Geological Survey (USGS) (Reed, 1982).

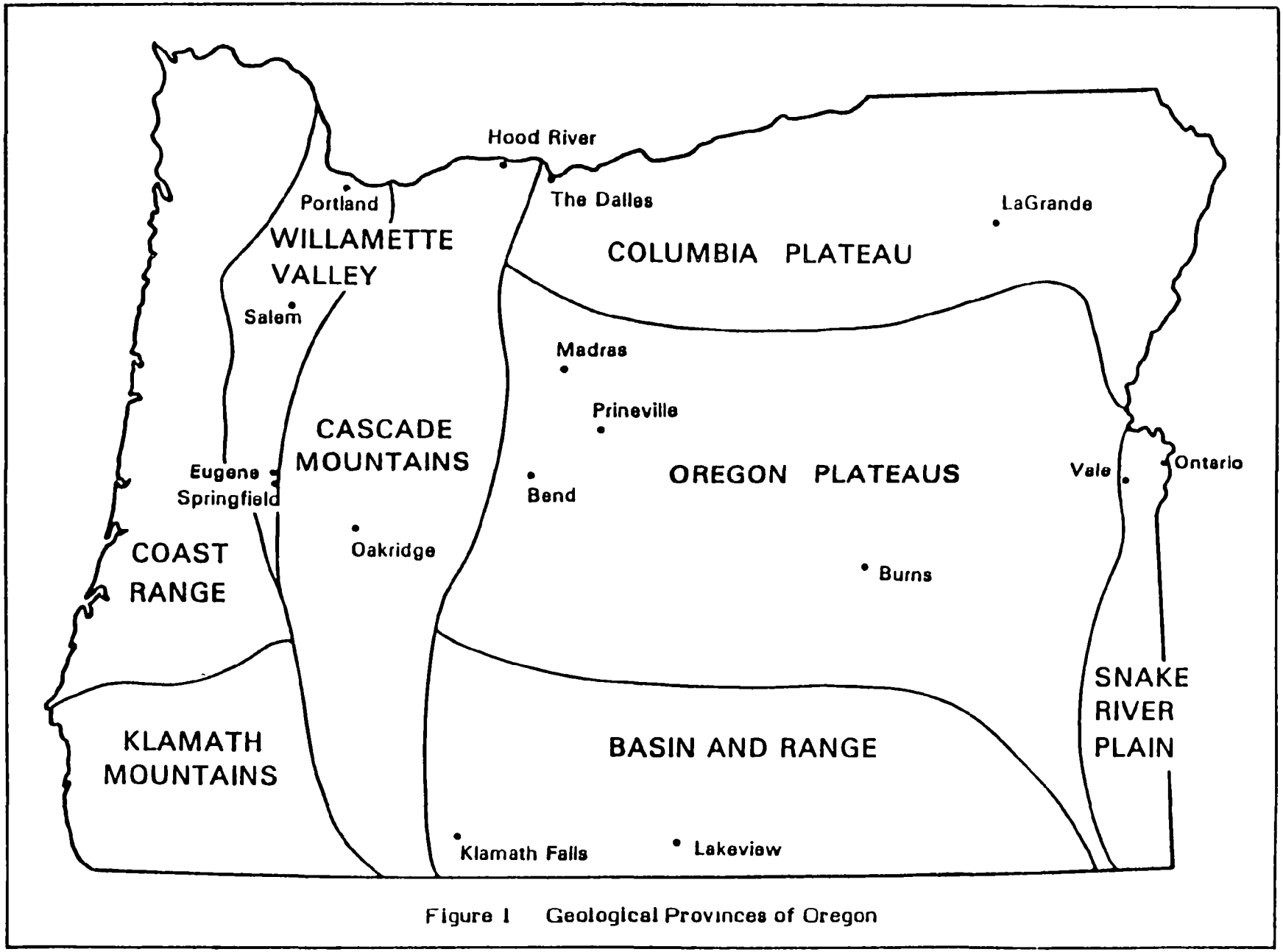

Figure 1 Geological Provinces of Oregon

Geologic province Geothermal area	Category	Mean reservoir temperature (°C)	Mean reservoir area (km^2)	Mean reservoir thickness (km)	Mean accessible resource base (10^{18} J)	Resource (10^{18} J)	Beneficial Heat (MW_t for 30 yr)	Comments
Basin and Range province								
Isolated systems----------	1	--	--	--	1.34±0.163	0.33	132	72 systems
Klamath Basin-------------	2	30	117	25	1.14±0.66	062	13.2	Wells (21°-90°C), 25 to 384 m deep. 2 wells (90°C) 127 m deep, (22°C) 344 m deep; TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1.8 km^2
Klamath Falls-Olene Gap---	2	60	32	25	93±0.36	.122	60	Springs (65°-74°C) and wells (21°-89°C), to 560 m deep, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1.07 km^2
Klamath Hills-------------	2	53	20	25	51±0.23	092	43	Wells (72° 93°C), temperatures do not change uniformly with depth, 2 wells (93°C) 86 m deep, (30°C) 235 m deep, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2.
Warner Valley-------------	2	58	40	25	1.13±0.63	104	51	20 springs and wells (20°-93°C), depths to 285 m, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1.14 km^2
Cascade Range province								
Isolated systems----------	1	--	--	--	1.82±0.23	45	230	15 systems.
Columbia Plateaus province								
Isolated systems----------	1	--	--	--	95±0.155	24	107	11 systems.
Cove----------------------	2	43	7.3	.25	.135±0.052	032	13.0	Springs and wells (20°-42°C), TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2.
Hot Lake------------------	2	67	7.3	.25	25±0.097	.058	23	Springs (30°-80°C) and wells (25°-82°C)· no depth data, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2
La Grande-----------------	2	71	13.7	25	50±0.21	.101	53	Wells (26°-28°C), no depth data, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2
Rhinehart-Imbler----------	2	55	11.0	25	29±0.178	062	30	Wells (22°-31°C), no depth data, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2.
Oregon Plateaus province								
Isolated systems----------	1	--	--	--	2.5±0.22	0.63	260	35 systems.
Baker Spring--------------	2	45	7.7	25	151±0.059	036	15.1	2 springs (21°C) and 1 well (23°C), TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2
Burns---------------------	2	52	14.0	25	34±0.145	068	31	Wells (25°-30°C), some are artesian, depths about 30 m, $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2
Powell Buttes-------------	2	45	63	25	1.24±0.55	040	17.0	Marginal well temperatures (20°-32°C), no depth data, TDS (1), $\underline{T}$=0.0025 m^2/s, $\underline{s}_w$=2.55 km^2
Southeast Harney Lake-----	2	55	30	25	78±0.32	068	32	Springs (20°-51°C), possibly associated with high-temperature system, TDS (2), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1.08 km^2.
Warm Springs Valley-------	2	56	27	.25	.70±0.32	104	50	Springs and artesian wells (20°-26°C), on northeast side of Harney Lake, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1.03 km^2.
Western Snake River Plain province								
Isolated systems----------	1	--	--	--	25±0.082	062	31	2 systems.
Vale Well-----------------	2	40	4.3	25	070±0.024	017	6.3	2 wells (36° and 40°C), 212 m deep· possibly associated with a high-temperature system, TDS (1), $\underline{T}$=0.005 m^2/s, $\underline{s}_w$=1 km^2
Total			394.3				1197.6	

Table 1 Estimated reservoir values and thermal energies of identified low temperature geothermal resources in Oregon (modified from Reed, 1982)

The hotter the ground water, the more attractive it is for development of geothermal resources. However, all ground water contains stored heat. The specific heat of a substance is that quantity of heat required to increase the temperature of a unit weight of that substance 1°C. Water, the standard substance for defining that quantity of heat, has a specific heat of 1.0. With only a few exceptions, water has the highest specific heat of all compounds. Because of this, all aquifers are prime reservoirs of the earth's stored heat energy.

Current technology in heat pumps enables heat to be extracted economically, in some areas, from water as low as 40°F (4°C). Some designs of heat exchangers allow heat to be extracted with no withdrawal of water. Earth heat extraction via ground water resources may one day become the dominant method of space heating in the United States. In other applications, binary generators are making electrical generation possible from water as cool as 180°F (82°C). District heating systems have the potential to supply thermal and electrical energy to many customers with significant savings compared to conventional sources of heat and electricity. With ground water now commonly used as a heat source, the diversity of ground water use is compounded. This emphasizes the public policy issue of adequate protection and management for future generations.

METHODS OF HEATING AND HEAT EXTRACTION

Ground Water Heat Pumps:

A heat pump is generally any system that uses refrigeration equipment to provide space heating or cooling. Most familiar is the air-to-air heat pump used in many residential, commercial and industrial buildings. In these systems, air is used both as heat source and heat sink. With the variability of air temperature and its seasonal fluctuations, efficiency drops during temperature extremes. When heating is required in winter, the cold outside air can provide little heat energy. The reverse is true in summer when cooling is required. However, because of water's high specific heat and the insulating effect of rocks and soil, ground water temperatures vary little throughout the year. This constancy makes ground water effective as a heat source in winter when it is warmer than mean air temperatures and as a heat sink in summer when it is cooler than mean air temperatures. Recent designs of ground water source heat pumps make it economical in some areas to extract heat from ground water with temperatures as low as 40°F (4°C).

During the heating cycle, the ground water source heat pump works by using heat from ground water to evaporate freon (or other low-boiling point refrigerants). The gaseous freon is then circulated through a compressor to the condensor side of the heat exchanger coil where air is blown over the coil. The air cools the gaseous freon, condensing it to a liquid which releases heat to the area to be heated. The liquid freon then recirculates to the evaporator side of the heat exchanger where heat from the ground water is again absorbed causing the freon to vaporize. The gaseous freon repeats the circulation pattern by condensing and releasing the absorbed heat to the air. In the process, the ground water is cooled and the air is warmed. This describes the water-to-air heat pump, however water-to-water heating is also common.

This repeating process of evaporation, compression, condensation and expansion in the heat pump is known as the Carnot cycle. See Figure 2. The process is reversed for space cooling.

The ratio of thermal output (Btu/hr) to electrical input (kWh) is a measure of system efficiency or coefficient of performance (COP). COPs of recently manufactured ground water heat pumps range from about 2.5 to 5, depending on water temperature and system design. The ground water heat pump needs about 2.5 gallons of water per minute for 12,000 Btus/hour of heat extraction. Thus, during demand time the average home needs about 5 to 12 gallons of water per minute, depending on the size of the house and the air and ground water temperatures.

Potential problems for ground water heat pumps are the possibility of corrosion, scaling or iron bacteria growth fouling the system. Chemical treatment of poor quality ground water can often prevent such problems. Other problems are finding a sustainable source of ground water and discharging the effluent in conformance with government standards. As described in a later section, discharging the effluent to waste is allowable in many situations, but is considered by WRD to be a "nonstandard" method of effluent disposal. Preferably, the ground water is consumed after heat is exchanged or is reinjected to the same or a suitable aquifer. This insures longevity of supply and is a responsible approach to a sustainable energy future.

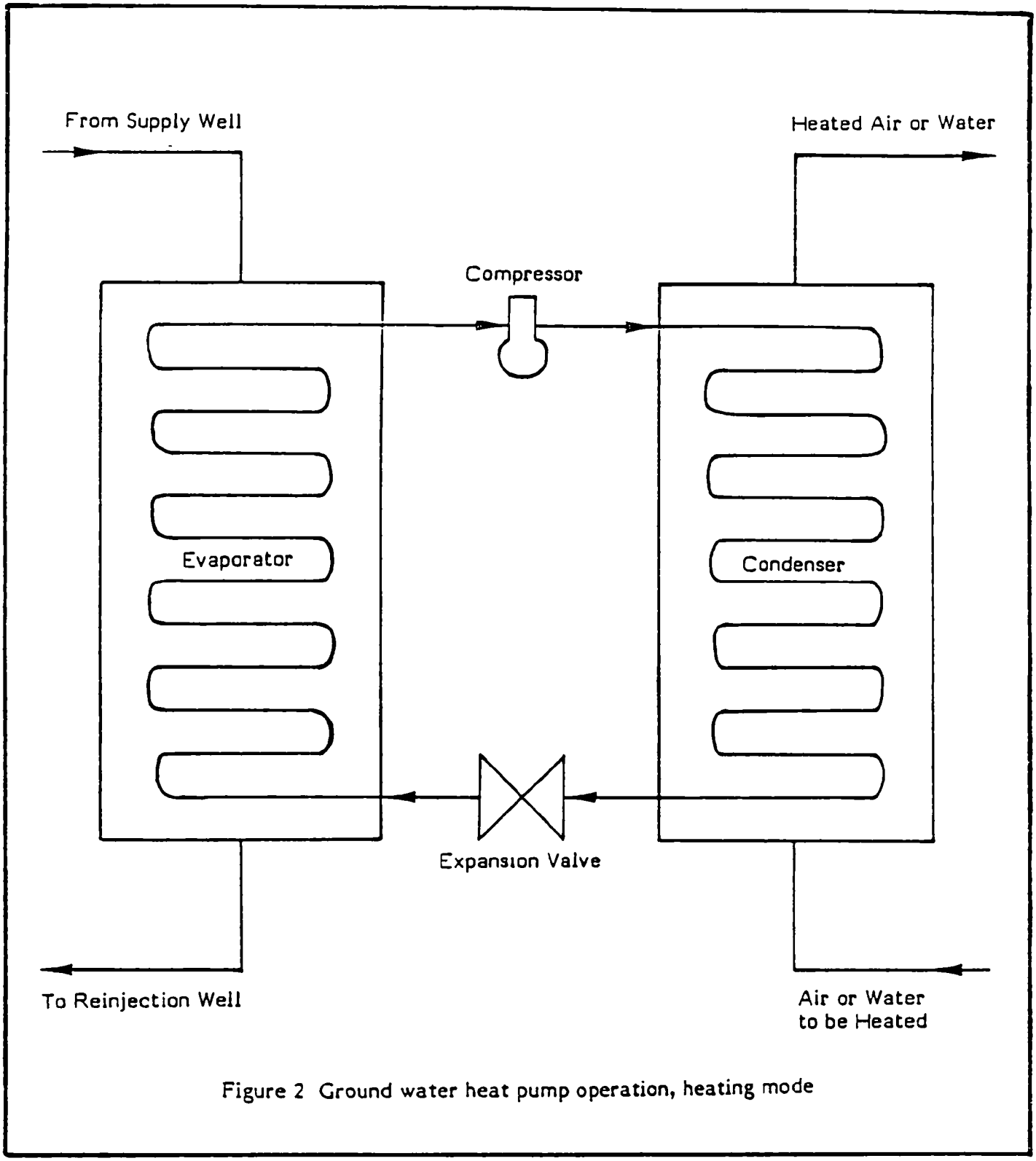

Figure 2 Ground water heat pump operation, heating mode

Estimates by ODOE indicate that about five applications for tax credits on ground water heat pumps currently are submitted each month. Most of these are being installed in the Willamette Valley (Personal Communication, David Brown, 1983). Tax credits are offered for systems with a COP of at least three for space heating and a COP of at least two for water heating.

To operate these heat pumps, both "standard" and "nonstandard" disposal systems are being used. The effluent is not contaminated in any way by the typical heat pump system. However, the water temperature is altered by 5 to 20°F (3 to 11°C). This opens the potential for thermal degradation of aquifers, especially when reinjection wells are significantly dense or the volume of reinjected effluent is significantly large. Monitoring has begun in some parts of the nation to study effects of thermal pollution resulting from reinjected heat pump effluent on different aquifer types. To date, Oregon has no such monitoring, although it is planned.

Hydronic Heating Systems:

Hydronic heat emitting systems such as radiant panels, finned-tube baseboard convector units and forced-air systems are commonly used for space conditioning. They are most efficient when thermal fluids can be used directly. However, thermal fluids often contain chemical impurities that result in scaling or corrosion to the heat emitting equipment. Because of this, a heat exchanger or heat pump is often used to heat a benign secondary fluid. The heated secondary fluid is then circulated through the distribution system and reheated by the source thermal fluid in a closed loop arrangement.

Heat Exchangers:

Downhole Heat Exchanger — Downhole heat exchangers, sometimes known as closed loop earth-coupled systems, work by extracting heat from a well without withdrawal of water. The downhole heat exchanger functions by circulating a secondary fluid through a closed U-shaped conduit placed in a well. The secondary fluid extracts heat from the well. In most cases the fluid is circulated by a thermostatically controlled in-line pump. The heated working fluid is then piped to some type of convective, radiant and/or forced-air heat distribution unit. In the case of low temperature, the heated fluid may be used in a heat pump.

Well depth requirements are a function of water temperature, depth to water, seasonal fluctuations in water level, and heating or cooling requirements.

Closed loop systems are common in Klamath Falls and to a lesser extent in La Grande, Lakeview and Vale. More than 400 such downhole heat exchangers are used for space heating and hot water in Klamath Falls. Most are installed in the hot well area of the city where ground water temperatures range from 190 to 235°F (87 to 113°C). With temperatures this high, cool city water is used as the working fluid. In most cases, no circulating pump is necessary because natural convection circulates the city water. For the Klamath Falls system, each foot of coil will yield about 1500 Btus/hour (Lund, et al., 1978). Figure 3 shows a typical Klamath Falls well equipped with a downhole heat exchanger.

In Klamath Falls, most wells are constructed to commingle water from two or more permeable hot aquifers. Apparently, the convection cell that is established within the borehole enhances the heat exchange process. It is unknown what the long-term effect of this commingling has been or will be. Additionally, the heat exchangers are removing stored heat from the reservoir. Under contract with ODOE, WRD established a network of wells in 1982 to monitor long-term effects of heat removal and commingling in the dense hot well area of Klamath Falls.

The closed loop or downhole heat exchanger is not as efficient as the ground water source heat pump. However, not all aquifers have ample supply and recharge capacity to justify withdrawal of water for heating and not all users can afford to reinject the effluent created by a ground water source heat pump. Another advantage of the downhole heat exchanger is that ground water quality or quantity is of no importance. As the cost of conventionally produced heat rises, so will the popularity of the downhole heat exchanger.

Plate Heat Exchanger -- The plate heat exchanger consists of a series of plates clamped together in a frame. Commonly the plates are made of stainless steel, titanium or brass. The thermal and secondary fluids move through the plates in single-pass counter flow providing efficient exchange. The plates dismantle easily for cleaning. Additional plates can be added in series to increase heating capacity. This type of heat exchanger is readily available for applications of all sizes.

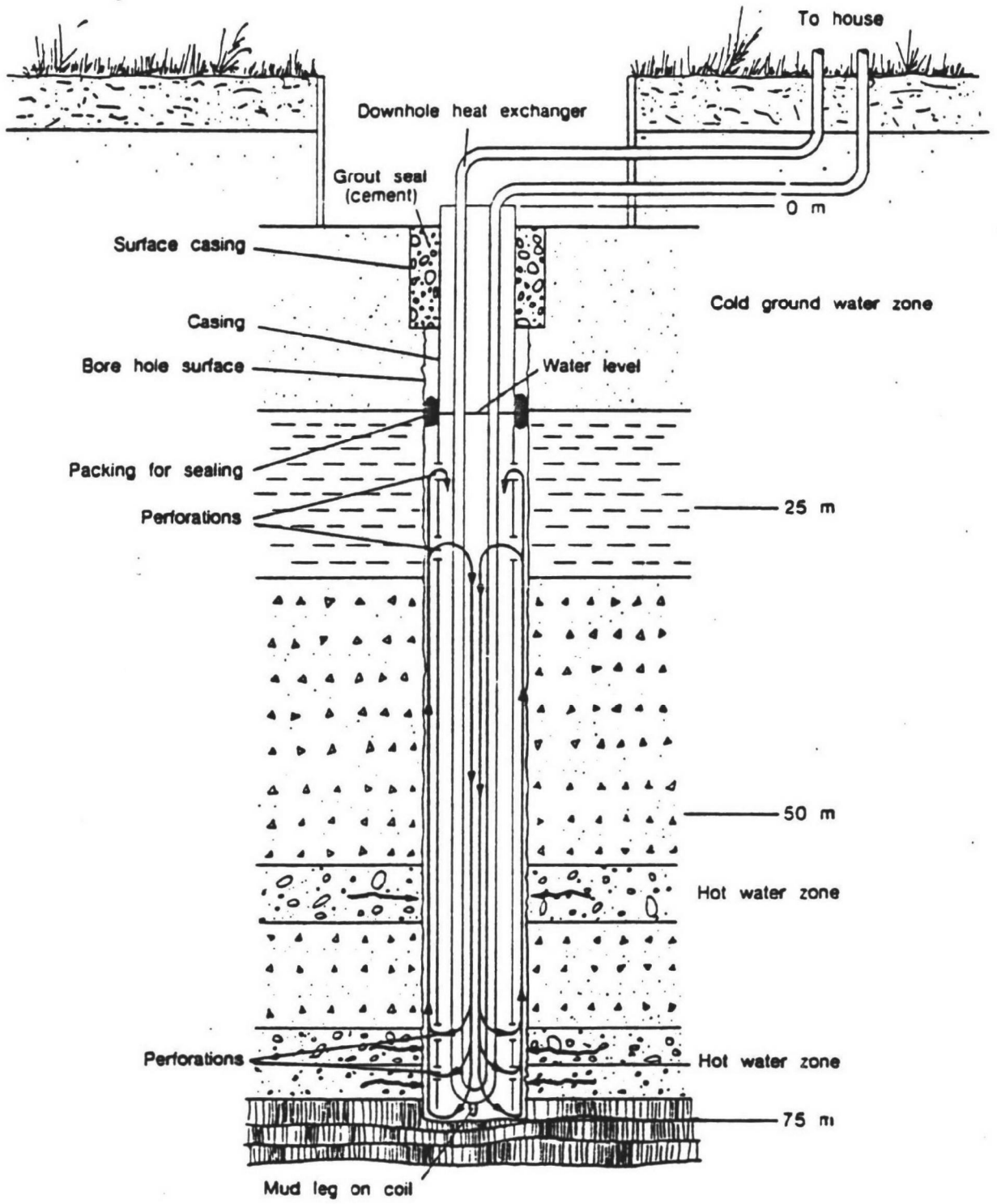

Figure 3 Typical Klamath Falls well with downhole heat exchanger (Justus, 1980)

Shell-and-Tube Heat Exchanger -- This very common heat exchanger consists of a series of tubes enclosed by shells. The tubes carry the source thermal fluid and the shells, the secondary fluid. The tubes are designed for relative ease of cleaning. Shell-and-tube exchangers can be used in series for greater heating capacity. This type of heat exchanger is generally used in large commercial and industrial applications.

BINARY GENERATION FOR ELECTRICAL PRODUCTION

The Public Utility Regulatory Policies Act (PURPA) passed by Congress in 1978, guarantees a market for power produced from small (80 MW or less per plant), non-utility plants that use renewable resources. Electrical power generation using the organic Rankine cycle binary generator currently is the accepted technology for low temperature geothermal resources. Organic Rankine cycle binary generators are designed to produce electricity using heat from water in the range of 180 to 500°F (82 to 260°C). The system works by using geothermal water to vaporize a working fluid, usually a fluorocarbon, with a boiling point suitable to the range of temperatures found in the heating and cooling waters. During the Rankine cycle, the vaporized working fluid is expanded through a turbine to generate electricity. The working fluid is then cooled and condensed by heat exchange with cool water and/or air. Finally, a pump circulates the condensed fluid back through the evaporator and the turbine. See Figure 4. More energy is released by the expansion of vapor through the turbine than is required to circulate and condense the working fluid, operate the cooling system and pump the geothermal fluid. The result is net production of electricity.

These systems are most effectively operated as a closed system with the geothermal water pumped out of a production well, passed through the binary generator, and reinjected back into the reservoir via a return well. This system eliminates problems associated with geothermal gas emissions, effluent disposal, land subsidence and water level decline. However, the plume of reinjected water potentially could cool the production area, change the aquifer properties by deposition of secondary minerals, or interfere with other uses of ground water.

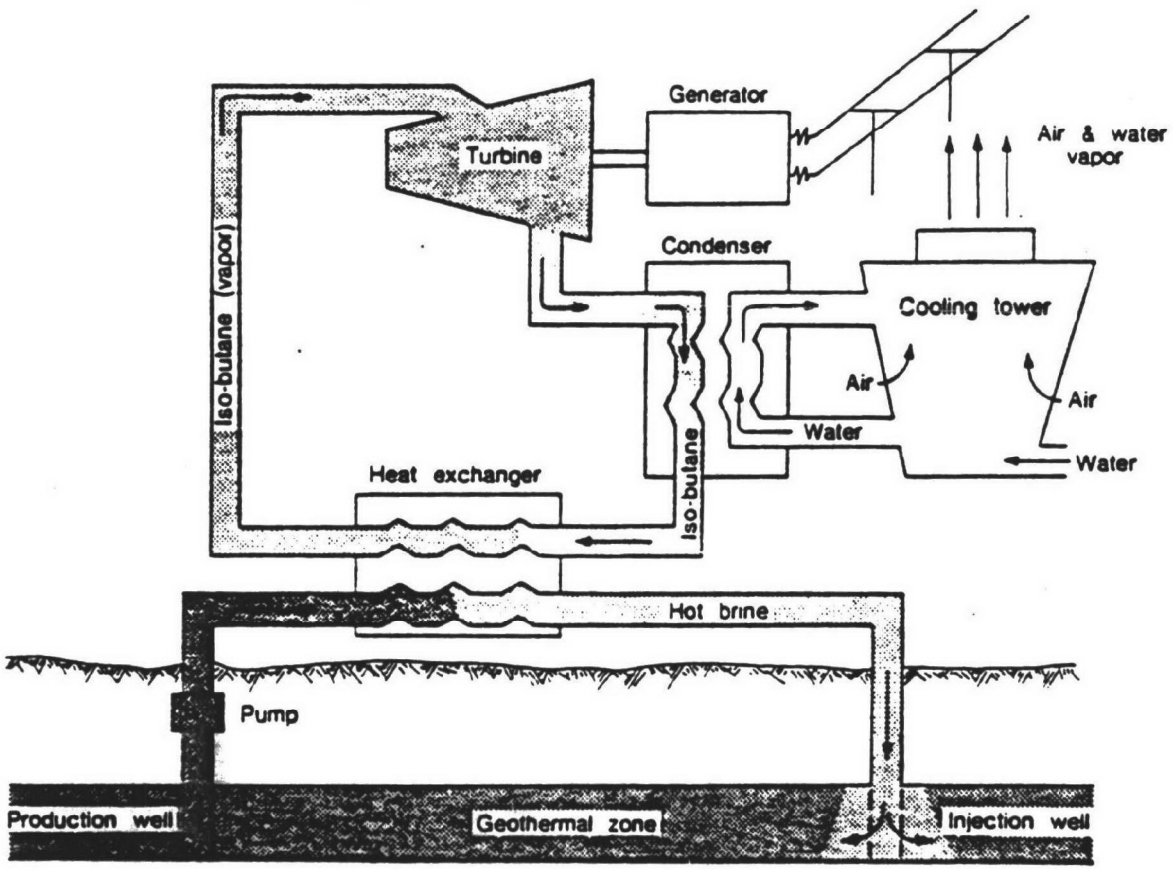

Figure 4 Binary cycle power plant (Justus, 1980)

Cooling the working fluid can be attained by using either wet or dry cooling, or a combination. If cool water is available, a cooling tower or pond is the least expensive cooling method. However, wet cooling presents problems with waste water disposal and the cooling tower plume may impair visibility, cause icing or be visually objectionable.

Geothermal fluid with temperatures of 180°F (82°C) are associated with many of the geothermal anomalies shown in Figure 1. Currently, it is not economically feasible to develop 180°F water and sell electricity produced by the Rankine method unless the hot water is an industrial by-product that normally was discharged to waste, or the hot water is put to direct application after power generation. As the price of electricity rises or as exploration reveals hotter geothermal resources, use of Rankine binary generators will increase. The relatively low cost and modular design makes them attractive investments. Currently, a 213°F (100°C) well in Lakeview is equipped with six Rankine binary turbo-generators that have successfully been tested. Others are planned for Vale. Long-term testing will be necessary to assess aquifer response to sustained pumping and reinjection and to determine impact on other nearby uses of ground water.

Figure 5 shows various methods of energy extraction with temperature.

ADMINISTRATIVE DELEGATION OF THERMAL FLUIDS

Geothermal fluid in Oregon is defined as any fluid derived from a process designed to extract heat from a ground water or geothermal resource ("Oregon Interagency Geothermal Fluid Report", 1978). Geothermal fluids are legislatively divided into two administrative categories on the basis of temperature. Thermal fluids 250°F (120°C) or hotter are considered a portion of the surface or mineral estate of the property and are regulated by the Department of Geology and Mineral Industries (DOGAMI). Fluids less than 250°F are considered ground water resources which are the property of the public trust and are regulated by WRD.

Drilling standards are a function of both fluid temperature and well depth. Wells which seek thermal fluids 250°F or hotter and/or are 2000 feet or more in depth must be drilled under DOGAMI requirements. Wells intended to produce ground water resources cooler than 250°F that are shallower than 2000 feet deep must be drilled under the requirements of WRD.

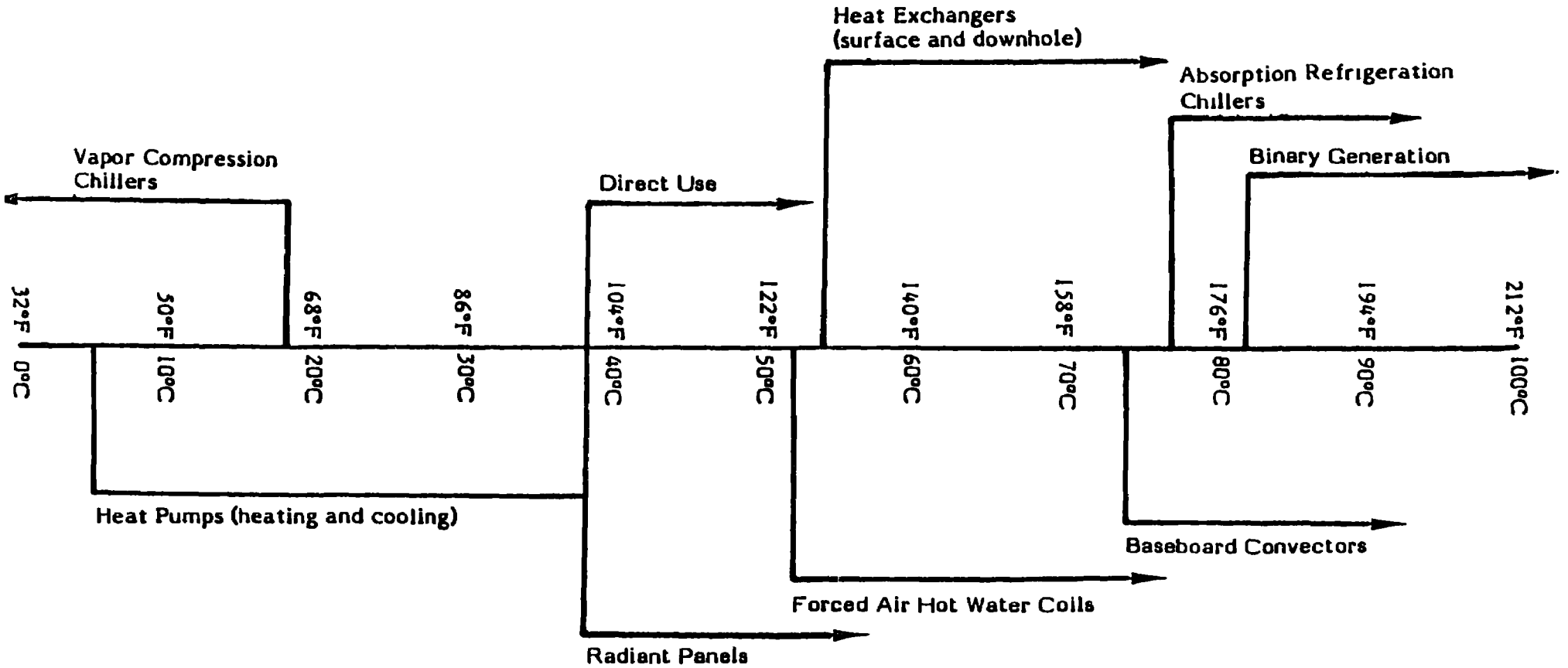

Figure 5 Methods of energy extraction with temperature (modified from Justus, 1980)

The Legislative division on the basis of temperature has proven to be an adequate working policy. However, the 2000-foot depth division has been somewhat controversial. The division is based upon the intended use of the well and could be cumbersome if ground water resources are desired from wells greater than 2000 feet deep. However, to insure public safety, specific casing and blow-out prevention requirements should exist for deep wells regardless of their intended use. DOGAMI has such specific construction rules for deep wells that protect against encountering natural gas and/or geothermal fluids at unknown subsurface pressures.

Water is so rarely sought from depths greater than 2000 feet that there have been no previous administrative problems with the depth division. However, should ground water be desired from this depth, perhaps DOGAMI and WRD should work together to require appropriate construction standards with respect to the subsurface geology in the area of the well. Depending on the WRD/DOGAMI decision, the drilling requirements for the ground water well could be as for oil and gas wells (DOGAMI ORS Chapter 520), as for geothermal wells (DOGAMI ORS Chapter 522), or as for ground water wells (WRD ORS Chapter 537). This type of joint management over deep ground water well drilling would insure public safety during drilling of deep wells regardless of the intent of the well.

In Oregon, ground water appropriation is statutorily protected on the basis of date of priority. If a developer cannot anticipate what resource temperature may be encountered, simultaneous applications to DOGAMI and WRD would ensure the earliest possible priority date. Otherwise, if application is first made to DOGAMI and the resource is less than 250°F, a new water right priority date is established when application is made to WRD. Currently, there are no provisions for a transfer between WRD and DOGAMI with retention of the original priority date.

If a well that initially contained fluid 250°F or hotter, cools to a temperature less than 250°F, DOGAMI and WRD will consult with the well owner and decide which agency is responsible for the well. This process is described in ORS 522.025. If fluid cooler than 250°F rises to 250°F or hotter, the problem is addressed in a similar manner in ORS 537.090. Both these statutes apply to wells in all stages of construction and completion.

POLICY FOR LOW TEMPERATURE GEOTHERMAL WELLS AND EFFLUENT DISPOSAL SYSTEMS

Pursuant to House Joint Resolution 50, the "Oregon Interagency Geothermal Fluid Report" was prepared in October 1978. Representatives of WRD, DOGAMI, ODOE and the Department of Environmental Quality (DEQ) formed a committee to develop consistent policies regarding disposal of geothermal fluids. The main considerations for disposal are conservation of the resource and protection of surface and ground water for all recognizable and potential beneficial uses.

WRD Rules for Effluent Disposal Systems:

In December 1982, WRD adopted Oregon Administrative Rules in Chapter 690, Division 65 "Standards and Procedures for Low Temperature Geothermal Wells and Effluent Disposal Systems". The rules cite well construction standards for low temperature geothermal wells and reinjection wells that supplement WRD well construction standards in OAR 690-10-005 to 690-10-045 and 690-60-005 to 690-63-045. The new rules address separation distances between supply and reinjection wells using the same aquifer and cite standards for pump testing of supply and reinjection wells.

Users planning to reinject may be required to provide WRD and DEQ with a chemical analysis of the water in the producing aquifer, the water to be reinjected, and the water in the receiving zone of the return well. These measures help prevent ground water contamination, thermal degradation or significant changes in aquifer properties. A copy of the rules is included as Appendix I.

The rules use a dual classification system for standard and nonstandard effluent disposal. Standard effluent disposal systems are those in which: 1) no contaminants are added to the geothermal fluid and the effluent is put to a secondary beneficial use; or 2) no contaminants are added to the geothermal fluid and the effluent is returned to the producing, or suitable aquifer and there are no other problems or special conditions determined by WRD.

Nonstandard effluent disposal systems are those in which: 1) any portion of the effluent is disposed of in a nonbeneficial manner (including for example, disposal to a storm sewer,

drainage hole, land surface or any surface water body); 2) the effluent contains contaminants that have been added to the geothermal fluid; 3) the effluent is reinjected to an "unsuitable" aquifer (in most cases this will not be allowed); or 4) there are any other special conditions or potential problems such as instability of near-surface earth materials, leakage of effluent downslope, alteration of geothermal characteristics, etc.

A low temperature geothermal well is defined in OAR 690, Division 65 as any well with a bottom hole temperature less than 250°F that is constructed or used for the thermal properties of the fluid encountered. As such, the use of ground water for its thermal properties is beneficial but nonconsumptive. That is the reason for dual classification of effluent disposal systems. If a user reinjects the effluent to a suitable aquifer or uses it for secondary beneficial consumptive purposes, the water right for that user will be considered standard. As such, the right will be protected on the basis of priority date against all future ground water appropriations. However, if after heat extraction, the effluent is disposed of in any nonstandard manner, the water right will only be protected against those of subsequent users who also utilize a nonstandard disposal system. Thus, it will be subsequent in priority to future beneficial consumptive ground water rights.

Effluent disposal systems may change from nonstandard to standard or vice versa, or may be standard during irrigation season and nonstandard the remainder of the year. Regardless of changes, the date of priority remains the same. If ground water regulation is needed in an area, effluent disposal systems will be classified according to their status at that time and water rights will be protected accordingly. As part of the regulation, a deadline may be imposed requiring all disposal systems to be made standard.

DEQ Requirements:

Reinjection -- A Water Pollution Control Facilities (WPCF) Permit is required for subsurface effluent disposal when: 1) reinjection is to a different aquifer than the producing aquifer; 2) the receiving aquifer is of better quality than the producing aquifer and a beneficial use potentially may be impaired; or 3) chemicals are added to the effluent. However, when a reinjection system is classified as standard by WRD, DEQ likely will waive its WPCF Permit requirements.

Land Surface Effluent Disposal -- Land disposal of effluent also requires a WPCF Permit. However, if the primary purpose of applying the geothermal fluid effluent to the land is for beneficial agricultural purposes (and the fluid is of such a quality as to not endanger flora or ground water), no WPCF Permit will be required. With the recent increase in ground water use for domestic heating, DEQ currently is considering a general WPCF Permit to

address uncontaminated, low-volume effluent disposal to land surface. This general permit probably will not involve fees.

Effluent Disposal To Surface Water -- DEQ requires a National Pollutant Discharge Elimination Systems (NPDES) Permit for any discharge of pollutants, including heat, to surface waters of the State. In most cases, large heat discharges require cooling prior to discharge. Small discharges of heat are evaluated on a case-by-case basis. DEQ now issues a general NPDES Permit that addresses uncontaminated, low-volume effluent disposal of compatible temperature to a surface water body. There is no fee.

PROTECTION FOR HEAT EXTRACTION WITHOUT WITHDRAWAL

Use of ground water for its thermal properties is considered a commercial/industrial use. As such, a ground water permit from WRD is required for appropriation of 5000 or more gallons per day. The 1983 Legislature amended ORS 537.545 to protect owners of downhole heat exchangers even though there is no withdrawal of water. Non-extractive use of ground water for its thermal properties formally is exempt from the requirement to file for water rights. The use of the heat, however, automatically constitutes a right to the use of ground water equal to that established by a ground water right certificate. Such protection is statutorily provided for any use of ground water specifically exempt from the requirement to file for water rights.

THERMAL DEGRADATION AND THERMAL INTERFERENCE

Recommended Statute Changes:

Legislative changes to provide resource management and protection for low temperature geothermal users will likely be proposed by WRD during the 1985 Session. Currently, there is no clear legal protection against thermal degradation or thermal interference between wells. Appendix II includes portions of ORS Chapter 537 "Appropriation of Water Generally" and cites preliminary ideas for amendment to protect beneficial use of water for its thermal properties.

Critical Ground Water Area Rules:

In March 1983, rules were adopted in OAR Chapter 690, Division 10 "Initiation of Proceeding for Determination of a Critical Ground Water Area". With implementation of statutory changes recommended in Appendix II, the proposed critical area rules would then also apply to areas suffering thermal degradation or thermal interference.

In an area undergoing WRD management of ground water decline or non-thermal interference, appropriators who wish to continue extracting heat may be required, within a certain time period, to only use standard effluent disposal systems.

Interference Between DOGAMI and WRD:

When interference is noted between ground water appropriators governed by WRD and geothermal appropriators governed by DOGAMI, ORS 537.095 mandates that DOGAMI and WRD shall work cooperatively to resolve the conflict and develop a cooperative management program for the area. Goals considered for the cooperative agreement shall be: 1) achieving the most beneficial use of the water and heat resources; 2) allowing all existing users of the resource to continue to use those resources to the greatest extent possible; and 3) insuring that the public interest in efficient use of water and heat resources is protected. It is recommended that local officials help develop the management plan so that local interests are not overlooked.

When an application to appropriate ground water discloses possible interference with heat extraction from a well hotter than 250°F, ORS 537.620 allows WRD to: 1) approve the application; 2) impose conditions on the application; 3) reject the application after a hearing; or 4) initiate proceedings for the determination of a critical ground water area.

GEOTHERMAL HEATING DISTRICTS

In areas of localized hydrothermal discharge where use of geothermal resources is intensified, comprehensive reservoir assessment and management are necessary if all ground water uses are to be protected and used to their maximum beneficial capacity. Population centers near geothermal discharge areas have tremendous potential to use the resource. Hydrothermal systems often are complex and resource assessment and management is difficult without local participation.

Though statewide ground water resource management is predominantly WRD's responsibility, Oregon law allows cities, counties or private corporations to operate a geothermal heat distribution system to consumers much as a municipal water district supplies water. This authority is described in ORS Chapter 523 "Geothermal Heating Districts". This statute is the first of its kind in the nation. It authorizes districts to: 1) contract for services; 2) hold and transfer real property; 3) sue and be sued; 4) form cooperative agreements; 5) issue general obligation, revenue or refunding bonds; 6) exercise the power of eminent domain; 7)

levy special assessment taxes; 8) levy special ad-valorem taxes; and 9) provide supplemental energy from non-geothermal sources in emergencies.

Under ORS 523, an incorporated city is empowered to provide geothermal heating district services by a home rule charter or by a vote of the people when a home rule charter does not exist.

Currently, there are no established geothermal heating districts in Oregon. Plans for a city-operated geothermal heating district in Klamath Falls have existed for some time. The idea is also being considered in Lakeview and Vale.

Klamath Falls, A Case Study:

Of the geothermal areas in Oregon, Klamath Falls has received the most attention. Hydrogeologic studies and socio-political conflicts make it an important case study of problems associated with low temperature geothermal reservoir assessment and management.

In January 1977, formation of a city-operated geothermal heating district in Klamath Falls was proposed. Construction of Phase I of the heating system began in 1979. Phase I, requiring 700 gpm of 220°F (104°C) geothermal fluid, is designed to supply space heating and hot water to 14 government office buildings in the downtown area and later to 127 homes in two low-income residential areas. This was planned as the first of six phases that initially would supply heat to the central business district and later would expand to serve the entire urban area of approximately 20 square miles and 35,000 persons.

Phase I was completed in Fall 1982. Two production wells and one reinjection well were completed and the distribution system was installed. Having a home rule charter, the City did not need a charter amendment to authorize formation of the geothermal heating district. However, to reinforce district formation, the City offered citizens a choice to vote on a charter amendment as well. During a special election in March 1982, voters, apparently worried about impacts to the aquifer, rejected the charter amendment.

Three months later, an initiative filed by Citizens for Responsible Geothermal Development (CRGD), was approved by voters. The decision obstructs use of the completed geothermal heating system. This ordinance prevents withdrawal of thermal waters unless the water, undiminished in volume, is returned to the same well.

The initiative was challenged by WRD in the Klamath County Circuit Court. Because the initiative virtually inhibits use of the geothermal resource except through downhole heat exchange (where there is no withdrawal of water), WRD claimed that the initiative, in essence, regulates the appropriation of ground water resources. WRD contended that such local regulation is an infringement of WRD's exclusive statutory authority to manage ground water. However, the initiative was upheld by Circuit Court on the basis that the State has not preempted local governments from adopting regulations and the local ordinance did not conflict with any existing state regulations pertaining to ground water resources. WRD has taken the case before the Oregon Court of Appeals. A judgement is expected in 1984.

A major concern to the Klamath Falls City Council is the outcome of the WRD appeal of the Circuit Court decision on the citizen initiative. While awaiting a decision, positive steps have been taken to resolve the conflict among independent citizens, City Council and CRGD. In January 1983, the Klamath County Chamber of Commerce began organizing a long-term test of the city heating system.

A $150,000 grant from the U.S. Department of Energy (USDOE) funded several scientific research groups to conduct an eight-week aquifer and tracer test of the Klamath Falls geothermal reservoir. Primary investigator and coordinator for the testing program was Edward Sammel of the USGS. Sammel has long stressed the need for a sustained aquifer test of the production and reinjection system to accurately determine how Phase I will affect the geothermal reservoir. Playing the key role in aquifer test analysis were Sally Benson and Dr. Norman Goldstein of LBL. Also as part of the testing program, Alfred Truesdell of the USGS, sampled waters for chemical and isotopic analyses; Dr. John Gudmundsson of Stanford University, directed tracer studies to help indicate ground water flow paths and velocities; Drs. Paul Lineau and Gene Culver of the Geo-Heat Center at OIT, provided logistical support. Local coordinators of monitoring and data collection were Susan Swanson and Dennis Long of D.C. Long Energyman, Inc., Klamath Falls. Volunteer data gathering was coordinated by Bud and Deborah Hart of CRGD.

The eight-week aquifer test began July 5, 1983, with a pumping rate of 720 gpm from the 900-foot deep City Well 2. On July 27, approximately three weeks into the test, reinjection began into the Museum Well. Reinjection continued for almost one month until pump shutoff on August 24, 1983. Preliminary analysis indicates that with suitable reinjection, the reservoir may be capable of sustained yields at greater pumping rates than tested. In response to pumping, City Well 2 had a maximum drawdown of 7.5 feet. The nearest monitor well, located 120 feet away, had 4.66 feet of drawdown. These measurments were taken at the end of the non-reinjection phase of pumping. After reinjection began, water levels began to recover. After two weeks of reinjection, water levels appeared to stabilize as the withdrawal and reinjection process equilibrated (Personal Communication, Benson, 1983). A final report by Sammel and others will be made public in 1984.

Final results from the 1983 aquifer test will provide long-awaited information to the people of Klamath Falls. Data from this eight-week test should allow long-term effects of withdrawal and reinjection to be accurately predicted. This scientific information will help guide Klamath Falls residents in evaluating options for the future of the geothermal resource and Phase I of the heating system. The cooperation by diverse groups all over Klamath Falls is an unprecedented recognition of the importance of wise stewardship of local renewable resources through community action.

Klamath Falls is an example of a city where the disparate uses of ground water and a historical lack of technical understanding have resulted in conflicts. Clearly, a locale in which residents rely heavily on geothermal resources for much of their energy needs deserves comprehensive reservoir management. Comprehensive management requires thorough technical understanding. The City of Klamath Falls recognized this need. The City was concerned that the small staff at WRD could not give reservoir evaluation and management the attention it could receive through local authority. With ODOE funding in 1980, The City contracted with Eliot Allen and Associates to author the "Preliminary Model Ordinance for Municipal Geothermal District Heating and Reservoir Management". In addition to presenting a comprehensive administrative scheme, the ordinance presents a case for joint management of the geothermal reservoir between WRD and geothermal heating districts. The ordinance has been studied by the University of Oregon Bureau of Government Research, the Earl Warren Legal Institute of Berkeley, California, the U.S. Conference of Mayors in Washington, DC, and the National Conference of State Legislatures, and is considered a prototype for planning in states where geothermal resources exist. The State of Colorado has adopted legislation that allows similar joint state and local management of geothermal heating districts.

Oregon Alternate Energy Development Commission Recommendations:

In September 1980, the Oregon Alternate Energy Development Commission submitted final recommendations to Governor Atiyeh. The purpose of the report was to promote the development of renewable resources by recommending mitigating legislation and policy to accelerate geothermal energy development.

Recommendation 44 suggests a program be developed allowing geothermal heating districts to assist WRD with reservoir management plans. Under the plan, WRD would specify standards that the district would be required to meet. The district would then prepare a management plan subject to WRD conditioning and approval. The program would ensure that all water development within the district would promote maximum local benefits and be consistent with state water policy (Oregon Alternate Energy Development Commission, 1980).

Recommendation 45 suggests a program whereby geothermal heating districts are informed by WRD and DOGAMI of drilling notices in the vicinity of the district. This would ensure that the district would have notification of action that potentially could affect the resource (Oregon Alternate Energy Development Commission, 1980).

Both recommendations were adopted by Governor Atiyeh and presented to the 1981 Legislature. However, the Legislature did not approve funding to implement Recommendation 44; Though not a complete solution, Recommendation 45 is addressed by WRD in a weekly news release to all county planning divisions and various state agencies, as well as by fee to any interested parties. The news release is a list of applications made to WRD to use water. Each entry contains information regarding the source, type, amount and place of water use, in addition to the applicant's name and mailing address, the application number and date of receipt. Unfortunately, project construction often begins prior to making application to WRD. When a geothermal heating district becomes established this procedure could be restructured to notify the district prior to project construction.

Local Cooperation in Reservoir Management:

Currently, geothermal heating districts do not have formal reservoir management powers. This point, however, is under debate in the Oregon Court of Appeals concerning the Klamath Falls ordinance. There is no preemption by WRD to local ordinances that do not attempt to regulate appropriation of ground water. For instance, a local ordinance can be adopted requiring residents to register information about their well and water uses. The ordinance could also specify notification and fee requirements before the well is constructed. Such a comprehensive county ordinance is now in effect in Lane County under Lane Code, Chapter 9. An ordinance is also in effect in Josephine County. Benton County has special pump test requirements.

A geothermal heating district obviously needs to have comprehensive resource assessment in order to implement a sustainable heating system plan. The district also needs to know the nature and extent of all other uses of the reservoir. Without this knowledge it would be impossible to determine potential interferences between water users or to determine the limit of stress the reservoir could sustain with time. In the vicinity of a geothermal heating district, this kind of assessment would require much time and expertise and would need to be on-going throughout the life of the district. To accomplish this, a geothermal heating district would inevitably need a registration system for wells and water uses and would also need a resident hydrogeologist.

Despite a lack of formal management powers there are ways in which a heating district can promote or influence some reservoir management decisions by WRD. For instance, if an application to appropriate ground water indicated potential to adversely impact present uses of ground water in the district, the district could formally protest the application at WRD. The district would be given the opportunity to present evidence in a contested case hearing as to why the permit should not be issued. After examination of all evidence submitted in such a hearing, WRD could exercise its options under ORS 537.620 and condition, deny or approve the permit.

If a district believed that part or all of the hydrogeologic system was sensitive to developmental impacts, it could petition WRD to declare a critical ground water area. While WRD did an investigation, district experts could share their data and interpretation of the reservoir and aid WRD in whatever management plan ensued.

This existing structure for participation in management unfortunately invites adversarial positioning between WRD and the geothermal heating district. This structure has the potential to be costly and inefficient.

Colorado recently added Article 90.5 "Geothermal Resources" to Title 37, Colorado Revised Statutes. Article 90.5 recognizes the use of water as a material medium from which heat can be extracted. As such, all applications to appropriate ground water in order to utilize its heat energy are considered applications to appropriate geothermal fluid. "Geothermal Management Districts" are addressed in the article under Colorado Revised Statutes 37-90.5-108. The statute follows:

> 37-90.5-108. Geothermal management districts.
>
> 1) The State Engineer may adopt procedures under which geothermal management districts may be established. In such districts, the State Engineer has the authority to:
>
> a) control well-spacing and production rates;
>
> b) control the quantity of geothermal fluid extracted from geothermal resources by such methods and procedures as he deems appropriate, including requirements to reinject;
>
> c) adopt a comprehensive plan for the most efficient use of geothermal resources, guided by the principles of equitable apportionment, maximum economic recovery and prevention of waste.
>
> 2) The State Engineer may delegate some or all of his authority under this section to a geothermal management district upon finding that the district has adequate organization and capability to administer an acceptable management plan.

This addition to Colorado Law was written by Kenneth Wonstolen and was adopted under Senate Bill 390 in May 1983 (Personal Communication, Wonstolen, 1983). The bill was written by Wonstolen while on an ad hoc committee in Colorado comprised of the Public Utilities Commissioner, the State Engineer, the National Conference of State Legislatures (NCSL) and others. Wonstolen formerly worked with the NCSL developing policy options regarding geothermal fluid management for the Oregon Legislature from 1978 through 1981.

The Colorado statute regarding geothermal management districts was controversial (Personal Communication, Kenneth Wonstolen, 1983). However, the local powers are at the discretion of the State. A plan such as this was proposed in the Eliot Allen and Associates' "Preliminary Model Ordinance for Geothermal Heating Districts and Reservoir Management" in 1980. Similar legislation was recommended for Oregon by the Alternate Energy Development Commission in 1980 and adopted by Governor Atiyeh in 1981. Though no geothermal heating districts presently exist, the idea deserves continued consideration in light of the increasing economic need for district heating, energy independence and sustainable reservoir management. As envisioned in the Allen model, the idea is quite simple:

* First, the district would develop a reservoir management plan. The plan would have to be based on comprehensive technical assessment of the resource. The plan would have to take into consideration current and potential uses of ground water in the district. The plan would be subject to approval and/or changes by WRD.

* Following WRD approval of the plan, the district would then be empowered by WRD to implement the plan. The district's hydrogeologist and other experts would work closely with WRD to see that the plan is implemented properly.

* If problems or conflicts arise in the plan itself or in the implementation of the plan, the district would refer the matter to WRD for ultimate disposition.

As such, the public policy issue of low temperature geothermal reservoir management becomes the mutual goal of WRD and the district.

WHAT DOES THE FUTURE HOLD?

As development of low temperature geothermal resources gains popularity, it adds to the complexity of ground water management. State-of-the-art concepts in low temperature heat extraction are rapidly accelerating. Water at 213°F (100°C) is producing electricity using a binary generation method in Lakeview. Similar ventures are envisioned in Vale. Additionally, heat pump technology now makes it economically attractive to extract heat from the cool ground waters of the Willamette Valley and elsewhere.

Ground water reservoirs now supply not only domestic, stock, fire protection, irrigation, commercial and industrial needs, but also provide heat and electricity. Space heating and cooling, greenhouse horticulture, food drying, aquaculture and myriad other commercial/industrial uses are becoming common.

Near areas of concentrated hydrothermal discharge, district heating has the potential to serve many people with a minimum of expense, both in terms of capital outlay and long-term sustainability of the resource. Comprehensive resource assessment is therefore vital to proper management. In the vicinity of a geothermal heating district, long-term impacts to the reservoir in terms of reinjection, thermal degradation, overdraft, and interference with existing uses of ground water will need to be continually monitored. The intensive monitoring required may warrant a decentralized approach to water/energy management. Requiring district hydrogeologists to be in charge of implementing a mutually agreed upon management plan within the district is an option to be considered by WRD. This would ensure hands-on monitoring of reservoir capabilities and would provide an early warning system for conflicts or problems that may occur. Greater knowledge of ground water resources would be provided to the state by the local hydrogeologists. The management functions of the district would always be at the discretion of WRD.

The mandate of Oregon Water Law is that the water of the state belongs to the public. To ensure preservation of public welfare, safety and health, beneficial use without waste is the basis of the right to appropriate water. To accomplish this goal, WRD needs to evaluate known and potential low temperature geothermal resource areas so use of ground water for its thermal properties can be managed and protected in concert with other uses of ground water.

It is the responsibility of WRD to administer public law and policy relative to ground water supplies. Evidence indicates that ground water use is becoming a popular source of space heating and cooling. With the use of ground water now conceptually reframed to include thermal applications, WRD will be considering policy that will continue to serve the public.

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APPENDIX I

OREGON ADMINISTRATIVE RULES

CHAPTER 690, DIVISION 65 - WATER RESOURCES DEPARTMENT

STANDARDS AND PROCEDURES FOR

LOW TEMPERATURE GEOTHERMAL WELLS AND EFFLUENT DISPOSAL SYSTEMS

65-005 POLICY AND PURPOSE:

(1) All Low Temperature Geothermal Fluids are part of the ground water resources of the State of Oregon and shall be administered by the Water Resources Director (Director) under the provisions of ORS 537.010 to 537.795. The Director recognizes that these fluids are developed primarily because of their thermal characteristics and that special management is necessary. Reservoir assessment of Low Temperature Geothermal Fluids shall be conducted by the Director in the same manner as ground water investigations outlined in ORS 537.665 and ORS 537.685.

(2) The purpose of the following rules is to provide standards and procedures for the development, use and management of Low Temperature Geothermal Fluids, while insuring proper management of all ground water resources so maximum beneficial use of the resource will be most effectively attained.

(3) These rules supplement OAR 690-10-005 to 690-10-045, 690-60-005 to 690-63-045, and 690-64-000 to 690-64-010. Rule 690-60-050, paragraph 47 and 690-61-181 are hereby rescinded.

DELETE:

[690-60-050 (47) "Thermal Ground Water": means ground water having a temperature greater than 90 degrees Fahrenheit or 32 degrees Celsius. (The statutes of Oregon delegate to the Department of Water Resources the appropriation and supervision of thermal ground water having a temperature of less than 250 degrees Fahrenheit or 121 degrees Celsius, and occurring within 2,000 feet of the land surface.)]

[690-61-181 CONSTRUCTION OF THERMAL OR HOT WATER WELLS:
All thermal or hot water wells having a maximum water temperatue of less than 250 degrees Fahrenheit (121 degrees Celsius) and constructed to depths of less than 2,000 feet shall be constructed in conformance with rules 690-61-006 through 690-61-176. The bottom-hole temperature shall be measured and recorded on the water well report.]

65-010 DEFINITIONS:

(1) Bottom Hole Temperature: The maximum temperature measured in the well or bore hole. It is normally attained directly adjacent to the producing zone, and commonly at or near the bottom of the borehole.

(2) Low Temperature Geothermal Effluent: The outflow, discharge or waste fluid, with its associated dissolved or suspended constituents (being original or introduced), that is produced by a Low Temperature Geothermal Well and its utilization system.

(3) Low Temperature Geothermal Fluid:

(a) Any ground water produced from a Low Temperature Geothermal Well which is used for its thermal characteristics; or

(b) any other fluids, approved by the Director, that circulate, with or without withdrawal, within a Low Temperature Geothermal Well, where in all cases of (a) and (b) the fluid circulated because of its thermal characteristics, is used for various heating and/or cooling purposes including, but not limited to, residential, commercial, industrial, electrical, agricultural and aquacultural applications.

(4) Low Temperature Geothermal Reinjection Well: Any well as defined under ORS 537.515(7) that is constructed or used for returning Low Temperature Geothermal Effluent to a ground water reservoir.

(5) Low Temperature Geothermal Well: Any well as defined under ORS 537.515(7) with a bottom hole temperature less than 250°F that is constructed or used for the thermal properties of the fluid contained within.

(6) Nonstandard Low Temperature Geothermal Effluent Disposal System: Any Low Temperature Geothermal Effluent Disposal System in which one or more of the following conditions are met:

(a) Any portion of the effluent is disposed of in a manner considered non-beneficial by the Director. This includes, but is not limited to, disposal via storm sewer, drainage hole or direct discharge to land surface or a surface water body.

(b) The effluent contains contaminants, other than heat, that have been added to the Low Temperature Geothermal Fluid.

(c) The effluent is reinjected to a ground water reservoir that is not considered suitable by the Director. Factors which may render a ground water reservoir unsuitable include, but are not limited to, chemical or physical incompatibility of the fluids involved or adverse hydraulic characteristics of the receiving reservoir.

(d) There are existing or potential problems or special conditions as determined by the Director. Problems or special conditions resulting from the effluent disposal system which may warrant a nonstandard designation include, but are not limited to, instability of near-surface earth materials, undue alteration of thermal characteristics, unreasonable head changes or downslope subsurface leakage of effluent.

(7) Secondary Use: Consumption of Low Temperature Geothermal Effluent for beneficial use including, but not limited to, domestic, irrigation, stock watering, commercial and industrial uses.

(8) Standard Low Temperature Geothermal Effluent Disposal System: Any Low Temperature Geothermal Effluent Disposal System in which one of the following conditions are met:

(a) No contaminants except heat have been added to the Low Temperature Geothermal Fluid and the effluent is put to a Secondary Use.

(b) No contaminants except heat have been added to the Low Temperature Geothermal Fluid and the effluent is returned to the producing or other suitable ground water reservoir and there are no other existing or potential problems or special conditions as determined by the Director including, but not limited to, those factors, problems and conditions listed in 65-010 definition 6, paragraphs c and d.

SUBDIVISON I
WELL CONSTRUCTION STANDARDS

65-015 LOW TEMPERATURE GEOTHERMAL WELL AND REINJECTION WELL CONSTRUCTION: Low Temperature Geothermal Wells and Reinjection Wells shall be constructed in conformance with applicable rules (OAR 690-10-005 to 690-10-040 and 690-60-005 to 690-63-045) with specific additions and modifications as described in OAR 690-05-005 to 690-05-070.

65-020 LOW TEMPERATURE GEOTHERMAL REINJECTION WELL LOCATION: For appropriations not exceeding 15,000 gallons per day no Low Temperature Geothermal Reinjection Well shall be located within 75 feet of any existing Low Temperature Geothermal Well utilizing the same ground water reservoir without authorization from the Director, unless both the withdrawal and reinjection wells are on the same parcel of land and are used by the same ground water appropriator. A variance from the 75-foot setback requirement may be issued by the Director, following a written request for special standards (described by 690-60-040) by the water well constructor or landowner, who under the provisions of 537.753, is constructing the well, if hydrologic and thermal conditions permit closer spacing.

For appropriations exceeding 15,000 gallons per day, the appropriator shall submit plans for review to the Director or his authorized representative, indicating separation distances between production and reinjection wells on the parcel of land on which the production well is located, on the parcel of land on which the reinjection well is located, and on all adjoining parcels of land. In addition, the plans shall indicate the anticipated hourly production and reinjection rates, the maximum anticipated daily production, and any planned safeguards against undue thermal and hydrologic interference with existing rights to appropriate ground water and surface water.

65-025 DESCRIPTION OF PROPOSED USE: For any Low Temperature Geothermal Well or Low Temperature Geothermal Reinjection Well, the report required under ORS 537.762 prior to commencing construction shall identify the intended use of the well, the appropriator's name and the appropriator's mailing address.

65-030 IDENTIFICATION OF INTENDED WELL USE: Any Low Temperature Geothermal Well or Low Temperature Geothermal Reinjection Well shall be clearly identified as such on the water well report filed with the Water Resources Department.

65-035 WELL-HEAD PROTECTION EQUIPMENT: Adequate well-head equipment to insure public safety and the protection of the ground water resource shall be immediately installed on any Low Temperature Geothermal Well or Low Temperature Geothermal Reinjection Well when fluid temperatures of 65° C (150°F) or greater are encountered during drilling. Low Temperature Geothermal Fluids produced during drilling or testing of such a well shall be disposed of in such a manner as to minimize health hazards. A variance from the requirement for well-head protection equipment may be granted if a written request demonstrates that the equipment is not necessary to safely complete the well.

65-040 PUMP TESTING OF LOW TEMPERATURE GEOTHERMAL REINJECTION WELLS: All Low Temperature Geothermal Reinjection Wells shall be pump tested for a period of at least one hour; results must be recorded on the water well report. This minimum test shall be conducted as follows:

(1) Prior to testing, the static water level in the well shall be measured and recorded.

(2) Water shall be pumped into or from the well at a measured and steady rate; the rate shall approximate the maximum anticipated injection rate of the operating well.

(3) For tests that withdraw water, only bailing or pumping the well is acceptable.

(4) The water level in the well shall be measured and recorded both at the end of pumping and after one hour of recovery.

(5) For proposed disposal exceeding 15,000 gallons per day the Director may prescribe a more detailed test that could include, but is not limited to, increased frequency of water level measurement, increased test duration and monitoring of observation wells. Such modifications will be required when possible impacts resulting from the development include, but are not limited to, thermal or hydrologic interference with existing water rights, water quality degradation or failure of well construction.

65-045 WATER TEMPERATURE MEASUREMENT: For any Low Temperature Geothermal Well that withdraws ground water, the water well report must include the maximum temperature measured in the borehole and its corresponding depth, and the temperature of the fluid as measured at the discharge point at the beginning and conclusion of a timed production test (i.e. pump or bailer test - air test unacceptable). The maximum temperature measured in the borehole and its corresponding depth is required on the water well report for a Low Temperature Geothermal Well that does not withdraw ground water.

65-050 ADDITIONAL STANDARDS FOR LOW TEMPERATURE GEOTHERMAL REINJECTION WELLS: Procedures required to reinject effluent into a Low Temperature Geothermal Reinjection Well must not cause failure of casing and seal material or other components of the well construction.

SUBDIVISION 2

LOW TEMPERATURE GEOTHERMAL EFFLUENT DISPOSAL

65-055 EFFLUENT DISPOSAL BY REINJECTION / FLUID QUALITY ASSESSMENT: Prior to reinjection, users required to file for water rights shall supply the Director fluid quality information concerning the Low Temperature Geothermal Fluid, the Low Temperature Geothermal Effluent, and the ground water in the receiving zone of any Low Temperature Geothermal Reinjection Well for systems that withdraw and reinject ground water in order that the Low Temperature Geothermal Effluent Disposal System be classified as Standard or Nonstandard. The required information shall include a certified chemical analysis for the following parameters: Temperature, pH, Suspended Solids, Specific Conductance, Total Dissolved Solids, Total Coliform Bacteria, Arsenic, Boron, Calcium, Carbonate or Bicarbonate, Chloride, Iron, Magnesium, Manganese, Potassium, Silica, Sodium and Sulfate. If poor water quality or water quality incompatible with the reinjection zone fluids is suspected, the Director may require additional specific data. The Director may waive the requirement for specific portions or all of the chemical analysis if the fluid quality is known to be suitable for the intended withdrawal and reinjection.

SUBDIVISION 3
WATER RIGHTS PROCEDURE

65-060 PROCESSING OF APPLICATIONS: The appropriator shall make application for a water right to appropriate Low Temperature Geothermal Fluid unless an exemption is provided for under ORS 537.545.

65-065 EXEMPTION FROM WATER RIGHT PERMIT APPLICATION / USE OF LOW TEMPERATURE GEOTHERMAL FLUID: Low Temperature Geothermal Fluid appropriation for single industrial or commercial use including, but not limited to, electrical, agricultural, aquacultural, heating and/or cooling in an amount not exceeding 5,000 gallons per day shall be exempt from application for a water right as provided for under ORS 537.545. This exemption applies to the use of ground water for any such purpose to the extent that it is beneficial and constitutes a right to appropriate ground water equal to that established by a ground water right certificate.

65-070 WATER RIGHT LIMITATION FOR NONSTANDARD EFFLUENT DISPOSAL SYSTEMS: If the Low Temperature Geothermal Effluent is disposed of by way of a Nonstandard Low Temperature Geothermal Effluent Disposal System, the right to appropriate the Low Temperature Geothermal Fluid shall be inferior to all subsequent rights for beneficial consumptive use and/or to the rights of those appropriators who make use of a Standard Low Temperature Geothermal Effluent Disposal System. If a Nonstandard Low Temperature Geothermal Effluent Disposal System is upgraded to a Standard Low Temperature Geothermal Effluent Disposal System the associated water right retains the priority date established upon initial filing.

APPENDIX II

537.450 Rules for proof as to work and use of water under permits, noncompliance as evidence in cancellation proceedings. The Water Resources Director may by rule provide that the owners of permits shall submit or furnish proofs of commencement of work, prosecution of work with due diligence, completion of work, and of the application of water to a beneficial use under the permits. Failure to comply with his rules in respect to such proofs shall be considered prima facie evidence of failure to commence work, prosecute work with due diligence, complete work, or apply water to the beneficial use contemplated by the permit, as the case may be, in the proceedings provided in ORS 537.410 to 537.440 for the cancellation of permits.

APPROPRIATION OF UNDERGROUND WATERS (GROUND WATER ACT OF 1955)

537.505 Short title. ORS 537.505 to 537.795 shall be known as the "Ground Water Act of 1955." [1955 c.708 §1; 1963 c.293 §1]

537.510 [Repealed by 1955 c.708 §38]

537.515 Definitions for ORS 537.505 to 537.795. As used in ORS 537.505 to 537.795, unless the context requires otherwise:

(1) "Altering" a well means the deepening, recasing, perforating, reperforating, the installation of packers or seals and other material changes in the design of the well.

(2) "Constructing" a well includes boring, digging, drilling or excavating and installing casing or well screens.

(3) Ground water" means any water, except capillary moisture, beneath the land surface or beneath the bed of any stream, lake, reservoir or other body of surface water within the boundaries of this state, whatever may be the geological formation or structure in which such water stands, flows, percolates or otherwise moves.

(4) 'Ground water reservoir" means a designated body of standing or moving ground water having exterior boundaries which may be ascertained or reasonably inferred.

(5) "Pollution" of ground water means any impairment of the natural quality of such ground water, however caused, including impairment by salines, minerals, industrial wastes, domestic wastes or sewage, whether indrafted directly or through infiltration into the ground water supply.

(6) "Public agency' means the United States or any agency thereof, the State of Oregon or any agency thereof or any county, city, district organized for public purposes or other public corporation or political subdivision of this state.

(7) "Well" means any artificial opening or artificially altered natural opening, however made, by which ground water is sought or through which ground water flows under natural pressure or is artificially withdrawn, provided, that this definition shall not include a natural spring or wells drilled for the purpose of:

(a) Prospecting, exploration or production of oil or gas.

(b) Prospecting or exploration for geothermal resources, as defined in ORS 522.005, or

(c) Production of geothermal resources, as defined in ORS 522.005, derived from a depth of greater than 2,000 feet.

(8) 'Well drilling machine' means any power driven percussion, rotary, boring, digging or augering machine used in the construction of water wells. [1959 c.708 §3; 1961 c.334 §8; 1975 c.552 §35]

537.520 [Repealed by 1955 c.708 §38]

537.525 Policy. The Legislative Assembly recognizes, declares and finds that the right to reasonable control of all water within this state from all sources of water supply belongs to the public and that in order to insure the preservation of the public welfare, safety and health it is necessary that:

(1) Provision be made for the final determination of relative rights to appropriate ground water everywhere within this state and of other matters with regard thereto through a system of registration, permits and adjudication.

(2) Rights to appropriate ground water and priority thereof be acknowledged and protected, except when, under certain conditions, the public welfare, safety and health require otherwise.

(3) Beneficial use without waste, within the capacity of available sources, be the basis, measure and extent of the right to appropriate ground water.

Propose to add to 537.515 as (5):

"Low temperature geothermal fluid" means any "Ground water" used for its thermal characteristics that is encountered in a well with a bottom hole temperature less than 250°F.

(4) All claims to rights to appropriate ground water be made a matter of public record

(5) Adequate and safe supplies of ground water for human consumption be assured while conserving maximum supplies thereof for agricultural, commercial, industrial, recreational and other beneficial uses

(6) The location, extent, capacity, quality and other characteristics of particular sources of ground water be determined

(7) Reasonably stable ground water levels be determined and maintained

(8) Depletion of ground water supplies below economic levels impairment of natural quality of ground water by pollution and wasteful practices in connection with ground water be prevented or controlled within practicable limits

(9) Whenever wasteful use of ground water, impairment of or interference with existing rights to appropriate surface water, declining ground water levels, interference among wells, overdrawing of ground water supplies or pollution of ground water exists or impends controlled use of the ground water concerned be authorized and imposed under voluntary joint action by the Water Resources Director and the ground water users concerned whenever possible, but by the director under the police power of the state when such voluntary joint action is not taken or is ineffective

(10) Location, construction, depth capacity, yield and other characteristics of and matters in connection with wells be controlled in accordance with the purposes set forth in this section [1955 c.708 §2]

537.530 [Repealed by 1955 c.708 §38]

537.535 Unlawful use or appropriation of ground water, including well construction and operation. (1) No person or public agency shall use or attempt to use any ground water, construct or attempt to construct any well or other means of developing and securing ground water or operate or permit the operation of any well owned or controlled by such person or public agency except upon compliance with ORS 537.505 to 537.795 and any applicable order rule or regulation promulgated by the Water Resources Director under ORS 537.505 to 537.795

(2) Except for those uses exempted under ORS 537.545, the use of ground water for any purpose, without a permit issued under ORS 537.625 or registration under ORS 537.605, is an unlawful appropriation of ground water [1955 c.708 §4; 1957 c.331 §5; subsection (2) enacted as 1961 c.668 §2]

537.540 [Repealed by 1955 c.708 §38]

537.545 Exempt uses. No registration, certificate of registration, application for a permit, permit, certificate of completion or ground water right certificate under ORS 537.505 to 537.795 is required for the use of ground water for stockwatering purposes, for watering any lawn or noncommercial garden not exceeding one half acre in area for single or group domestic purposes in an amount not exceeding 15,000 gallons a day or for any single industrial or commercial purpose in an amount not exceeding 5,000 gallons a day. The use of ground water for any such purpose to the extent that it is beneficial constitutes a right to appropriate ground water equal to that established by a ground water right certificate issued under ORS 537.700. The Water Resources Director, however, may require any person or public agency using ground water for any such purpose to furnish information with regard to such ground water and the use thereof [1955 c.708 §5]

537.550 [Repealed by 1955 c.708 §38]

537.560 [Repealed by 1955 c.708 §38]

537.570 [Repealed by 1955 c.708 §38]

537.575 Permits granted, approved or pending under former law. Any permit granted or application for a permit approved under ORS 537.510, 537.520, 537.530, 537.540, 537.550, 537.560, 537.570, 537.580, 537.590 and 537.600 prior to and still valid and in effect on August 3, 1955, is considered to be a permit issued under ORS 537.625. Any application for a permit under ORS 537.510, 537.520, 537.530, 537.540, 537.550, 537.560, 537.570, 537.580, 537.590 and 537.600 prior to, pending and not yet approved on August 3, 1955, shall be governed as an application for a permit under ORS 537.615 to 537.625 [1955 c.708 §6(1)]

537.580 [Repealed by 1955 c.708 §38]

537.585 Beneficial use of ground water prior to August 3, 1955, recognized as right to appropriate water when registered. Except as otherwise provided in ORS 537.545 or 537.575 or 537.595 and subject to determination under ORS 537.670 to 537.695, actual and lawful application of ground water to beneficial use prior to August 3, 1955, by or

Propose that 537.525(5) be modified to read:

Adequate and safe supplies of ground water for human consumption be assured while conserving maximum supplies thereof for agricultural, commercial, industrial, thermal, recreational and other beneficial uses.

Propose that 537.525(9) be modified to read:

Whenever wasteful use of ground water, impairment of or interference with existing rights to appropriate surface water, declining ground water levels, alteration of ground water temperatures, interference among wells, thermal interference among wells, overdrawing of ground water supplies or pollution of ground water exists or impends, controlled use of the ground water concerned be authorized and imposed under voluntary join action by the Water Resources Director and the ground water users concerned whenever possible, but by the director under the police power of the state when such voluntary joint action is not taken or is ineffective.

Propose to add to 537.525:

(11) Reasonably stable ground water temperatures be determined and maintained.

(m) Such other information as the director deems necessary

(3) Each application for a permit shall be accompanied by such maps and drawings and other data as the director deems necessary [1955 c.708 §9; 1959 c.437 §3]

537.620 Acceptance, recordation and approval of applications. (1) The Water Resources Director shall accept all applications for permits referred to in ORS 537.615 submitted to the director in proper form, indorse thereon the date of receipt and record each application in a book kept by the director for that purpose.

(2) If, upon examination by the director, the application is found to be defective, the application shall be returned to the applicant to remedy the defect. The date of and the reasons for the return shall be indorsed on the application and the indorsement shall be made a record in the office of the director. No application shall lose its priority of filing on account of any such defect providing an acceptable application is filed in the office of the director within 30 days from the date of the return of the application to the applicant, or such further time, not exceeding one year, as may be allowed by the director.

(3) When an application discloses the probability of wasteful use or undue interference with existing wells or that any proposed use or well will impair or substantially interfere with existing rights to appropriate surface water by others, the director may impose conditions or limitations in the permit to prevent the same or reject the same after hearing, or, in the director's discretion, initiate a proceeding for the determination of a critical ground water area under ORS 537.730 to 537.740.

(4)(a) When an application discloses the probability that a proposed use or well will impair or interfere with the ability to extract heat from a well with a bottom hole temperature of at least 250 degrees Fahrenheit, the director may:

(A) Approve the permit.

(B) Impose conditions or limitations in the permit to prevent the probable interference or impairment.

(C) After a hearing, reject the application, or

(D) Initiate a proceeding for the determination of a critical ground water area under ORS 537.730 to 537.740.

(b) In deciding whether to issue, deny or condition a permit under this subsection, the director shall consider any orders or permits applicable to the reservoir issued by the governing board or State Geologist of the State Department of Geology and Mineral Industries under ORS chapter 522.

(5) An application may be approved for less ground water than applied for or may be approved upon terms, conditions and limitations necessary for the protection of the public welfare, safety and health. In any event the application shall not be approved for more ground water than is applied for or than can be applied to a beneficial use. No application shall be approved when the same will deprive those having prior rights of appropriation for a beneficial use of the amount of water to which they are lawfully entitled. [1955 c.708 §10; 1961 c.569 §4]

537.622 Protest against issuance of permit, hearing. (1) Any owner of or claimant to a right to appropriate surface or ground water may file, jointly or severally, with the Water Resources Director at any time prior to the issuance of a permit to appropriate ground water under ORS 537.625, a protest against the issuance of the permit.

(2) Whenever, in the opinion of the director, a hearing is necessary to determine whether the proposed use or well described in an application under ORS 537.615 will conflict with existing rights to appropriate surface or ground water, he or his authorized assistant may hold a hearing on 10 days' written notice to the applicant and protestants, such hearing to be in the manner provided by ORS 537.430 (1969 Replacement Part). [1957 c.341 §2]

537.625 Issuance of permit if application approved, contents of permit, effect, rejection of application. (1) The approval of an application referred to in ORS 537.615 shall be set forth in a ground water right permit issued by the director. The permit shall specify the details of the authorized use and shall set forth such terms, limitations and conditions as the director considers appropriate. A copy of the permit shall be filed as a public record in the office of the director. The permit shall be mailed to the applicant, and upon receipt thereof the permittee may proceed to take all action required to apply the water to the designated beneficial use and to perfect the proposed appropriation.

Propose that 537.620(3) be modified to read:

When an application discloses the probability of wasteful use or undue interference with existing wells or that any proposed use or well will impair or substantially interfere with existing rights to appropriate surface water by others, or that any proposed use or well will impair or substantially interfere with existing rights to appropriate ground water for its thermal characteristics for beneficial purposes, the director may impose conditions or limitations in the permit to prevent the same or reject the same after hearing, or, in the director's discretion, initiate a proceeding for the determination of a critical ground water area under ORS 537.730 to 537.740.

(c) The wells of ground water claimants or appropriators within the area in question interfere or are likely to interfere with the production of geothermal resources from an area regulated under ORS chapter 522 or the production of geothermal resources from an area regulated under ORS chapter 522 interferes or is likely to interfere with an existing ground water appropriation,

(d) The available ground water supply in the area in question is being or is about to be overdrawn, or

(e) The purity of the ground water in the area in question has been or reasonably may be expected to become polluted to an extent contrary to the public welfare health and safety

(2) The director or the authorized assistant of the director shall hold a public hearing on the question of the determination of a critical ground water area Written notice of the hearing shall be given to each water well contractor and each well drilling machine operator licensed under ORS 537.747 whose address as shown on the license is within any county in which any part of the area in question is located and to each person or public agency known to the director from an examination of the records in the office of the director to be a claimant or appropriator of ground water in the area in question Notice of the hearing shall also be published in at least one issue each week for at least two consecutive weeks in at least one newspaper of general circulation in the area in question If the area in question is located in whole or in part within the limits of any city, notice of the hearing shall be published in at least one issue each week for at least two consecutive weeks in a newspaper of general circulation published in the city if any and written notice of the hearing shall be given to the mayor or chairman of the governing body of the city Written notices shall be given and the last publication date of published notices shall be at least 30 days prior to the hearing

(3) Oral and documentary evidence may be taken at the public hearing A full record shall be kept of all evidence taken at the hearing and the procedure shall be such as to secure a full fair and orderly proceeding and to permit all relevant evidence to be received
[1955 c 708 §26 1957 c 341 §8 1981 c 589 §5]

537.735 Order declaring critical ground water area, contents of order. (1) If, at the conclusion of the public hearing held under ORS 537.730, the Water Resources Director finds that any of the circumstances set forth in ORS 537.620 (3) and (4) if the proceeding is initiated thereunder, or in ORS 537.730 (1) if the proceeding is initiated thereunder, are true, and further finds that the public welfare, health and safety require that any one or more corrective controls be adopted, the director shall by order declare the area in question to be a critical ground water area

(2) The order of the director shall define the boundaries of the critical ground water area and shall indicate which of the ground water reservoirs located within the area in question are included within the critical ground water area Any number of ground water reservoirs which either wholly or partially overlie one another may be included within the same critical ground water area

(3) If the order is based completely or in part on actual or likely interference between ground water users and geothermal resources regulated under ORS chapter 522 the order shall demonstrate consideration of any orders or permits applicable to the reservoir issued by the governing board or State Geologist of the State Department of Geology and Mineral Industries under ORS chapter 522

(4) The order of the director may include any one or more of the following corrective control provisions

(a) A provision closing the critical ground water area to any further appropriation of ground water, in which event the director shall thereafter refuse to accept any application for a permit to appropriate ground water located within such critical area

(b) A provision determining the permissible total withdrawal of ground water in the critical area each day, month or year, and, in so far as may be reasonably done, the director shall apportion such permissible total withdrawal among the appropriators holding valid rights to the ground water in the critical area in accordance with the relative dates of priority of such rights

(c) A provision according preference, without reference to relative priorities to withdrawals of ground water in the critical area for residential and livestock watering purposes first Thereafter the director may authorize withdrawals of ground water in the critical area for other beneficial purposes, including agricultural, industrial, municipal other than residential, and recreational purposes, in such order as the director deems

Propose to add to 537.730(1):

(f) Ground water temperatures in the area in question are expected to be altered, are being altered, or have been altered excessively.

advisable under the circumstances so long as such withdrawal will not materially affect a properly designed and operating well with prior rights that penetrates the aquifer

(d) A provision reducing the permissible withdrawal of ground water by any one or more appropriators or wells in the critical area

(e) Where two or more wells in the critical area are used by the same appropriator, a provision adjusting the total permissible withdrawal of ground water by such appropriator or a provision forbidding the use of one or more of such wells completely

(f) A provision requiring the abatement, in whole or in part or the sealing of any well in the critical area responsible for the admission of polluting materials into the ground water supply or responsible for the progressive impairment of the quality of the ground water supply by dispersing polluting materials that have entered the ground water supply previously

(g) A provision requiring and specifying a system of rotation of use of ground water in the critical area

(h) Any one or more provisions making such additional requirements as are necessary to protect the public welfare health and safety in accordance with the intent purposes and requirements of ORS 537 505 to 537 795

(5) As used in this section residential purposes" means

(a) Single family residence use including watering lawns or noncommercial gardens one half acre or less in size in an amount not to exceed 5 000 gallons per day, or

(b) Use by a dwelling owner or tenant who is billed by a municipality for water received at the dwelling [1955 c 708 §27 1981 c 569 §6 1981 c 919 §1]

537 710 Filing findings of fact and order, copy to parties, changing order (1) The Water Resources Director shall file in his office his findings of fact based upon the evidence and his order based upon such findings made as provided in ORS 537 715 The director shall deliver copies of such findings and order to all parties in the proceeding for the determination of a critical ground water area The director shall file a copy of the order with the county clerk of each county within which any part of the critical ground water area lies and such county clerk shall record the order in the deed records of the county

(2) The director may suspend, modify or cancel any order made as provided in ORS 537 735 upon such notice and in such manner as he deems proper A certified copy of each suspension, modification or cancellation shall be filed and recorded as provided for orders in subsection (1) of this section [1955 c 708 §28]

537 745 Voluntary agreements among ground water users from same reservoir (1) In the administration of ORS 537 505 to 537 795, the Water Resources Director may encourage, promote and recognize voluntary agreements among ground water users from the same ground water reservoir When the director finds that any such agreement, executed in writing and filed with the director, is consistent with the intent purposes and requirements of ORS 537 505 to 537 795, and in particular ORS 537 525 537 730 to 537 740 and 537 780, he shall approve the agreement, and thereafter such agreement until terminated as provided in this subsection, shall control in lieu of a formal order rule or regulation of the director under ORS 537 505 to 537 795 Any agreement approved by the director may be terminated by the lapse of time as provided in the agreement by consent of the parties to the agreement or by order of the director when he finds after investigation and a public hearing upon adequate notice, that the agreement is not being substantially complied with by the parties thereto or that changed conditions have made the continuance of the agreement a detriment to the public welfare safety and health or contrary in any particular to the intent, purposes and requirements of ORS 537 505 to 537 795

(2) When any irrigation district, drainage district other district organized for public purposes or other public corporation or political subdivision of this state is authorized by law to enter into agreements of the kind referred to in subsection (1) of this section, the director may approve such agreements as provided in subsection (1) of this section Any such agreement approved by the director shall have the same effect and shall be subject to termination in the same manner and for the same reasons set forth in subsection (1) of this section [1955 c 708 §11]

537.747 Water well constructor's license. (1) No person shall advertise services for construction or alteration of water wells, offer to, or enter into a contract with another person or public agency to construct or alter a well for such other person or cause any well

Propose to add to 537.735(4):

(i) A provision closing all or part of the critical ground water area to further appropriation of ground water for its thermal characteristics.

(j) A provision determining the permissible total appropriation of ground water for its thermal characteristics in all or part of the critical ground water area each day, month or year, and, in so far as may be reasonably done, the director shall apportion such permissible total appropriation of ground water for its thermal characteristics among the appropriators holding valid rights to the ground water in the critical area in accordance with the relative dates of priority of such rights.

respect to the amount of water pumped per minute when a pump test is made

(h) The kind and nature of the material in each stratum penetrated with at least one entry for each change of formation, and the thickness of aquifers

(i) The temperature of the ground water encountered and other characteristics of such ground water in such detail as may be required by the director

(3) If required by the director, the person, public agency or licensee referred to in subsection (1) of this section shall furnish to the director samples of the ground water and of each change of formation in containers furnished and transportation expense paid by the director [1955 c.708 §29; 1961 c.334 §11; 1981 c.416 §6]

537.770 [1955 c.708 §30; 1957 c.341 §9; repealed by 1961 c.334 §12]

537.775 Wasteful or defective wells. (1) Whenever the Water Resources Director finds that any well, including any well exempt under ORS 537.545, is by the nature of its construction, operation or otherwise causing wasteful use of ground water is unduly interfering with other wells or is polluting ground water or surface water supplies contrary to ORS 537.505 to 537.795, the director may order discontinuance of or impose conditions upon the use of such well to such extent as may be necessary to remedy the defect.

(2) In the absence of a determination of a critical ground water area, any order issued pursuant to this section imposing conditions upon interfering wells shall provide to each party all water to which the party is entitled, in accordance with the date of priority of the water right. [1955 c.708 §25; 1981 c.919 §2]

537.777 Regulation by Water Resources Director of controlling works of wells and distribution of ground water. Whenever the Water Resources Director finds that any person or public agency is using or attempting to use any ground water or is operating or permitting the operation of any well owned or controlled by such person or public agency except upon compliance with ORS 537.505 to 537.795 and any applicable order, rule or regulation promulgated by the director under ORS 537.505 to 537.795, or that it is necessary in order to secure the equal and fair distribution of ground water in accordance with the rights of the various ground water users, the director shall regulate or cause to be regulated the controlling works of wells and shall distribute ground water in such a manner as to secure such compliance or such equal and fair distribution. Such regulation of controlling works and distribution of ground water shall be as nearly as possible in the same manner as provided in ORS 540.010 to 540.130. [1957 c.341 §4]

537.780 Powers of Water Resources Director. In the administration of ORS 537.505 to 537.795, the Water Resources Director may

(1) Require that all flowing wells be capped or equipped with valves so that the flow of ground water may be completely stopped when the ground water is not actually being applied to a beneficial use.

(2) Prescribe and enforce general standards for the construction and maintenance of wells and their casings, fittings, valves and pumps and special standards for the construction and maintenance of particular wells and their casings, fittings, valves and pumps.

(3) Prescribe and enforce uniform standards for the scientific measurement of water levels and of ground water flowing or withdrawn from wells.

(4) Enter upon any lands for the purpose of inspecting wells, including wells exempt under ORS 537.545, casings, fittings, valves, pipes, pumps and measuring devices.

(5) Prosecute actions and suits to enjoin violations of ORS 537.505 to 537.795, and appear and become a party to any action, suit or proceeding in any court or before any administrative body when it appears to the satisfaction of the director that the determination of such action, suit or proceeding might be in conflict with the public policy expressed in ORS 537.525.

(6) Call upon and receive advice and assistance from the Environmental Quality Commission or any other public agency or any person, and enter into cooperative agreements with any such public agency or person.

(7) Promulgate and enforce such rules as the director deems necessary to facilitate and assist in carrying out functions under ORS 537.505 to 537.795. Such rules include, but are not limited to rules governing

(a) The form and content of registration statements, certificates of registration, applications for permits, permits, certificates of completion, ground water right certificates,

Propose that 537.775(1) be modified to read:

Whenever the Water Resources Director finds that any well, including any well exempt under ORS 537.545, is by the nature of its construction, operation or otherwise causing wasteful use of ground water, is unduly interfering with other wells or is polluting ground water or surface water supplies or is causing substantial alteration of ground water temperatures or is causing substantial thermal interference with other wells contrary to ORS 537.505 to 537.795, the director may order discontinuance of or impose conditions upon the use of such well to such extent as may be necessary to remedy the defect.

Section 3.2

Heat Pump/Air Conditioning Return Flow Wells
Supporting Data

SECTION 3.2.1

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	Ground-Water Heat Pumps in Pennsylvania
AUTHOR: **(or INVESTIGATOR)**	E.W. Pine, C.W. Westlund, Bureau of Water Quality Management
DATE:	Not dated
STUDY AREA:	Pennsylvania USEPA Region III
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	This report examines the operation of a groundwater heat pump system including water temperature and volume requirements. Also considered are the groundwater resources of Pennsylvania, specific applications, and cost comparisons with other heating and cooling systems. Areas of regulatory concern are also discussed.

GROUND-WATER HEAT PUMPS

IN

PENNSYLVANIA

Eugene W. Pine, Hydrogeologist I
Carlyle W. Westlund, Chief
Ground-Water Unit
Division of Water Quality

Bureau of Water Quality Management

INTRODUCTION

Today, most Pennsylvanians are faced with the high cost of heating and cooling their homes. As a result, some previously overlooked technologies are attracting renewed interest. Such is the case with ground-water heat pumps. Ground water provides an excellent source of energy for residential and commercial heat pump systems, and is rapidly becoming an economic alternative to conventional sources of heat. They are especially efficient in states which experience wide variations in outdoor air temperatures and have adequate sources of ground water.

This report examines the operation of a ground-water heat pump system and their water temperature and volume requirements. Also considered are the ground-water resources of Pennsylvania, specific applications of ground-water heat pumps and cost comparisons with other heating and cooling systems. Finally, areas of regulatory concern are presented for the protection of our ground-water resources.

OPERATION

The operation of a heat pump simply involves taking thermal energy (heat) from ground water and transferring it into the home during the winter months. Summer cooling is provided when the system puts excess heat from the home back into the ground water.

The heating cycle begins when the ground water is piped through tubes to a heat exchanger. Surrounding these tubes is a container filled with a liquid refrigerant (freon). The freon, absorbing heat from the ground water, forms a warm gas. The gas is then directed to a compressor, which compresses this warm gas to a hot, denser gas (an average of 180°F and 245 pounds per square inch pressure for most models). The hot gas then flows to another heat exchanger, where the heat from the freon gas is released to air and ducted throughout the house. After this release of heat, the freon condenses to a liquid and is forced through an expansion device, which reduces the pressure and consequently lowers the temperature again. Finally, the refrigerant re-enters the first heat exchanger and the cycle is repeated.

For home cooling, the above process is reversed. The compressor sends the hot, dense freon gas directly to the heat exchanger, where this heat is absorbed by the ground water. The refrigerant is cooled by this process. The now liquid freon enters a small valve leading to an expansion device, which further lowers its temperature and pressure. The cool liquid refrigerant flows to the second heat exchanger, where it absorbs heat from the air in the house. In exchange, cooler air is released and ducted through the house. The warmed refrigerant returns to the compressor to repeat the cycle.

Many of the heat pumps installed today are reversible, meaning they can provide cooling as well as heating. This is made possible by using a device called a refrigerant reversing valve, which permits the flow of refrigerant to be reversed. Some units may also be equipped to provide hot water heat as an alternative to hot air. In addition, some units are equipped with a small heat exchanger between the refrigerant reversing valve and the compressor, which provides hot water for domestic needs.

Ground water which has circulated through the heat pump on either a cooling or heating cycle is ready for disposal. Methods of disposal include discharge of the ground water into sewer systems, tile fields, ponds or the land surface. At first glance, these methods appear convenient and relatively trouble-free, but their disadvantages

may indicate other methods of disposal [illegible] Many sewer systems cannot handle the large volumes of water which ground-water heat pumps can produce (up to 7,000 gallons a day for some domestic units). Back-up of the sewer lines may result. Tile fields may be overloaded and can halt action. Ponds have scenic value as well as wildlife or recreational usefulness, but may occupy large areas of property (not normally available in highly populated residential and commercial zones) and surface discharge may create bogs, accelerate leaching of pollutants back into the ground-water system, and form ice mounds in winter. In some instances, however, ponded water derived from cycled ground water may be used for livestock and farming needs. This method might eliminate the need for drilling a second well.

The most practical disposal system for the used water, however, is by means of a vertical disposal well. Ideally, this well should extend down to the same aquifer from which the supply well derives its water. This practice of returning water to its original source is necessary for water conservation and insures a continuous, adequate supply of ground water for heat pump operation. Conservation of our water resources has been especially needed in light of the near drought conditions many areas of the state have experienced over the past year.

Some advantages in using a vertical disposal well include:

(a) it is the most efficient and economical method of recharging the aquifer,

(b) it allows direct vertical access to the well for cleaning and injecting.

From discussions with representatives of the water well industry, most ground-water heat pumps installed in Pennsylvania at this time make use of a supply well and a vertical disposal well. The supply well may provide water for domestic needs as well as for the heat pump. The disposal well recycles the warmed or cooled water back into the aquifer.

Other possibilities for well design incorporating vertical recharge wells include:

(a) using a single well for supply and disposal - this method has been considered at times, mostly for economic reasons (one well versus two), but research has shown it to be impractical in some cases. For disposal in a supply well, approximately 100 feet of vertical separation is required for every 12,000 BTU's of heating or cooling produced per hour. A typical domestic heat pump unit, with a 60,000 BTU capacity, would require 500 feet of separation in the well from the point of disposal to the point of supply. These depths may be impractical for much of Pennsylvania due to higher drilling and pumping costs.

(b) incorporating a two well system and alternating withdrawal and disposal between the wells in winter/summer - this method could take advantage of any temperature variations which may exist in the ground water from this process. In winter, a disposal well injects cooler water back into the aquifer. In summer, the disposal well (now acting as a supply well) could withdraw this cooler water back from the aquifer for more efficient cooling. The second well could be used in a similar way for warmer water. Alternating supply and disposal may also be beneficial as a preventative maintenance measure. This alternation in each well helps prevent clogging of the well screen, a common problem. This method of design is rarely practiced, probably due to its larger initial investment. The system would require

an additional pump (one per well) and more piping compared to other systems. Due to its high efficiency, however, this method may see future application in Pennsylvania, especially for industry.

Another method for disposal of the ground water used for heat pumps is by means of a horizontal disposal well. This incorporates an injection tube inside a shallow well to a horizontal well system. The system can be used as a single-line or multiple-line for disposal. It is economical to install in sandy soils but is subject to plugging and is difficult to clean and rehabilitate. This system has seen little application in Pennsylvania at this time.

WATER DEMAND

The water demand for a ground-water heat pump will vary with size and design. An average domestic ground-water heat pump unit, with a heat capacity of 60,000 BTU's per hour, will require approximately 5 to 15 gallons per minute from a supply well when in operation. Average daily use on cold winter days may approach 7,000 gallons. If the home relies on ground water for other domestic needs as well, the system should be designed to handle peak water consumption.

Most aquifers in Pennsylvania can easily meet the needs of ground-water heat pumps. If water quantity is inadequate, however, the system may be supplemented with storage tanks or more efficient heat pumps with a higher heat exchange. These are usually required if the well yields an average of less than five gallons a minute to the heat pump. Storage tanks may be located in a basement or buried underground. Their storage capacity should be approximately 5,000 gallons. In addition, many new heat pumps have higher heat exchange capacities than earlier models. This increase in efficiency relates to a corresponding decrease in water demand.

WATER TEMPERATURE

Today's ground-water heat pumps can operate efficiently at ground-water temperatures as low as 39°F. (Pennsylvania ground-water temperatures range from approximately 48°F in the northwest to 55°F in the southeast). Higher temperature ground water will, of course, put less demand on the system and make it more efficient. An important point to consider is that the temperature of ground water remains relatively constant throughout the year. A typical air-to-air heat pump system requires the use of a supplemental heating system when the temperature of the outside air falls below a certain point (usually 20° to 35°F). Cooling a home using hot summer air also reduces the efficiency of the cooling unit and may require a backup cooling system. Ground-water heat pumps use water which remains at a constant temperature throughout the year and thus operate at maximum efficiency all year. A ground-water heat pump used for both heating and cooling will operate most efficiently where ground-water temperatures range from 50° to 60°F. Most ground-water temperatures in Pennsylvania are within this range. In addition, a ground-water heat pump usually raises the temperature of the water by no more than 10°F. This water is usually returned to the original aquifer with no change in water quality and only a modest temperature difference.

GROUND-WATER RESOURCES OF PENNSYLVANIA

Pennsylvania is a water-rich state, receiving an average of 41 inches of precipitation per year. Approximately one-third of this precipitation infiltrates to aquifers, maintaining the more than 47 trillion gallons of usable ground water in underground storage. Each year between 9 and 12 trillion gallons of this ground water is discharged

naturally to springs and seeps into Pennsylvania streams. Ground water may contribute nearly 100 percent of total streamflow during the drier months of August through October.

Currently, 25 to 35 percent of Pennsylvania population depends on ground water for domestic needs. Twenty-one counties obtain more than half of their total water supply from aquifers, and more than 68 percent of all public water supply systems in the state rely on ground water for all or part of their needs.

Ground water has often been preferred over surface water for development in homes or industry. Its many advantages include: low development and treatment costs; relatively constant yield and supply; constant chemical quality; sediment-free nature; constant temperature; no evaporation losses; and minimal area requirements for development. Many of these advantages, especially ground-water's constant temperature, are directly applicable in considering the use of ground water as a heat source.

The demand for ground-water development will increase as our population, industry and per capita need for water increase. Ground water is often preferred by industry for cooling and processing because of its constant cool temperatures, low cost and sediment-free nature. Small and mid-sized communities may prefer ground water for their requirements due to its low development, expansion and treatment costs. It is likely that the use of ground-water heat pump applications will increase in areas where the population and industry are expected to increase. Parts of Northwestern, Southwestern, Southern, Central and Eastern Pennsylvania are projected areas of future population and industrial growth, and could see an increase in ground-water use as an energy source. Generally, water quantity is adequate in these areas for heat pump operation although local problems may exist. If water quantity is a problem, the system may be supplemented with storage tanks or other equipment (discussed in the previous chapter).

Ground water use may also increase in areas where surface waters are already polluted (most notably in the coal mining regions of the state). Ground-water supplies of adequate yield may be available at a cost considerably lower than that required to develop treatment facilities for surface water.

Even in areas where ground water is not of drinking water quality, ground-water heat pump applications are possible. The heat pump merely "borrows" the ground water for a time and returns it to its original source, withdrawing (or adding) only heat in the process, not the pollutants.

A common ground-water quality problem in many areas of the state is high concentrations of calcium, magnesium and iron. This "hard water" may form scale deposits in tubing and clog pipes. One way to prevent this is to install cupronickel instead of copper tubing. According to heat pump manufacturers, cupronickel expands and contracts with temperature, and its surface tends to flake off mineral and scale deposits.

If the practice of using any polluted waters for ground-water heat pump applications is employed, however, it is strongly recommended that the ground water be returned, through a properly constructed well, to its original source. This practice will avoid pollution of other surface or ground waters.

APPLICATIONS OF GROUND WATER HEAT PUMPS IN PENNSYLVANIA

Nearly half of the energy used in the residential and commercial sectors in the United States goes for space heating. This represents one-sixth of total U.S. energy use and one-fourth of total oil and natural gas consumption. (Leon R. Glicksman, "Heat Pumps: Off and Running. . .Again", Technology Review, June/July 1978, pp. 64-70). The magnitude of this demand, coupled with rising costs of fossil fuels, makes states like Pennsylvania prime candidates for improved heating and cooling technologies, including ground-water heat pump applications.

Individual residential ground-water heat pump systems are generally used for space heating and cooling. Some units may also be equipped to provide hot water for other domestic needs as well.

Another means of utilizing ground-water heat pump units for residential heating and cooling are district heating systems. This involves a centralized distribution of ground water to multiple end-users. Each end-user would use individual heat exchangers and compressors for their own heating and cooling needs. Common piping may be installed to deliver the ground water to service. Costs for obtaining, pumping, maintenance and disposal of the ground water can be mutually shared by all end-users.

Since Pennsylvania is an industrial state, applications of ground-water heat pumps may include service water heating and process heat as well as space heating and cooling. Many industries have these requirements, including textiles, chemical products, petroleum refining, fabricated products, food products, machinery and electrical equipment and transportation equipment. In addition, much of the heat generated by industry could be recovered by ground-water heat pumps and recycled into the aquifer. This increase in water temperature can maximize the efficiency of the heat pump system and provide less costly heat when required.

THE ECONOMICS OF GROUND-WATER HEAT PUMPS

To evaluate the economics of a ground-water heat pump system, its initial cost (equipment and installation) and its annual operating costs must be considered. The initial cost of the ground-water heat pump is higher than that of conventional systems, but its lower annual operating costs and maintenance requirements, ability to produce heating as well as cooling, and relative immunity to escalating fossil fuel costs make it economically competitive.

According to a survey of ground-water heat pump installers in Pennsylvania, the initial cost of a ground-water heat pump system will vary from area to area, but generally approaches $6,000. This includes the cost of the heat pump itself (usually $2,500-$3,000), a water well capable of supplying 2.5 gallons of water per minute per 12,000 BTU's of heating or cooling produced (generally $2,300-$2,700), ductwork in the home (approximately $400) and plumbing (usually $300-$400). Initial costs will be higher if two wells are employed (one for supply, one for disposal) and extra features such as corrosion-resistant cupro-nickel heat exchange coils are added. Initial costs will be lower if one or more wells already exist on the property. This eliminates drilling costs.

Average initial costs for conventional heating systems are lower. Some of these, with the cost of a cooling system included, are listed below:

Air-to-air heat pump	- $3,500
Natural gas furnace	- $2,500
Electric Resistance	- $1,500
Electric Furnace	- $2,500
Propane	- $2,700

The average annual operating costs of a ground-water heat pump system are usually much lower than conventional systems. This is due to its higher efficiency, since the unit simply transfers existing thermal energy from one place to another. The efficiency of a system may be measured by a ratio called the coefficient of performance (COP). The COP is simply a ratio of the amount of heat produced to the amount of energy required to produce that heat. The average COP for a ground-water heat pump is approximately 3.2, meaning that the heat pump will deliver 320 BTU's of heat for every 100 BTU's of electrical energy it consumes (to operate the pump, compressor and blower).

The COP of a ground-water heat pump is much higher than that of conventional systems. Some average COP's of those systems are listed below:

Air-to-air heat pump	- 2.0
Natural gas furnace	- 0.75
Electrical Resistance	- 0.95
Coal Furnace	- 0.70

The higher the COP, the lower the annual operating costs of the system will be. In comparison, 100 BTU's of energy will produce 320 BTU's of heat from a ground-water heat pump, but only 75 BTU's from a natural gas furnace (COP equals 3.2 and 0.75 respectively). This reduction in annual operating costs offsets the higher initial costs of a ground-water heat pump system. Depending on the initial investment, the cost difference between the ground-water heat pump and conventional heating systems can usually be eliminated over a period of two to six years. After this time, energy savings using ground-water heat pumps are substantial.

REGULATORY CONCERNS

The ground-water heat pump industry is growing in Pennsylvania. While the concept of heat pumps is still young, however, it is important to establish a policy which will protect the heat pump user as well as the ground-water resources upon which he relies.

Any policy concerning the use of ground-water heat pumps should address the specific effects of a heat pump system on ground-water quality and quantity: Do ground-water heat pumps cause pollution? If so, how? Should cycled ground water be reinjected or disposed of in surface waters? What are the effects of over-development? These questions and others must be considered and their possible effects on ground-water quality and quantity should be calculated.

It is unlikely that ground-water heat pumps themselves cause pollution. The units do, however, contain refrigerant (freon) and oil. It is conceivable that a rupture in the plumbing or an event causing a pressure loss in the system could allow the freon and/or oil to enter the ground-water system. Volumes of freon and oil in a domestic

heat pump are small, but are considerably larger with industrial units. Freon has a slight to moderate toxicity (Dangerous Properties of Industrial Material, Sax, 1968), and the presence of even small quantities of oil in ground water may make the water undrinkable.

Uncontrolled overpumping and overdevelopment of the ground-water heat pump industry may cause problems such as aquifer drawdown and well interference. Aquifer "drawdown" indicates that more water is being withdrawn from the aquifer than is being replaced and usually manifests itself by smaller yields and lower water levels in wells. Pumping a well usually creates a cone-shaped depression of the water table (the two-dimensional surface representing the top of the ground water), with the lowest point on the cone being the well location, where the water is being pumped. With over-pumping, two or more closely spaced wells may see an overlapping of their individual cones of depression. This is called "well interference" and also is reflected by lower well yields, as some of the available ground water must now supply two or more wells instead of one. Where the water is reinjected into the same producing aquifer by way of the source well or a second well, no aquifer drawdown or well interference will occur.

If a ground-water heat pump uses waters of low quality, contamination of shallow higher quality aquifers can result if the cycled ground water is reinjected into these shallow units. Also, surface disposal of used low quality ground waters may contaminate the high quality ground water and surface water.

Even if lower quality ground waters are reinjected to their original source, problems can result from faulty well construction. This usually occurs due to insufficient and substandard well casing, inadequate seals between the well casing and borehole, and poor welding of casing joints.

Other possible ground-water effects from the use of ground-water heat pumps concern temperature variations due to heat pump operation. Heating ground water may raise the temperature of surface water base flow (the ground-water contribution to total stream flow) to greater than 58^{0}F, which is the limit for cold water fisheries in the state. This could conceivably happen, but would require large volumes of heated ground water. Larger industries utilizing ground-water heat pump systems could generate this volume. Also, it is possible that heated discharges may raise surface water and ground-water temperatures for other nearby ground water users.

In addition, discharging water either to the surface or in seepage pits in carbonate (limestone, dolomite) rock terrain may accelerate sinkhole activity. Returning water to the original aquifer in this environment, however, will lessen this effect.

CONCLUSION

With modern technology, ground water may now be considered an energy source as well as a drinking water source. Ground-water supplies do not, unlike other energy sources, dwindle during cold winter seasons or suffer from OPEC price increases. It is, like solar power, considered "free energy".

The ground-water heat pump industry is expected to grow, as more and more people become aware of the advantages ground water has to offer. Associated with this growth, however, should be the proper planning and increased public awareness needed to ensure the protection of our ground-water resources.

Finally, the following list of DO'S and DON'TS should be taken into consideration:

DO SEEK reputable, knowledgeable well drillers and installers.

DO RETURN the ground water to its original source.

DO have all wells properly constructed.

DO report the location of your well to DER.

DO enlist the services of a qualified hydrogeologist when designing commercial and industrial systems that will require a large volume of water.

DON'T USE additives which could pollute ground water.

Legal Requirements of Water Well Drillers

Anyone considering installing a ground-water heat pump should be aware of the legal requirements of water well drillers. Act 610 of the Administrative Code, known as the Water Well Drillers License Act, requires all water well drillers in the Commonwealth to obtain a license. This program is administered by the Department of Environmental Resources, Bureau of Topographic and Geologic Survey, P.O. Box 2357, Harrisburg, PA 17120 (Telephone: 717-787-5828). Drillers are also required to complete a well completion report on a form provided by the Bureau; the form calls for geologic data, well description data, and well use. This report is sent to the Bureau of Topographic and Geologic Survey. This form has copies for the well owner, driller, and the county or municipality in which the well is drilled. Well owners do not always receive a copy of the report since it is not required in Act 610. Well owners desiring their copy should request it from their well driller.

For Additional Reading....

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National Conference of State Legislatures, Guidebook to Ground-Water Heat Pumps, (May 1980)

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SECTION 3.2.2

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	Ground-Water Heat Pumps in the Tidewater Area of Southeastern Virginia
AUTHOR: **(or INVESTIGATOR)**	SMC Martin, Inc.
DATE:	June, 1983
STUDY AREA:	Southeastern Virginia USEPA Region III
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	SMC Martin, Inc. was contracted by EPA to develop a data base (inventory) and assess the environmental impact of groundwater heat pumps in the Tidewater area of southeastern Virginia. This report provides the results of the investigation and includes an estimate of the number of heat pumps in the area, a listing of municipal regulations which could affect heat pump installation, and regulatory recommendations.

GROUND-WATER HEAT PUMPS IN THE TIDEWATER AREA OF SOUTHEASTERN VIRGINIA

Prepared by:

SMC Martin Inc.
900 W. Valley Forge Road
P. O. Box 859
Valley Forge, PA 19482

Submitted to:

U.S. Environmental Protection Agency
Region III
Ground-Water Protection Section
6th & Walnut Streets
Philadelphia, PA 19106

Contract No. 68-01-6288
Task #2, Amendment #5
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June 7, 1983

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1.0 INTRODUCTION

1.1 Background

Ground-water heat pumps have been in use for residential heating and cooling since the 1950s and have gained in popularity over the past decade. Heat pumps can be used for both heating and cooling and are particularly popular in areas of temperate climate and moderate ground-water temperatures where both central heating and air conditioning are desired. Although a ground-water heat pump costs more initially than a conventional heating or cooling system, the operating costs are generally lower than for other systems. Because the systems often pay for themselves in several years, many houses are being retrofitted with these systems in addition to units installed in new homes.

A ground-water heat pump system requires a water supply well, a small water pump, a heat pump (compressor) which circulates a liquid refrigerant (freon), a heat exchanger, a circulation system, and a discharge system. A schematic showing the heat pump operational cycles is shown in Figure 1.

During the heating cycle, freon flows through a capillary tube, lowering its pressure and boiling point. As the freon passes through the heat exchanger, it extracts heat from the surrounding water, boils and vaporizes. The cooled water is either discharged to the surface or is injected into the subsurface. The freon vapor flows to the

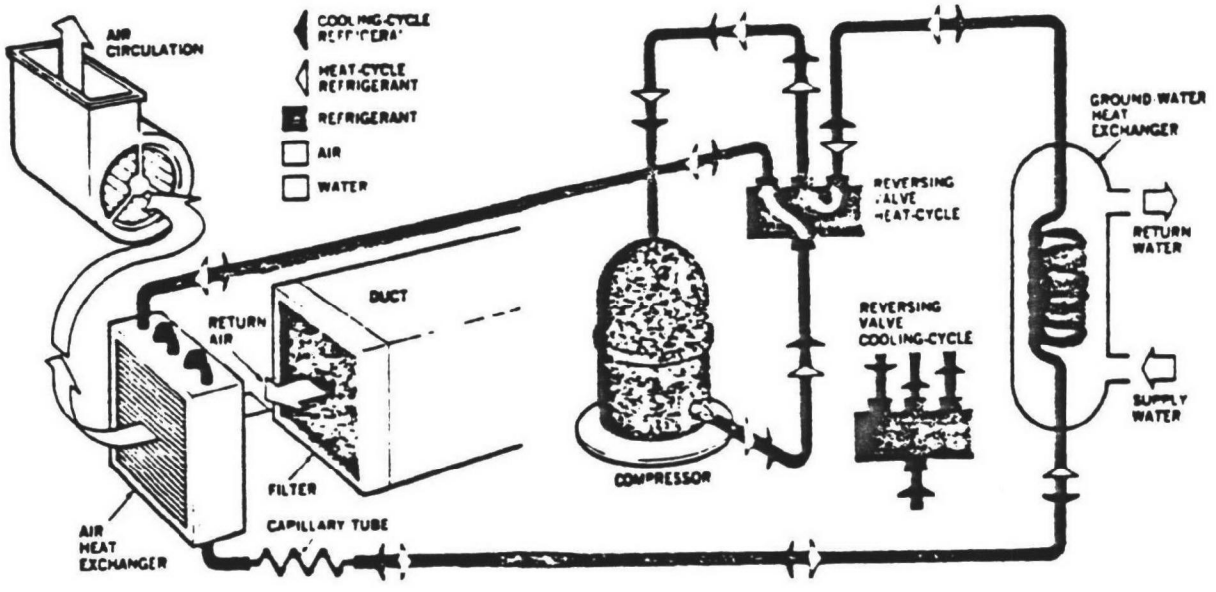

Figure 1: HEAT PUMP OPERATIONAL CYCLES

compressor and is pumped to the air heat exchanger as a hot, high-pressure gas. In the air heat exchanger, the freon condenses and releases heat to the air which circulates through the home's heating ducts.

This process is reversed for cooling, wherein the compressor pumps the hot freon vapor to the water heat exchanger, which releases heat collected from the house. The warmed ground-water is discharged as described above and the cooled, liquid freon flows through the capillary tube to the air heat exchanger. In the air heat exchanger, the freon absorbs heat from the house, vaporizes, and returns to the compressor, renewing the cycle. As illustrated, the ground water in the water heat exchanger does not directly contact the freon refrigerant or the atmosphere.

1.2 Scope of Work

In the Tidewater area of southeastern Virginia, a relatively small geographic area (Figure 2), the combination of a moderate climate, nearly constant ground-water temperature, and sufficient ground-water supplies have resulted in widespread use of ground-water heat pumps. Of the communities in this area, only Virginia Beach has initiated regulatory guidelines concerning the construction details of the heat pump system. As part of the permit conditions, heat pumps are required to inject the effluent via return wells; surface discharges are prohibited.

The remaining communities in the Tidewater area do not directly regulate the installation of ground-water heat

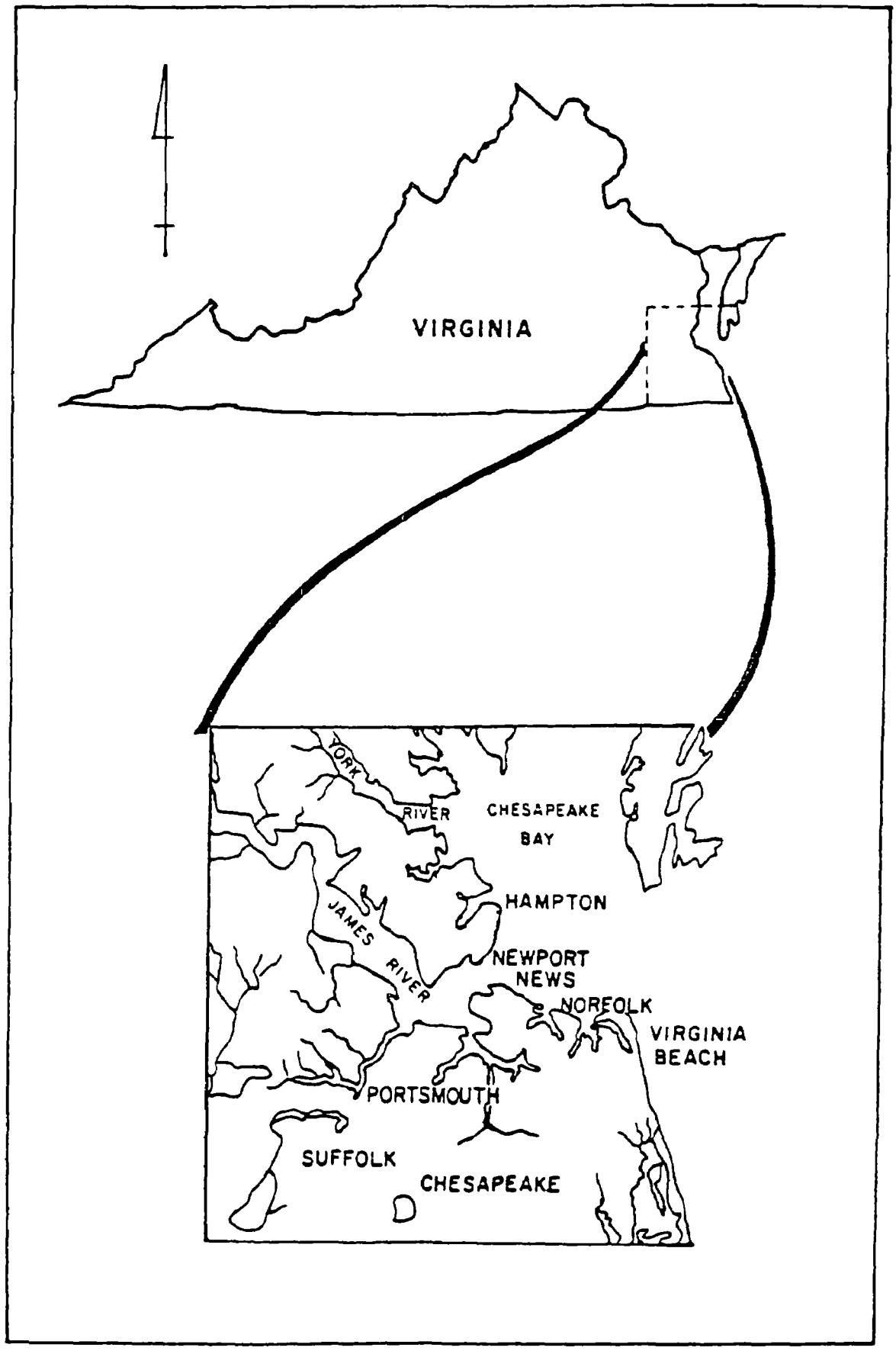

Figure 2: TIDEWATER AREA OF SOUTHEASTERN VIRGINA

pumps. As a result, the number of heat pumps in the area, along with construction specifics and operational data, are largely unknown.

Under Contract #68-01-6288, Task #2, Amendment #5, EPA Region III requested that SMC Martin develop an informational data base and assess the environmental impact of the ground-water heat pumps in the Tidewater area of southeastern Virginia.

The scope of work for the project was revised during a February 2, 1983 meeting with representatives of EPA Region III and SMC Martin. During this meeting, it was determined that the investigation should primarily include:

- Chemical contamination potential from cleaning, maintenance, and operation
- Recharge problems
- A listing of firms that install ground-water heat pumps
- Regulatory recommendations.

This report provides the results of the investigation and includes an estimate of the number of heat pumps in the study area, a list of existing municipal regulations which could affect heat pump installation, and regulatory recommendations.

1.3 Methodology

A comprehensive telephone survey was conducted in order to generate a list of ground-water heat pump installers in the Tidewater area, to estimate the number of heat

pumps in operation, and to obtain operational and construction details of the "typical" residential heat pump system. In the telephone survey, the following types of businesses were contacted:

- Local members of the Contractor Division of the National Water Well Association
- Water well drillers
- Heating contractors
- Water treatment contractors
- Heat pump dealers, distributors, and installers.

These businesses were asked about the number of ground-water heat pump systems they have sold and/or installed in the area, the number of recharge wells in the systems, and the relative proportion of residential versus nonresidential systems. Installers were also asked to describe construction details of ground-water heat pump systems, in particular, the size of a typical heat pump, the amount of water required, whether the water is treated with chemical additives, the number of systems installed on new construction or retrofitted to existing buildings, and any problems encountered with ground-water heat pumps.

The seven municipalities in the Tidewater area were contacted and asked about ordinances which may affect ground-water heat pumps. Municipal offices which were contacted include the Health Department, Building Inspection Department, Public Works Department, Zoning, City Clerk, City Solicitor, and the Sanitation Authority.

2.0 ENVIRONMENTAL SETTING

2.1 Physiography

The Tidewater area lies entirely within the Atlantic Coastal Plain physiographic province. Deposition and erosion of sediments by fluctuating sea levels over time have created the "stair-step" topography characteristic of the Atlantic Coastal Plain. This consists of wide gently eastward sloping plains separated by linear, steeper, eastward facing scarps. Elevation and relief become progressively lower, eastward through the area.

The study area is bounded on the east by the Atlantic Ocean, on the north by the Chesapeake Bay, and is bisected by the James River. The northern portion of the area drains into the James River and Chesapeake Bay, while the southern portion is drained by long southward-flowing streams which discharge into the Currituck and Abermarle Sounds. The areas between major streams are often flat and poorly drained.

2.2 Hydrogeology

The area is primarily underlain by a wedge of unconsolidated sediments deposited on a pre-Cretaceous basement of crystalline rock. The sediments, which consist primarily of clays, silts, sands, gravels, and shells, form a wedge which thickens toward the east. The sediment blanket begins at the Fall Line, which marks the border between the Piedmont and the Coastal Plain Provinces, and thickens to 2400 feet at the Atlantic Ocean.

There are four main aquifers in the Tidewater area (Figure 3). The water table or Quaternary aquifer extends to a depth of approximately 40 feet and supplies small amounts of fresh, nonpotable water. Water quality in this unit is highly variable; low pH and high iron content are the major quality limitations for use. Very few heat pumps use ground water from this aquifer. The Yorktown aquifer is the major potable aquifer and supplies essentially all ground-water heat pumps in the area. The Eocene and Cretaceous aquifers supply minor quantities of fresh or brackish water.

Most ground water for residential and light industrial use in the Tidewater area is obtained from the Yorktown aquifer. Beds of silt and clay and sandy clay, about 20 to 40 feet thick, separate the Yorktown aquifer from the overlying water table aquifer. Water enters the Yorktown primarily from downward leakage from the Quaternary aquifer and to a lesser extent by lateral flow from the west. The Yorktown formation is 300 to 400 feet thick, but the water-bearing portion is found in sand, gravel, and shell beds located in the upper 50 to 150 feet. The aquifer is divided into three major sand units separated by silt and clay beds. Domestic well yields typically range from 5 to 50 gallons per minute. Except in areas of significant pumpage, the water table generally follows topographic trends (Siudyla et al, 1981).

SYSTEM	SERIES	STRATIGRAPHIC UNITS		HYDROGEOLOGIC UNITS	DESCRIPTION OF HYDROGEOLOGIC UNITS
QUATERNARY	RECENT PLEISTOCENE	RECENT COLUMBIA GROUP		WATER TABLE OR QUATERNARY AQUIFER	Unconsolidated sand, silt, and some gravel. Sand units yield quantities adequate for domestic and small industrial demands, used extensively for lawn watering. Unconfined aquifer.
TERTIARY	UPPER	CHESAPEAKE GROUP	YORKTOWN	YORKTOWN AQUIFER	Sand and shell beds main water-bearing units. Adequate for moderate public and industrial supplies. Artesian
	MIOCENE MIDDLE		CALVERT	CONFINING UNITS	Silt and clay predominant, minor sand lenses
	EOCENE	MATTAPONI		EOCENE-UPPER CRETACEOUS AQUIFER	Glauconitic sand and interbedded clay and silt. Infrequently used as a water supply. Yields adequate for moderate supplies. Brackish in most of area. Artesian
	PALEOCENE				
CRETACEOUS	UPPER	LOWER CRETACEOUS	TRANSITIONAL BEDS	LOWER CRETACEOUS aquifer	Interbedded gravel, sand, silt, and clay. Yields are adequate for large industrial use. Brackish in most of area. Artesian
	LOWER		PATUXENT		

Figure 3: STRATIGRAPHIC AND HYDROGEOLOGIC UNITS OF SOUTHEASTERN VIRGINIA

FROM STUDYLA ET AL (1981)

Ground water from the Yorktown aquifer is generally of a quality suitable for residential use, though treatment to reduce iron concentrations is sometimes required. Throughout the area, the fresh water/salt water interface roughly parallels the shoreline. According to Siudyla et al (1981), "Invasion of brackish water into fresh water portions of the Yorktown aquifer due to pumping is a possibility. Intense well field development along the shoreline would probably result in brackish water encroachment into the well fields. Inland, the concern is upward movement or upwelling of brackish water found at about 150 feet mean sea level into the fresh water portion of the Yorktown aquifer."

3.0 OPERATIONAL DATA

3.1 Existing municipal regulations

The code of the city of Virginia Beach (Section 37-18.1) (see Appendix A) requires all ground-water heat pumps to "return all such ground water after usage in an unaltered biological and chemical condition to the aquifer from which it was originally withdrawn" unless otherwise provided by an SPDES permit from the State Water Control Board. All ground-water heat pumps must be permitted by the Department of Permits and Inspections. Since the Department began keeping records in April 1980, 554 ground-water heat pumps have been permitted in Virginia Beach through May 1983.

Chesapeake has an ordinance (Chapter 38, Article II, Section 1) which prohibits the taking of water from a private well for domestic use if city water is available. Section 32.1-162(2) of the State Public Water Supply statutes defines household heating as a domestic use. The ordinance, which was adopted in 1969, was intended to require homeowners to hook into the city water system. Since the entire municipality is served by public water, this ordinance, in effect, prohibits the use of ground-water heat pumps. City officials contacted are unaware of the implications of this ordinance, and the ordinance is not actively enforced against heat pumps.

The Hampton Roads Sanitation District operates the wastewater treatment facility for the entire study area

except a portion of Portsmouth which is not yet served by a sanitary sewer system. Since November 1, 1978, the regulations of the sanitation district have prohibited discharge of "any significant quantities of . . . ground water . . . or any other unpolluted water" into any portion of the sanitary sewerage system (Part III, Section 301(E): Industrial Wastewater Discharge Regulations). The Industrial Waste Division sent a letter stating this to all heat pump installers in the Tidewater area in 1979 and to municipal building and plumbing inspectors in 1982. The State Water Control Board must approve of all heat pump discharges to the storm sewer system, although permits are not required.

3.2 Inventory

Ground-water heat pumps have been installed in the Tidewater area since the 1950s and their popularity has greatly increased since the rise of energy costs in the 1970s. It was not possible to contact many of the contractors who have been installing heat pumps since the 1950s, since some of these firms are no longer in business. However, 178 heat pump contractors in the Tidewater area were contacted regarding the ground-water heat pump systems they have installed in the study area. Fifty-six contractors reported that they have installed systems in the study area (Appendix B). Each contractor was asked to estimate the number of systems he had installed (Appendix C); these estimates totalled 2,678 systems. Using this approach, this

estimate should be considered a first-cut approximation of the total number of heat pumps in the area. The survey method had no provisions for field verification of the installers' estimates. Also, a number of installers could not be reached, and many installers could only estimate the number of ground-water heat pumps they installed within the past several years.

3.3 Discussion of Heat Pump Systems in the Tidewater Area

In recent years, most ground-water heat pump systems have been retrofitted to existing homes and buildings. Although a significant number are installed in new homes, it does not appear feasible to estimate numbers or trends in ground-water heat pump installations in new homes from records of building permits.

Residential ground-water heat pumps generally require two to three gallons of water per ton every minute of operation. The supply well should discharge at least 5 to 15 gallons per minute. If this is not available, several supply wells may be used. Most wells in the Yorktown aquifer have sufficient yield to supply a ground-water heat pump (Siudyla et al, 1981), although many heat pump installers and water well drillers report that insufficient yield is a major limitation on ground-water heat pumps in some areas.

The depth of both the supply and the recharge wells typically ranges from roughly 50 to 200 feet and

averages approximately 80 feet. Wells can be drilled deeper to the west as the fresh-water salt-water interface is deeper further from the ocean. Nearly all ground-water heat pump wells are screened in the Yorktown aquifer; very few heat pumps are supplied by shallow (less than 40-foot) wells in the Quaternary aquifer. Both supply and recharge wells are usually drilled to roughly the same depth. Most drilling is subcontracted to water well drillers, although some heat pump contractors are acquiring their own well drilling capabilities.

Most wells in the Tidewater area used in heat pump operations are 1-1/4 to 4 inches in diameter. The wells are drilled with a mud rotary drilling rig and are typically cased with Schedule 40 PVC casing to the total depth. The screened interval is typically 5-20 feet, with slot sizes ranging from .008 inch to .025 inch. Jet ejector pumps are usually used for flows under 16 gpm and in the smaller diameter wells; submersible pumps are occasionally used in the 4-inch wells.

The vast majority of these ground-water heat pump systems have small heat pumps, defined as 5 tons or smaller (1 ton = 12,000 BTU). A 2 or 3-ton heat pump is sufficient for most residential applications. Large homes and buildings are frequently subdivided into different heating zones (e.g., living versus sleeping areas) and a heat pump may be installed for each zone. The individual heat pumps may

operate on separate sets of wells although it is common to have all the heat pumps in a large building mutually connected to several supply and recharge wells.

Several design options are available for non-residential buildings which require heat pumps larger than approximately five tons. Water to air heat pumps can at least in theory be built to any size, with the maximum size usually limited by the number and capacity of the supply and recharge wells. Ten-ton units may be constructed by pairing two 5-ton units, and larger units (a 20-ton unit is considered large) may be custom built by a contractor. The current trend is to combine several smaller heat pumps and to inject the effluent.

Water to air heat pumps in many large buildings use drinking water from the municipal water system as a heat source or sink. The water is discharged to cooling or evaporation towers and/or the municipal sewer. These systems do not use any wells and are not expected to have any direct impact on the ground water.

Very few water-to-water heat pumps are in use in the Tidewater area. In these systems, ground water is used as a heat source for the building's hot water heating system. The ground water may be discharged to recharge wells or to the surface. It has been estimated five or six such systems are in the Tidewater area, with the largest unit a 250-ton heat pump which discharges to a lake.

Recharge well failure is the most common problem faced by ground-water heat pump contractors and owners. Plugging of the well screen by silt was the most common failure mechanism. Some contractors reported that installing filters in the supply line can aid in preventing these problems. Thorough well development is important to prevent fine sediments from plugging the well screen. Some contractors recommend pumping the recharge wells to waste on an annual basis.

Ground water in the study area contains relatively high iron concentrations, which can contribute to well failure. As the ground water passes through the pump, dissolved oxygen in the water may oxidize the iron, resulting in iron oxide precipitation. Iron encrustation may build up within the heat pump, recharge well, or recharge aquifer. At least one case of iron precipitates plugging a surface discharge pipe was reported.

4.0 POTENTIAL IMPACTS

4.1 Impact of effluent disposal by surface discharge

4.1.1 Ground-water depletion

Residential ground-water heat pump systems withdraw an average of ten gallons of water per minute of operation. The widespread use of these systems in conjunction with surface discharge of effluent, and/or injection of effluent to an aquifer other than the pumped aquifer, can contribute to ground-water depletion. In the first case, the discharged effluent will either runoff to a surface water body or percolate into the water table aquifer, which in the study area, is not widely used as a heat pump water source. In the second case (the injection of effluent to an aquifer other than the pumped aquifer), a depletion of the pumped aquifer can also occur. This depletion could induce salt water intrusions (4.1.2) and/or diminish the available supply of potable water.

As previously noted, Virginia Beach has required injection of heat pump effluent since March 1, 1982. The State Water Control Board requires SPDES permits for all surface discharges from heat pumps. The Hampton Roads Sanitation District, the sewer treatment authority covering the majority of the study area, has prohibited the discharge of ground-water heat pump effluent into the sanitary sewer system since November 1, 1978. Furthermore, the State Water Control Board must approve discharges into the storm sewers.

These regulations severely limit the surface discharges from heat pumps but do provide for injection via recharge wells. Most of these wells inject into the Yorktown, the pumped aquifer.

A portion of the systems which were constructed before these regulations went into effect do, however, discharge effluent to the surface. Waterfront homes frequently discharge to the lakes. Contacts with heat pump installers also indicated that there are a small number of systems which discharge into the public sewer system, although these could not be specifically identified. This discharging of effluent to the sewer system appears to be used primarily as a last resort after several attempts to inject the effluent have failed. Some systems do not inject or discharge the effluent but use all or part of it to water lawns, wash cars, and other non-drinking water uses. Some of this water will eventually reach the water table.

Communications with various heat pump installers suggest that approximately 95 percent of the systems currently installed dispose of effluent via injection wells set into the Yorktown aquifer. This is also the aquifer from which the water is drawn, thereby setting up a "closed circulation system" and reducing the potential for groundwater depletion. However, depletion could potentially become a problem in areas where the surface discharge of effluent is practiced or in areas with systems built prior to the aforementioned regulations.

4.1.2 Potential for saltwater intrusion

Extensive ground-water withdrawals have the potential to alter existing ground-water flow gradients. In areas near the ocean, this can cause intrusion of salt water into fresh aquifers. According to Siudyla et al (1981), excessive ground-water withdrawals from the Yorktown aquifer could cause lateral saltwater encroachment and upconing of brackish water from underlying strata. It is possible that ground-water withdrawals and returns could cause the fresh water-saltwater interface to become locally more diffuse. However, if essentially all the water is recharged to the same depth, which is generally the case in the study area, saltwater intrusion is not anticipated to be a serious problem.

4.2 Impacts of effluent injection

4.2.1 Recharge well failure and formation plugging

Failure of a recharge well is a common occurrence, with the most immediate consequence being nuisance flooding of the ground surface. Once a recharge well has become plugged, two new recharge wells are generally constructed. If recharge wells repeatedly fail, effluent is sometimes discharged into the sewer. Interviews with heat pump contractors suggested that some contractors do this primarily as a last resort.

A more long-term consequence of recharge well failure is plugging of the injection formation by precipitation of iron oxides or other compounds, which would interfere

with the use of that aquifer. The likelihood of this iron oxide precipitation is increased if the ground water contains significant concentrations of iron, if air is able to leak into the system, or if waters from two different aquifers are mixed. Although the ground water in parts of the study area contains significant concentrations of iron, the heat pump systems are constructed to be airtight. The supply and recharge wells are generally completed at approximately the same depth, preventing the mixing of waters from two different aquifers. The heat pump contractors reported no cases of iron-oxide precipitation causing problems outside of the well bore.

4.2.2 Thermal impacts

The effluent from the heat pump is usually 8° to 10°F warmer than the influent in summer, and 5° to 10°F cooler in winter. The injection of ten gallons per minute of water of a different temperature than the ground water has a local effect on the ground-water temperature. This could impact nearby ground-water heat pumps and possibly have an effect on organisms in the aquifer and/or induce or inhibit chemical reactions (precipitation, etc.). The areal extent of temperature changes in the aquifer is difficult to estimate, although heat pump contractors and drillers indicated that injection of warm or cold water rarely has a significant effect on the temperature of the supply well. However, according to Mr. Spalding of Cox-Powell Corporation, some supply wells in the shallow Quaternary

aquifer experience a seasonal temperature fluctuation of 5°F or more. Wells in the underlying Yorktown aquifer have a larger sink and are not as sensitive.

4.2.3 Impact of a contaminated supply well

If the supply well of a heat pump system were contaminated, the injection of effluent into the aquifer via the recharge well could rapidly spread the contamination. Some water well drillers reported that they had been requested to drill heat pump wells in a septic system absorption field. In such a location, a shallow supply well could withdraw incompletely renovated sewage, which in turn would be pumped to a recharge well, and upon injection could overload the absorption field causing it to fail. One driller reported working with one or two cases in which a leaking residential fuel oil tank contaminated a heat pump system on the same property. However, each pair of supply and recharge wells in the Tidewater area are generally drilled to the same depth. Other than the fuel oil contamination, contacts with installers, drillers and municipalities did not suggest that any serious ground-water contamination problems have been spread by heat pumps.

4.2.4 Chemical additives

One chemical problem associated with heat pumps is the potential for freon contamination of the ground water caused by a damaged and/or leaking condenser. The leaking would probably be detected only when the heat pump stopped working properly due to freezing of the condenser coils.

Breaks in the condenser may be caused by corrosion or by clogging with precipitates. It was not possible to accurately determine how frequently this occurs, although it is not thought to be common.

Water for ground-water heat pumps in the study area is generally used solely by the heat pumps and not as a drinking water source. The heat pump contractors surveyed reported that the use of chemical additives in heat pumps throughout this area is rare. Although ground water in some portions of the Tidewater area may contain high concentrations of iron or total dissolved solids, treatment to prevent corrosion, precipitation, or algae is not commonly used. It was reported that one nonresidential system withdraws water with a pH of 5 and treats it with very small amounts of caustic soda to raise the pH to 6.

The heat pump condenser is generally periodically cleaned by adding chemicals to remove and inhibit scale formation. The heat pump is shut down, the cleaner is circulated through the condenser, and then removed. It is not released into the ground water during normal operations.

5.0 CONCLUSIONS

5.1 Existing regulations

- The Virginia Beach regulations establish a comprehensive regulatory framework for the proper installation and operation of ground-water heat pump systems.
- Most of the municipalities in the Tidewater area have not promulgated specific regulations for ground-water heat pumps. A Chesapeake ordinance by inference prohibits ground-water heat pumps. Several state regulations and municipal ordinances concerning sewer hookups and wastewater discharges discourage alternatives to effluent injection.

5.2 Construction and operation

- In general, current construction practices are adequate to insure safe operation of the system. However, significant variations in practices exist, and, without strict regulatory controls, it is possible that some systems are installed which could fail and discharge refrigerant or chemical additives to the subsurface.

- Most systems utilize return wells for effluent injection. Most of the systems which discharge effluent to surface water predate the current trend of using injection wells.
- Because most systems inject the heat pump effluent, regional ground-water depletion is unlikely.
- The most common problem encountered in the modern systems is failure of the recharge wells.
- Several options for effluent disposal are available; the most attractive and most frequently-employed option is to inject the effluent into the same geologic horizon from which it was withdrawn.
- Effluent discharge into sanitary sewers is not a viable option since the effluent could overload the wastewater treatment plant.
- From a purely technical standpoint, land application of the effluent is feasible, though in this area a large number of problems could result, ranging from runoff flooding a neighbor's yard, to aquifer depletion.

5.3 Environmental impact

- When properly installed and operated with efficient production and injection wells, ground-water heat pumps should not produce long-term degradation of the environment.

- The risk of refrigerant and/or chemical additive losses to the environment can easily be minimized through the use of quality-built systems, and trained personnel to install and service the units.

6.0 RECOMMENDATIONS

- Ground-water heat pump systems should employ injection wells and should be closed systems, pressurized, and air-free.
- A drop pipe should be used in the injection well to insure that effluent is injected below the static water level. The end of the drop pipe should contain a back-pressure valve to prevent water from draining from the drop pipe. This practice will minimize the introduction of air into the well.
- Fluid-carrying lines and pipes should be constructed of corrosion-resistant materials.
- Policy should be established which strongly encourages effluent injection into the same horizon from which it was withdrawn.
- If injection into a zone other than the production horizon is permitted, caution should be taken to insure that overdrafting of the aquifer does not occur. The overall water quality of the producing zone should be equal (or better) than the water quality in the injection zone.
- When feasible, pump tests should be performed to determine the specific capacity (yield/drawdown) of the return well. The specific capacity provides a rough estimate of the increase in water level

expected in the return well at a given injection rate. Graphs relating head increase to recharge rate and specific capacity are given in Keech (1982). Marginal wells could then be redeveloped or modified to improve performance, reducing the potential for future recharge well failure.

- The Chesapeake ordinance in Chapter 38, Article II, Section 1, should be changed to permit the use of private wells for ground-water heat pumps even where city water and sanitary sewer lines are available.
- Prohibit discharges of ground-water heat pump effluent to septic systems.
- Establish isolation distances between the supply and recharge well(s) and septic systems, building foundations, and other wells. It may also be advisable to establish minimum depth criteria and minimum well yields.
- In situations where a recharge well repeatedly fails, it may be advisable to permit temporary discharges of heat pump effluent to the storm or sanitary sewer system on an emergency, temporary basis. If this is feasible, temporary sewer discharges could be less undesirable than overflowing recharge wells.

- The most widespread problem associated with ground-water heat pumps in the Tidewater area is recharge well failure. To minimize this occurrence, the well(s) should be thoroughly developed before connecting it to the heat pump, a filter could be installed in the intake line, and the recharge well could be pumped to waste periodically to remove accumulated silt.
- The rate of new heat pump installations will probably increase in the future. At present, a great deal of misinformation and confusion exists, both in the general public and in industry. The state and/or federal agencies should develop and implement a public information/education program to educate all parties involved with this growing technology.

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APPENDIX A

VIRGINIA BEACH MUNICIPAL ORDINANCE REGARDING GROUND-WATER HEAT PUMPS

AN ORDINANCE TO AMEND THE CODE OF THE CITY OF VIRGINIA BEACH BY ADDING SECTION 37-18.1 RELATING TO WATER-TO-AIR HEAT PUMPS

BE IT ORDAINED BY THE COUNCIL OF THE CITY OF VIRGINIA BEACH, VIRGINIA:

That the Code of the City of Virginia Beach is hereby amended by adding the following Section 37-18.1:

Section 37-18.1. Aquifer Recharge System required for water-to-air heat pumps.

(a) Unless otherwise provided by the State Water Control Board, all water-to-air heat pumps and/or other devices which utilize groundwater for purposes of heating or cooling shall be equipped and installed in such a manner as to return all such groundwater, after usage, in an unaltered biological and chemical condition to the aquifer from which it was originally withdrawn.

No such water-to-air heat pump or other device which utilizes groundwater shall be approved for installation unless it is so designed or equipped. The site and design of all wells (intake or discharge) utilized by any such water-to-air heat pump or other device which utilizes groundwater shall be subject to approval by the Health Department.

(b) No property owner, lessee or other person who is in control of premises upon which any such water-to-air heat pump or other device which utilizes groundwater is located shall allow operation of any such pump or device in a manner inconsistent with the provisions of paragraph (a) above.

(c) The provisions of this section shall be administered and enforced by the Department of Permits and Inspections. Any violation of this section shall constitute a Class 3 misdemeanor. Each day any violation of this section shall continue shall constitute a separate offense.

Adopted by the Council of the City of Virginia Beach, Virginia, on the First Day of March, 1982.

RHM/CO/du
7/31/81, 8/25/81,
1/18/81, 2/10/82 & 2/11/82
(1581-D)

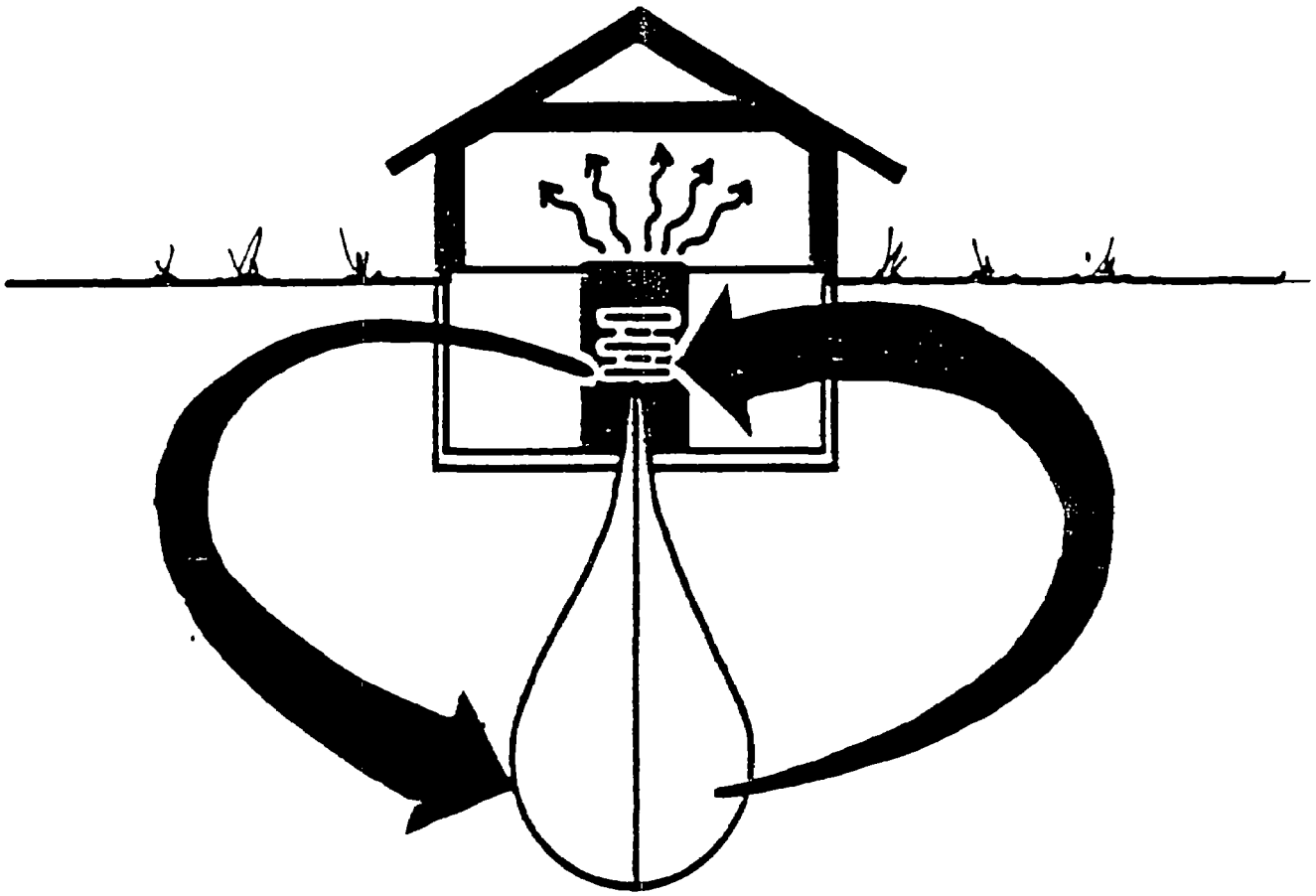
SECTION 3.2.3

TITLE OF STUDY: (or SOURCE OF INFORMATION)	Report to the Wisconsin Legislature on Experimental Groundwater Heat Pump Injection Well Project
AUTHOR:	Wisconsin Dept. of Natural Resources
DATE:	July 1, 1984
STUDY AREA:	Wisconsin USEPA, Region V
NATURE OF BUSINESS:	Not Applicable
BRIEF SUMMARY/NOTES:	The Wisconsin Department of Natural Resources (DNR) was authorized by the legislature to approve up to 60 heat pump systems utilizing injection wells. During the project period (1981-1983) only 3 systems were constructed. The report cites the limited interest in the systems and the potential for groundwater contamination, and recommends that the project be terminated and no new systems allowed in the future. In the event that a need for such systems is identified in the future, recommendations are presented for the establishment of a regulatory program. Due to the length of the report, only the executive summary has been included here.

(Attachment 4)

Wisconsin Department of Natural Resources

Report to the Wisconsin Legislature on Experimental Groundwater Heat Pump Injection Well Project



as required by

Section 2038(4)C.20.L. 1981
(non-statutory provision)
of the 1981-83 Biennial Budget Bill

July 1, 1984

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES
Carroll D Besadny
Secretary

BOX 7921
MADISON, WISCONSIN 53707

File Ref 3300

July 1, 1984

To: Wisconsin Citizens and Legislators

Wisconsin has an abundance of high quality groundwater. This resource, however, is fragile; and when contaminated due to the activities of man, it may take decades or centuries to purify itself, but probably can never be returned to its previous condition.

In addition to the traditional uses of groundwater (drinking, irrigation, industrial), the resource can also serve as a source of energy. Groundwater heat pumps borrow energy from groundwater or lend energy to groundwater when operating as heating or cooling systems. These systems utilize groundwater to transfer or absorb heat in the heating or cooling of homes or buildings. The waste groundwater may then be injected into the underground aquifer or discharged at the surface or be recycled in a "closed loop".

Wisconsin has had a long history prohibiting the injection of waste materials into groundwater. Even with the closed loop groundwater heat pump systems, there is the potential for contamination to reach the groundwater. Because of this concern, the Legislature in 1981 authorized an experimental program allowing a limited number of groundwater heat pump injection wells to be installed and requiring this report on the results of the program.

This report concludes that there has been limited interest in the use of groundwater heat pumps and concludes that the potential for groundwater contamination still exists. Therefore, the existing prohibition against injection of waste should be maintained. The report does recognize that in the future the use of groundwater heat pumps may increase as the cost of conventional energy sources rise. Therefore, recommendations are made on how a regulatory program might be structured if and when conditions make such a program necessary.

If there are any questions on the contents of this report, they should be directed to the Bureau of Water Supply, Department of Natural Resources.

Sincerely,

C. D. Besadny,
Secretary

Wisconsin Department of Natural Resources

Report to the Wisconsin Legislature on Experimental Groundwater Heat Pump Injection Well Project

as required by

Section 2038(4)C.20.L. 1981
(non-statutory provision)
of the 1981-83 Biennial Budget Bill

July 1, 1984

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Executive Summary

The 1981-83 budget bill authorized the Department of Natural Resources to approve 60 groundwater heat pump systems which inject circulated water into the groundwaters of the state. Any groundwater heat pumps approved under this project were to be monitored by the Department. A final report with recommendations based on the results of the project was to be submitted to the legislature by July 1, 1984.

During the project period, only 6 requests for approval of groundwater heat pump systems were received by the Department. Of the 6 systems approved, only 3 have been constructed and only one has been in operation for more than 4 months. This lack of interest in the project has also resulted in a lack of data upon which to judge the environmental impact of the utilization of these systems.

The one operating system with any length of operating experience is located at the Hancock Experimental Station in Waushara County. Data from this installation was accumulated under the direction of the Wisconsin Geological and Natural History Survey. In general, this system did not result in any significant change in the chemical composition of the groundwater and had minimal thermal effects.

In view of the limited interest in these systems and because of the potential for groundwater contamination, the report recommends that the project be terminated and that such systems not be allowed in the future. The approved experimental systems will continue to be monitored until system failure or environmental degradation necessitate their abandonment. In the event, however, a need for such systems is identified, recommendations are presented for the establishment of a regulatory program to control the construction and operation of heat pump closed-loop and injection well systems.

SECTION 3.2.4

TITLE OF STUDY: OR SOURCE OF INFORMATION)	From Underground Injection Operations in Texas: A Classification and Assessment of Underground Injection Activities, Report 291
AUTHOR: (or INVESTIGATOR)	Texas Department of Water Resources, Ben K. Knape
DATE:	December, 1984
STUDY AREA:	Texas USEPA Region VI
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	The following section from the above report deals with air conditioning return flow wells in Texas. The Texas Department of Water Resources conducted a limited field investigation and an extensive literature survey and has judged groundwater heat pumps to have minimal contamination potential. Little inventory information is included; however, the report states that there are probably several hundred systems operating in Texas.

AIR CONDITIONING RETURN-FLOW WELLS

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AIR CONDITIONING RETURN-FLOW WELLS

Introduction

Air conditioning return-flow wells are used for underground injection of water which has been produced from a supply well and used for heating or cooling in a heat pump. Also referred to as "heat-pump wells," these are a specialized type of aquifer recharge well.

For over 30 years, the technology has existed to use the temperature difference between ground water and other fluid media, such as refrigerants and air, to heat or cool homes and office buildings. The heating and cooling systems which have been developed are commonly known as ground-water heat pumps.

A heat pump is a temperature-conditioning device which transfers heat or thermal energy from one medium to another. An example of a heat pump familiar to everyone is an air-to-air heat pump or "air conditioner" which heats or cools by using air both as a heat source and a heat-receiving medium (heat sink).

A ground-water heat pump may use ground water as a heat source or heat sink. Ground-water temperatures remain very constant relative to the great variability of air temperatures in homes and buildings imposed by climatic conditions. A ground-water heat pump can be an effective air temperature-conditioning device whenever a significant differential exists between ground-water temperature and ambient air temperature in the space to be "conditioned." Water is an ideal medium for use in heat pumps because of all ordinary substances water has the greatest specific heat. Thus it can both absorb and yield much more heat in calories per degree change in the temperature of the medium than does an equal weight of air.

The basic components of a heat pump are an evaporator, a condenser, a compressor, and an expansion valve. Figure 9-1 diagrams a ground-water heat pump refrigeration loop. The heat pump consists of a closed loop containing a refrigerant which alternates between liquid and gaseous phases. For heating buildings, the refrigerant in the gaseous phase is compressed and condensed to a liquid phase, yielding heat which may be used to warm the air which circulates through a building. Next, the compressed liquid refrigerant is jetted through an expansion valve into an evaporator, lowering the liquid pressure, and absorbing heat from the ground-water source, to cause the evaporation of the liquid once again to a gaseous phase.

In order for a heat pump to work properly, the heat source (ground water) temperature must exceed the refrigerant evaporation temperature. Therefore, the efficiency of heat pumps increases with the differential between ground-water temperature and refrigerant evaporation temperature. In yielding heat to the refrigeration loop, ground water is decreased in temperature by about 7 to 10°F in the heat-pump systems investigated by the Department. When a heat-pump system is used for cooling buildings, heat is absorbed into the refrigeration loop from the air inside a building, and transferred to ground water. The general effect of air conditioning return-flow wells is to locally increase ground-water temperatures in the receiving aquifer when the system is used for cooling buildings, and to decrease ground-water temperatures when the system is used for heating buildings.

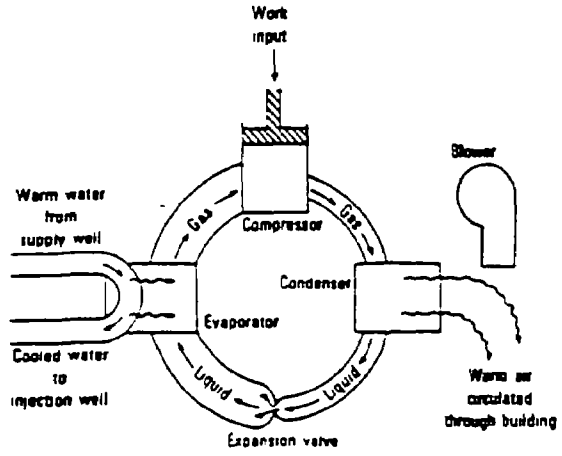

Figure 9-1 —Basic Components of a Ground-Water Heat-Pump System

The scope of the Department's investigation of heat-pump wells included the inventory of 29 heating and cooling well systems (Figure 9-2) and an extensive literature review The inventory consisted of field location and inspection of five wells in Blanco County and five wells in Montgomery County Locations of other heat-pump wells were obtained through water well drillers and heat-pump contractors. Water samples were obtained from three wells in The Woodlands in Montgomery County Two wells in Williamson County were investigated in November 1980 by William P Overesch of the Department. Those locations and water sample analyses are included in this report The literature was researched to determine how heat-pump well systems work, their various applications, ground-water contamination potentials, and outlook for their future development.

Geohydrology

More than 50 percent of the total surface area of Texas is underlain by major or minor aquifers (Figures 2-3 and 2-4) In addition to the delineated major and minor aquifers, there are other smaller aquifers which yield small to moderate quantities of water locally. The development of ground water from all of the State's aquifers has progressed rapidly during the past half century Future development of this valuable natural resource may involve large quantities of ground water for cooling in summer and heating in winter Tables 2-2 and 2-3 provide brief descriptions of the major and minor aquifers of the State, listing approximate thicknesses, geologic ages, and water-bearing properties.

The efficiency of a ground-water heat-pump system is largely determined by the temperature of the supply water Shallow ground-water temperatures correlate fairly closely with mean annual air temperatures for particular locations (Figure 9-3) Near-surface ground-water temperatures in Texas typically range from a low of about 60°F in the northwest corner of the Panhandle to a high of about 80°F in the lower Rio Grande Valley Below a few hundred feet in the subsurface, ground-water temperatures begin to be influenced by normal geothermal gradients which result from the inherent heat of the earth.

Construction Features

Two basic construction designs of air conditioning return-flow wells are shown in Figures 9-4 and 9-5. Designs of return-flow wells are essentially the same used for the heat-pump supply wells. Diameters of these wells normally range from 3 to 10 inches for heat-pump systems for single-family dwellings. Well diameter should be determined by water disposal requirements. Where large amounts of water must be disposed of, as with heat-pump systems for large buildings, increasing well diameter will yield a corresponding increase in well capacity. In

contrast, small-diameter wells are relatively economical to drill and construct. Small-diameter wells, however, tend to have more problems from sand plugging the wellbore.

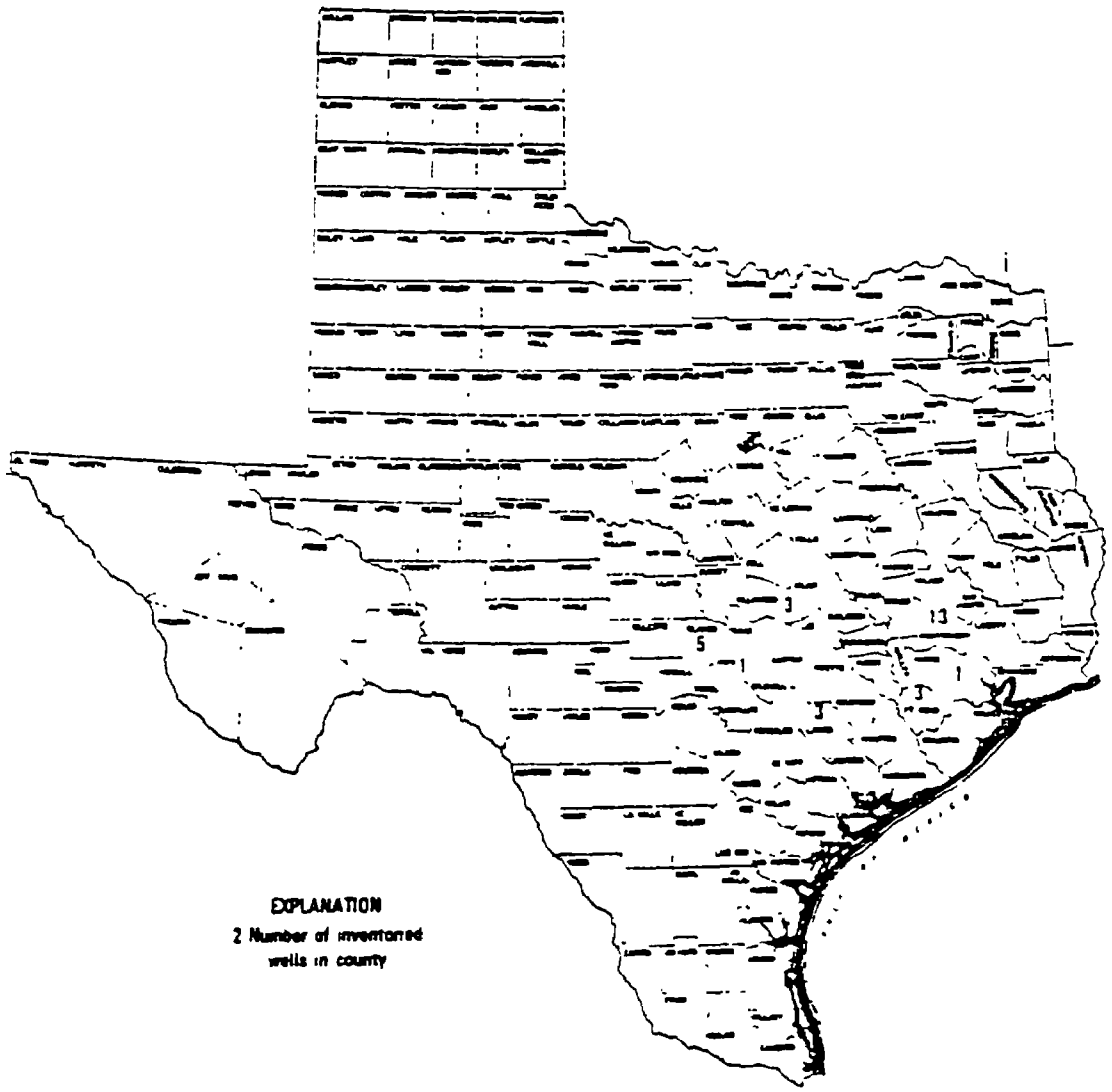

Figure 9-2.—Inventoried Air Conditioning Return-Flow Wells

Well depths are determined by the presence of porous and permeable water-bearing strata suitable for storing the injected water. Wells in The Woodlands residential development in Montgomery County which were inventoried by the Department have an average depth of about 200 feet. These wells inject into water-bearing sands of the Gulf Coast aquifer. In contrast, two wells inventoried in Williamson County in central Texas are completed in the Edwards aquifer with total depths of about 400 feet.

Polyvinyl chloride (PVC) pipe is most commonly used for well construction because it is economical, suitably durable, and corrosion resistant. Another material often used in heat-pump system wells is galvanized steel. Following casing installation, the wells are either completed with an open hole through the disposal zone in hard competent formations such as limestone, or

with well screen and gravel pack in unconsolidated sand formations. Careful slot size selection is necessary to achieve optimal well performance in terms of maximum water flow with a minimum influx of solids from the formation into the wellbore.

Figures 9-6 and 9-7 show the general simplicity of wellhead installations for heat-pump system supply and injection wells. Submersible pumps may be installed on both wells in the system to enable seasonal reversal of well functions. The systems investigated by the Department, however, used pumps only on the water-supply wells.

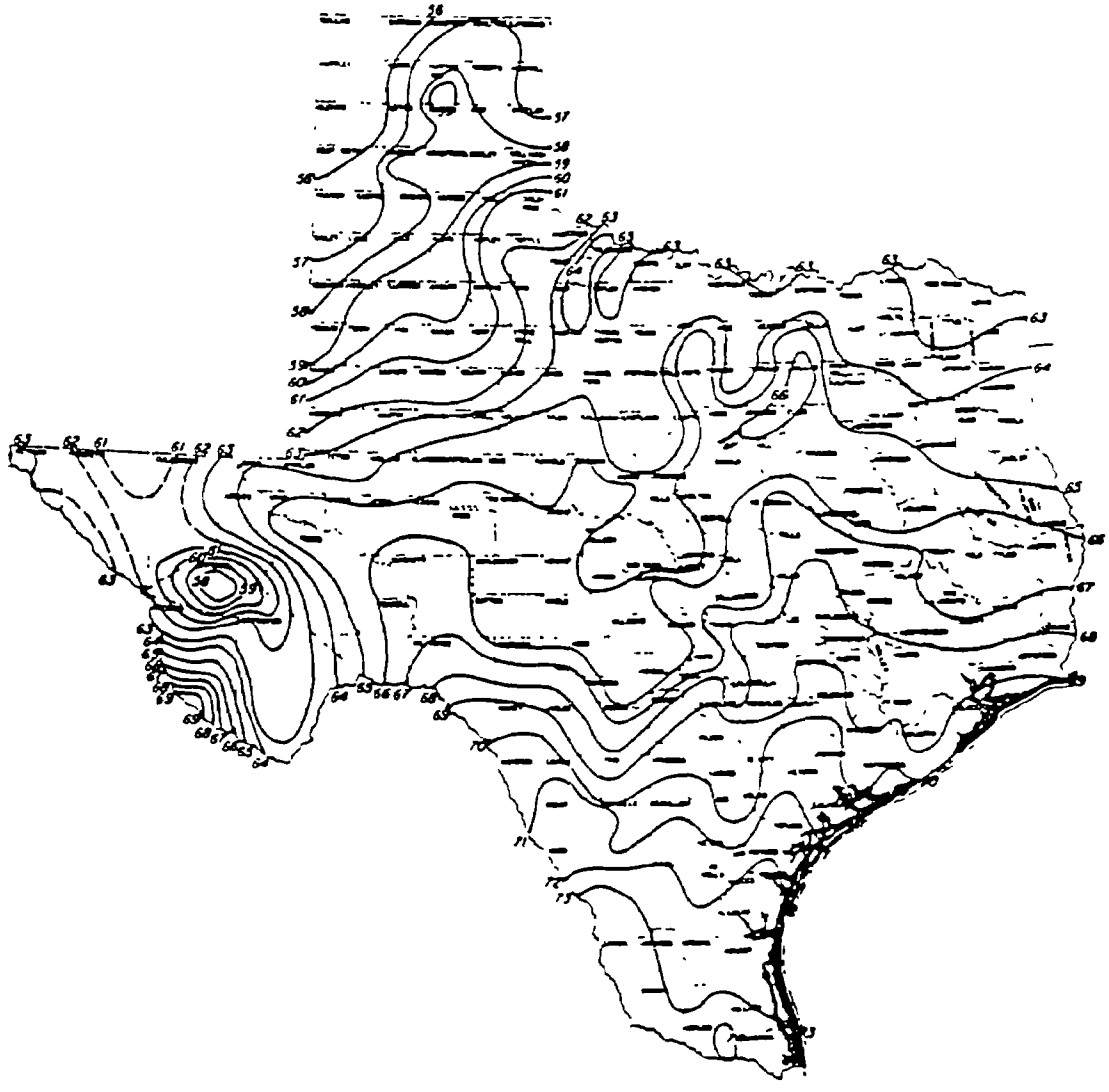

Figure 9-3.—Average Annual Temperature (°F), 1951-80

The literature on the subject of air conditioning return-flow wells includes designs for horizontal injection wells in which the heat-pump discharge water is dispersed through a horizontally emplaced well screen into the soil. These wells function best in sandy soils, and because a trench must be dug to install the horizontal well screen, the wells are necessarily very shallow. No such wells have been inventoried by the Department.

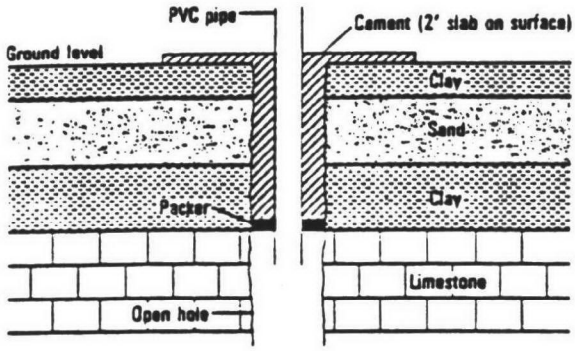

Figure 9-4.—Air Conditioning Return-Flow Well Design for Stone Formation

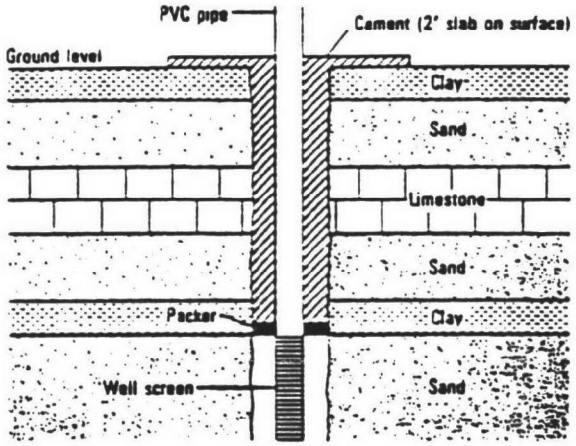

Figure 9-5.—Air Conditioning Return-Flow Well Design for Sand Formation

Well placement is an important consideration with ground-water heat-pump systems. If one aquifer is used for both supply and injection, the wells need to be spaced so that the temperature front traveling from the injection well does not reach the supply well, affecting supply water temperature and reducing heat-pump efficiency. Figure 9-8 shows a system using a single aquifer. If two aquifers are used, one for supply and one for injection, wells can be spaced closer together, since the injected water will be stratigraphically isolated from the system supply water. Being able to use closer well spacing is an advantage on small residential lots. A diagram of a two-aquifer system is shown in Figure 9-9.

Operating Practices

The basic energy requirements to run a ground-water heat-pump system consist of electric power to operate the heat-pump compressor and submersible pumps for the supply and injection wells. Incorporation of a refrigerant reversing valve in the heat pump allows the functions of the various elements in the system to be reversed seasonally to increase efficiency of heating and cooling. Also, pumps on both supply and injection wells allow the operator to backwash either well to remove sediment which may hamper well performance. None of the heat-pump systems investigated by the Department, however, are seasonally reversed, but instead accomplish satisfactory heating and cooling with a single direction of ground-water circulation.

The most common causes of diminished well performance involve occlusion of the wellbore by sediment or other debris, particularly in the screened or open-hole completion interval. To remedy sand plugging problems, wells may be backflowed, bailed, or jetted out. Also, wells may be chlorinated as needed to control algae and other biological organisms which may find favorable conditions for growth in the thermally altered water of heat-pump wells.

Nature and Volume of Injected Fluids

Standard chemical analyses and heavy-metal analyses of water samples from eight air conditioning return-flow wells are presented in Tables 9-1 and 9-2. Wells 1 and 2 are in the town of Round Rock in southern Williamson County. Wells 3 through 8 are in The Woodlands in central Montgomery County. Each injection (return-flow) well sampled is completed in the same aquifer that furnished the water supply for the heat-pump system.

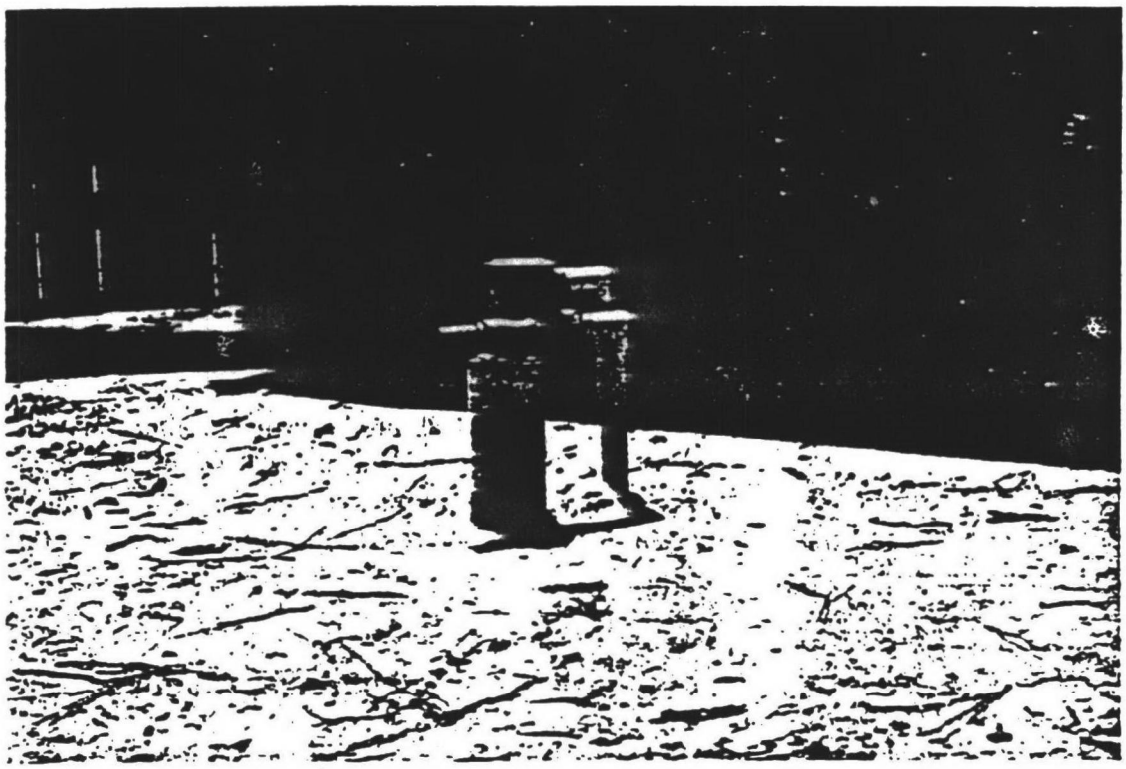

Figure 9-6.—Wellhead of Heat-Pump System Supply Well, Montgomery County

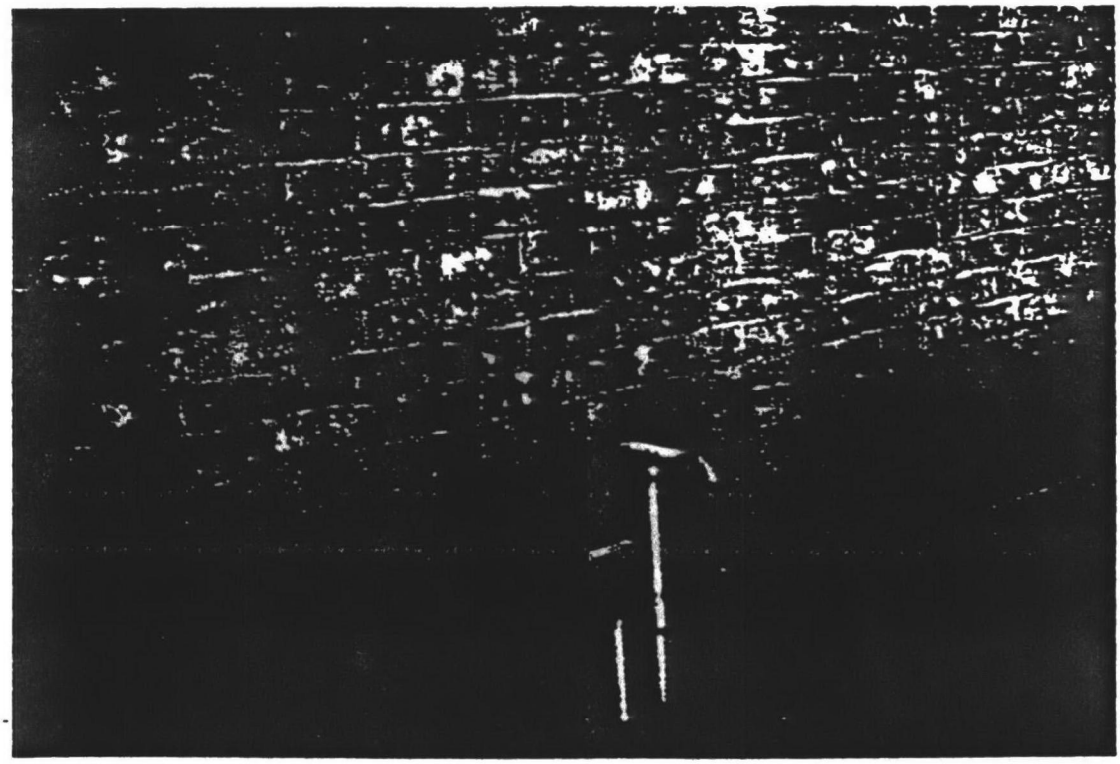

Figure 9-7.—Wellhead of Heat-Pump System Injection Well, Montgomery County

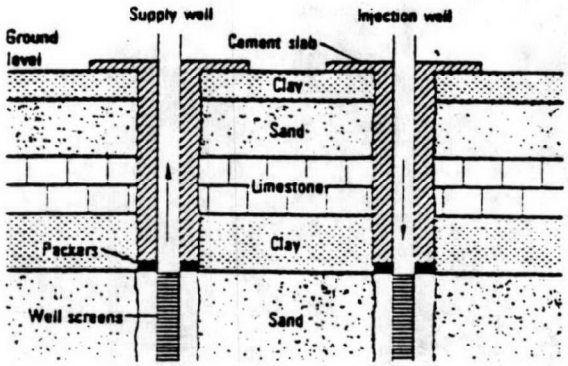

Figure 9-8.—Ground-Water Heat-Pump System Using Single Aquifer

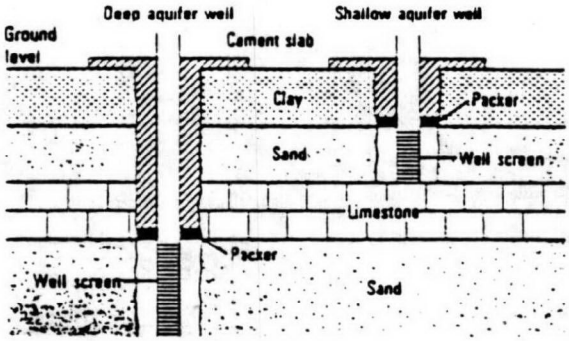

Figure 9-9.—Ground-Water Heat-Pump System Using Two Aquifers

Analyses of samples from wells 6 and 7 show lead concentrations in excess of U.S. Environmental Protection Agency standards for drinking water. However, there is insufficient historical ground-water data for the area to document the earlier presence of high concentrations of lead. At least one well driller experienced with air conditioning return-flow wells in Montgomery County has indicated in conversations with Department staff that these occurrences of lead in the ground water predated the use of heat-pump wells, and that the ground water has not been used as a source of drinking water. Department Report 136 on ground-water resources of Montgomery County (Popkin, 1971) indicates that corrosive (acidic) ground waters are found in the county in the Gulf Coast aquifer. These waters may corrode pump parts, plumbing fixtures, and iron casings in less than a year of contact. The PVC pipes used for the heat-pump wells are chemically nonreactive to such corrosive ground water. However, the metallic components of heat pumps may possibly be susceptible to corrosion and dissolution into the ground water under such conditions. The potential for contributions of metals to the acidic ground water by heat pumps is judged to be no greater than that for conventional domestic plumbing, and very small compared to the contributions which may have resulted from oil field activities in the immediate area. Production from the Conroe oil field has occurred over past decades during which time discharges of produced brines, drilling muds, and industrial chemicals to pits dug into sandy soils were commonplace.

On the Gulf Coast, inventoried heat-pump wells serving single-family residences operate at rates up to about 20 gallons per minute. In central Texas, a larger-scale heat-pump system which is planned for an office building is designed for a ground-water flow rate of up to 50 gallons per minute.

Potential Problems

The potential for contamination of ground water resulting from introduction of pollutants through air conditioning return-flow wells should be very low when wells are properly cased and cemented. Properly designed systems are, in effect, closed loops inaccessible to contamination from surface pollutants.

If ground water has been contaminated at some time prior to heat-pump use, such contamination could, however, spread from the location of the water supply well to the location of the

Table 9-1 —Chemical Analyses of Water Samples From Air Conditioning Return-Flow Wells
(Constituent concentrations are in mg/l except specific conductance and pH)

	Well							
	1	2	3	4	5	6	7	8
Date of collection	Nov 5 1980	Nov 5 1980	Mar 8 1982	Mar 8 1982	Mar 8 1982	Mar 8 1982	Mar 8 1982	Mar 8, 1982
Temp °F	—	—	72	72	70	78	79	77
°C	—	—	22 2	22 2	21 1	25 6	26 1	25 0
pH	8 6	8 5	7 4	7 5	6 3	7 1	7 2	6 2
Specific conductance micromhos at 25°C)	509	510	554	534	298	—	—	—
Dissolved solids (sum)	305	315	364	364	218	—	—	—
Boron (B)	—	—	21	11	< 02	—	—	—
Silica (Si)	12	12	—	—	—	—	—	—
Calcium (Ca)	76	80	—	—	—	—	—	—
Magnesium (Mg)	23	22	—	—	—	—	—	—
Sodium (Na)	13	12	—	—	—	—	—	—
Carbonate (CO_3)	8	6	—	—	—	—	—	—
Bicarbonate (HCO_3)	316	328	—	—	—	—	—	—
Sulfate (SO_4)	23	21	—	—	—	—	—	—
Chloride (Cl)	14	13	—	—	—	—	—	—
Fluoride (F)	1 4	1 3	—	—	—	—	—	—
Nitrate (NO_3)	< 04	< 04	—	—	—	—	—	—

Wells 1 and 2 are in the town of Round Rock in southern Williamson County and inject into the Edwards aquifer at a depth of approximately 400 feet
Wells 3 through 8 are in The Woodlands in central Montgomery County and inject into the Gulf Coast aquifer at a depth of approximately 200 feet
Analyses were performed by the Texas State Department of Health

Table 9-2.—Heavy Metal Anayses of Water Samples From Air Conditioning Return-Flow Wells (Constituent concentrations are measured in mg/l.)

	Well		
	6	7	8
Data of collection	Mar. 8, 1982	Mar 8, 1982	Mar 8, 1982
Arsenic (As)(mg) 1	< 01	< 01	< 01
Barium (Ba)	< 5	< 5	< 5
Cadmium (Cd)	< 01	< 01	< 01
Copper (Cu)	180	073	< 028
Chromium (Cr)	< 02	< 02	< 02
Iron (Fe)	026	022	< 02
Lead (Pb)	4	07	< 05
Manganese (Mn)	< 02	< 02	< 02
Mercury (Ha)	< 0002	< 0002	< 0002
Nickel (Ni)	< 02	< 02	< 02
Selenium (Se)	< 002	< 002	< 002
Silver (Ag)	< 01	< 01	018
Zinc (Zn)	.240	.14	02

Wells 6 through 8 are in The Woodlands in Central Montgomery County and inject into the Gulf Coast aquifer at a depth of approximately 200 feet.
Analyses were performed by the Texas State Department of Health.

injection well Similarly, when the wells in a heat-pump system are completed in different aquifers, water from an already contaminated aquifer may introduce pollutants to an uncontaminated aquifer The practice of seasonally reversing the functions of heat-pump wells, however, would tend to limit the spread of new contamination in an aquifer In any instance where a heat-pump injection well spreads pollutants from an existing contaminated aquifer, the injection well could be backflowed to partially recover the contaminated water.

Other concerns associated with air conditioning return-flow wells involve the effects of thermal alteration on an aquifer's hydrologic properties. Thermal alteration of an aquifer could theoretically generate adverse impacts such as precipitation of mineral salts. Salt precipitation could clog pores in an aquifer, leading to inhibited ground-water movement and decreased well effectiveness. The solubility of common salts, however, is highly dependent on the degree of acidity of a solution, and only to a lesser extent on temperature. Heat-pump systems do not affect the pH of an aquifer. Thus, at the 7 to 10°F differential between supply water and heat-pump discharge water common for the systems which the Department investigated, any impact from changing the solubility of salts in an aquifer should be noticeable only over extremely long periods of time, and localized to areas of significant well development.

It should be noted that thermal alteration of an aquifer will also influence the ability of an aquifer to transmit fluid, because of the inverse relationship between temperature and fluid viscosity. That is, as ground-water temperature is elevated, viscosity of ground water decreases and the aquifer transmits fluids more easily. Although changes in individual well performance could be observed, no significant hazard would result from aquifer transmissivity changes induced by ground-water heat-pump systems.

Several studies have been accomplished using computer modeling to simulate thermal impacts on an aquifer used in a heat-pump system (Andrews, 1978; Schaetzle and Brett, 1979). Factors taken into account in the computer models include rates of ground-water movement, amounts of thermal energy added or subtracted in the system, and inherent thermal properties of the aquifer. All studies concluded that, particularly where air conditioning return-flow wells were restricted to areas of low population density, thermal alteration of aquifers would likely be of minimal proportions and not likely to produce adverse effects.

Legal and Jurisdictional Considerations

Air conditioning return-flow wells are included in the Class V category of injection wells. These wells are presently authorized by rules of the Department.

The thrust of any new regulatory program for heat-pump system wells should be directed at large-scale systems involving one or more wells operating to heat or cool multi-unit residential or office complexes, schools, and hospitals. Because of their assessed low potential for causing ground-water problems, heat-pump systems for single-family dwellings should probably be given a lesser priority for regulation. The distinguishing criteria for large-scale versus small-scale systems would be based primarily upon ground-water pumping rates. For all ground-water heat-pump systems, the Department would continue to inventory the wells, and maintain opportunity for review of project proposals for the purpose of issuing permits as necessary to protect water resources.

Concluding Statement

The Department has conducted a limited field investigation and an extensive literature review of air conditioning return-flow wells. The total number of such wells in the State is probably on the order of several hundred. Ground-water heat-pump systems have demonstrated an increased efficiency over conventional systems in heating and cooling single-family dwellings and larger buildings. The number of heat-pump system wells is expected to increase greatly in the future with ever-growing incentives to cut home and office heating and cooling costs by using less expensive forms of energy. The potential hazards to ground water from heat-pump systems have been judged to be minimal.

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SECTION 3.2.4

TITLE OF STUDY: **OR SOURCE OF INFORMATION)**	From Underground Injection Operations in Texas: A Classification and Assessment of Underground Injection Activities, Report 291
AUTHOR: **(or INVESTIGATOR)**	Texas Department of Water Resources, Ben K. Knape
DATE:	December, 1984
STUDY AREA:	Texas USEPA Region VI
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	The following section from the above report deals with air conditioning return flow wells in Texas. The Texas Department of Water Resources conducted a limited field investigation and an extensive literature survey and has judged groundwater heat pumps to have minimal contamination potential. Little inventory information is included; however, the report states that there are probably several hundred systems operating in Texas.

SECTION 3.2.5

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	Summary of Heat Pump/Air Conditioning Return Flows from Various State Reports
AUTHOR: **(or INVESTIGATOR)**	Engineering Enterprises, Inc.
DATE:	November, 1986
FACILITY NAME AND LOCATION:	Not applicable
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	Case studies from Massachusetts, Minnesota, and Oregon are summarized.

MASSACHUSETTS

Heat pump/air conditioning return flow wells are exempt from the discharge permit program if the flow does not exceed 15,000 gallons/day. Two wells were chosen by Massachusetts to use for assessment purposes. Because they are closed circuit wells contamination potential of the site specific wells has been ranked as "very low." The only expected change in water characteristic and quality is a temperature change depending on season and use. Massachusetts rates these injection wells overall as having "moderately low" contamination potential.

The two wells selected for review in Massachusetts are located at the North Shore area in Ipswich and southeastern Massachusetts in Seekonk. Both systems serve private residences and are currently active. In the Ipswich system the supply and return wells are in the same aquifer at 39 feet below grade. The nearest drinking water well is 250 feet upgradient and serves the residence; at Seekonk the supply water comes from a bedrock well 605 feet deep (with a pump set at 250 feet). The nearest drinking water well is over 1,000 feet away, and this residence is supplied with municipal water. The spacing between supply and discharge points for both systems is between 200 and 250 feet. Neither system introduces additives, and the units are designed for temperature changes between 10 and 15^{o}F.

The Ipswich system's return flow well is completed at a depth of 30 feet and returns 11,520 gpd of heat pump effluent. There is no information on casing or grouting available. Aquifers

in the area include thin deposits in till materials and small to moderate supplies in stratified deposits. Information from the site indicated clay materials were present above the water-bearing strata suggesting confined or leaky confined aquifer conditions.

The Seekonk system's return flow well is completed at a depth of 19 feet and returns 2,500 gpd of heat pump effluent. There is no information on casing or grouting available. Aquifers in this area consist of poorly drained glacial tills mantling area bedrock. The water table is generally 10-15 feet below grade but can be as deep as 25 feet. Most water supply wells are finished in bedrock with depths in the hundreds of feet.

MINNESOTA

Holiday Inn

The Holiday Inn in Winona, Minnesota has utilized groundwater in its air conditioning cooling system since 1965. Reinjection has been used to dispose heated waters during the summer air conditioning season. This facility utilizes two separate withdrawal and injection systems: one for the administration building and one for the motel building.

Groundwater at about 50^{o} - 54^{o}F is pumped from a withdrawal well through a condenser and discharged to another well at about 75^{o}F (during peak summer loads). According to the Holiday Inn this water originally was returned to an injection well at the same spot, but this caused some problems. The driller stated that the injection well caused "boiling" of the water around the

pilings. Within a year the injection system was changed to 20-foot dry wells located 150 feet from the source.

The original system consisted of a 6-inch diameter supply well, 31 feet deep (including 10 feet of screen), and an injection well, 62 feet deep (with 20 feet of screen), located on the east side of the building. Wells for the system located on the north side of the building were installed 20 feet deeper with 20 to 30 feet of separation between supply and injection wells. The area lithology consists of 20 feet of blue muck/clay over 140 feet of sand and gravel.

While the Holiday Inn has indicated that the systems have operated without problems for 15 years and that groundwater temperatures in source wells have not risen, the driller has indicated that a house 150 feet northeast of the motel had its shallow water well heat up so much that they connected to city water.

El Presidente

The El Presidente Apartments, constructed in 1962 in Minneapolis, Minnesota, utilize groundwater in their air conditioning system. The system operates by bypassing the heating system's boiler in the summer and circulating cold well water for air conditioning.

Groundwater is withdrawn from two 6-inch diameter wells finished in the St. Peter Sandstone. It is pumped into a water pressure tank before cooling water and domestic water are

separated. The flow of water to the air conditioning system is controlled by a modulating valve, and temperatures in the water are raised only 3°F during use. This heated water is discharged into a 300 foot deep, 4-inch diameter injection well finished in the Shakopee Dolomite. This system is completely sealed, and no additives are used.

The system is designed for a maximum of 50,000 gpd. No confirmation on the operational status of this system was available.

Southdale

The Southdale Shopping Center in Edina, Minnesota has used groundwater in its central cooling plant since 1956. Reinjection was used in 1956 and discontinued in 1957 after the reinjection well became plugged and overflowed.

The system consists of two supply wells, 442 and 452 feet deep, which withdraw water from the Jordan Sandstone. Each well pumps at about 800 gpm. The 52° - 54°F groundwater passes through precooling units and the central cooling plant where the temperature is raised 20°F. It is then pumped to the package units in individual stores where condensors raise the temperature another 10°F. The water is then discharged to a stilling pond. Originally the heated water was injected into a 177 foot deep well which terminated in glacial sands and gravels. The system design was for 400 gpm injection at 95°F during the summer and 800 gpm at 60°F in the winter.

Because of serious plugging problems, reinjection was discontinued. It was speculated that plugging was caused by iron precipitation. During injection, there was often a strong sulfurous odor in the mall. Quality analysis of withdrawal water did not show high iron or sulfate content (0.1 and 21 ppm respectively). These analyses may have been in error because the water is very hard (270 mg/L as $CaCo_3$). Since the halt of reinjection, the well has been used as a supply well. The yield has steadily improved through continued use. This is to be expected as the plugged aquifer gradually opens up.

OREGON

In Oregon, 11 wells are used or have been used to dispose of groundwater used to heat or cool office buildings in the downtown business district of Portland. These wells were drilled prior to 1960 and range in depth from 158 feet to 930 feet.

The city of Portland is underlain by two water bearing rock units: the Columbia River Basalt, a 700-500 feet thick rock unit consisting of a series of basalt lava flows with sedimentary interbeds between the flows; and the Troutdale Formation, a water bearing unit of semi-consolidated gravels and sands ranging from a few feet to 235 feet thick. There is a thick mudstone unit between the Columbia River Basalt and the Troutdale Formation called the Sandy River Mudstone. The Sandy River Mudstone forms an effective aquiclude over the Columbia River Basalt making the Columbia River Basalt a confined aquifer and the Troutdale Formation an unconfined aquifer. The chemical quality of water

from the Troutdale Formation is generally good, although in some wells there is evidence of contamination with small amounts of organic chemicals. The chemical quality of the Columbia River Basalt, on the other hand, is low, and some wells penetrating this aquifer have been abandoned due to high mineral content.

Operators of heat pump/air conditioning return flow wells in downtown Portland utilize a variety of withdrawal and injection schemes in their systems. Some operators withdraw and inject water in a single formation while others withdraw from the Troutdale Formation and return to the Columbia River Basalt (and vice versa). Most operators have found the low chemical quality of the Columbia River Basalt unacceptable and threatening to the quality of water in the Troutdale Formation. This concern has since been reevaluated as the Oregon Department of Environmental Quality indicated in their Dec. 1986 Report on Class V Injections. The re-evaluation concluded that the Basalt Aquifer has higher quality water than the unconfined Troutdale formation.

No data on the volume, temperature, or water quality were presented in the two Oregon reports. The assessment portion of Oregon's preliminary report states that heat pump/air conditioning return flow wells may contaminate aquifers in the following ways: (1) temperature changes; (2) chemical changes due to mixing water from different aquifers; and (3) chemical changes due to chemicals added to the water as it circulates through the system.

S.G. Brown in 1963 stated that water from a cooling system reached temperatures as high as 120°F. This water was used in a system which injected to the Columbia River Basalt Aquifer whose natural temperature ranges from 54° to 70°F. This well was pumped 3 years later, and the temperature of the water initially recovered was as high as 76°F.

The practice of taking water from the Columbia River Basalt Aquifer and recharging it to the Troutdale formation became a problem soon after these air conditioning systems were put into use in Portland. The higher amount of sodium, calcium, and chloride and the greater hardness in water from the Basalt Aquifer began to raise the levels of these elements in water from the Troutdale Formation when the Basalt Aquifer waters were injected to the Troutdale Formation.

In a personal communication from Bill Bartholomew (Oregon Water Resources Department) to the Oregon Department of Environmental Quality in 1982, it was noted that sodium phosphate was added to waters used in these systems to reduce scaling, and hypochlorites were added to act as anti-bacterial agents. In addition, the communication noted that most of these systems were not closed. This probably resulted in contamination of the receiving aquifer.

In regard to air-conditioning return flow wells, the Oregon Department of Environmental Quality had four recommendations for the construction and operation of heat pump air-conditioning return flow wells. They are as follows: (1) monitor the

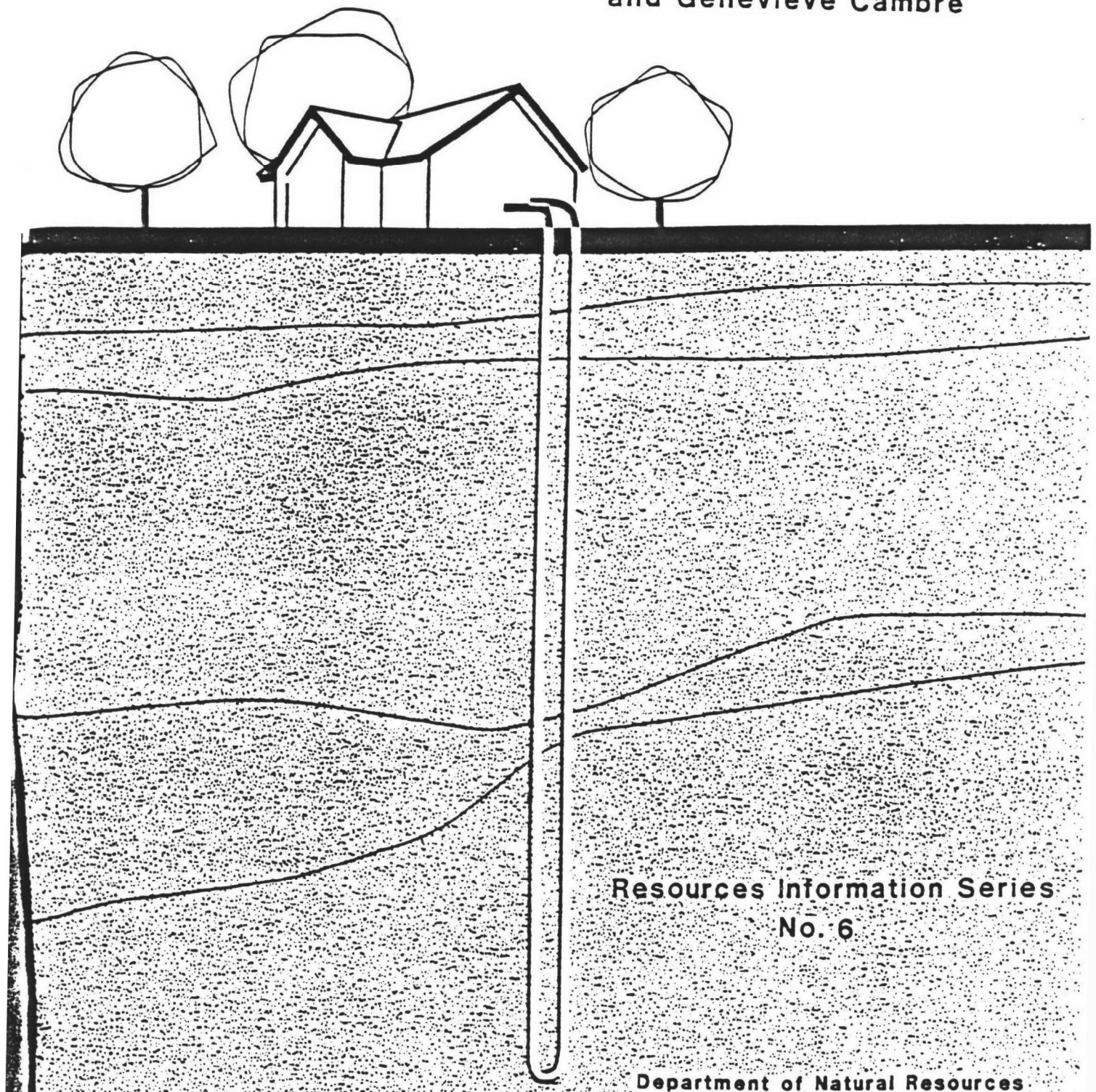
temperature and quality of waters prior to injection, (2) keep records on the volumes of water injected, (3) construct systems so that the mixing of waters from the Troutdale Formation with waters from the Columbia River Basalt is avoided, and (4) do not inject waters from the Columbia River Basalt to the Troutdale Formation.

SECTION 3.2.6

TITLE OF STUDY: (or SOURCE OF INFORMATION)	1981 Inventory of the Utilization of Water-Source Heat Pumps in the Conterminous United States
AUTHOR: (or INVESTIGATOR)	A.N. Turcan, Jr., Judith R. Bond, and Genevieve Canbre
DATE:	1984
FACILITY NAME AND LOCATION:	Not applicable
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	This report was prepared for the Louisiana Department of Natural Resources (DNR). The purpose of the study was to assess the future impact of groundwater heat pumps in Louisiana. The report consists of an inventory of systems in the continental U.S. and summaries of state regulatory programs. Responses were received from forty-one states.

1981 INVENTORY OF THE UTILIZATION OF WATER-SOURCE HEAT PUMPS IN THE CONTERMINOUS UNITED STATES

by A. N. Turcan, Jr., Judith R. Bond, and Genevieve Cambre



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A. Cover letter and questionnaire sent by the Louisiana Geological Survey, Department of Natural Resources

B. Selected letters from states

C. Selected guidelines, policy statements, regulations, legislation, and bulletins

PREFACE

In order to assess the future impact of water-source heat pump systems in Louisiana, the state conducted an inventory of the types of systems in use in other states and inquired about problems associated with their use and regulatory programs that have been enacted to control problems. This study was initiated by the Louisiana Geological Survey, Department of Natural Resources (DNR), to serve the needs of the Underground Injection Control (UIC) Program of the Office of Conservation, DNR. The Office of Conservation was granted regulatory authority over Class I, II, III, and V injection wells by the U. S. Environmental Protection Agency in April 1982. It, therefore, has regulatory authority over the return wells utilized in some water-source heat pump systems.

Toward this end, the Louisiana Geological Survey hired A. N. Turcan, Jr. (P.E., M.P.H., Registered Engineer, Louisiana No. 4682) to direct the study, summarize the findings, and make recommendations to the state concerning the regulation of these systems in Louisiana. This work was done under DNR contract 22013-82-01. Mr. Turcan wrote:

> The consultant wishes to thank the Louisiana Geological Survey, DNR, and the Office of Conservation, DNR, for the opportunity to participate in the compilation and evaluation of information and documents received from other states.
>
> Energy needs are one of the foremost concerns of the nation but the need for assurance that the availability of "safe or healthy" drinking water is not being endangered and limited is of greater concern. Present and potential sources of drinking water must be quantitatively evaluated so that "water use" priorities can be established and the effects of increased ground-water pumping can be predicted. Conservation practices as well as safe environmental practices should be emphasized to assure a long-term supply of drinking water and to prevent pollution.
>
> Interstate technology transfers should be encouraged to eliminate interstate conflicts over water use, overuse of ground water, and to prevent pollution. Informational and educational programs should be fully implemented to assure public awareness of the "pro and cons" connected with the use of water-source heat pumps.

The consultant recommends, for reading, the May 1980 U.S. Department of Energy report entitled "Ground Water and Energy," CONF-800137 summary.

ACKNOWLEDGMENTS

The state of Louisiana and, in particular, the Louisiana Geological Survey, Department of Natural Resources, thank each state and the agency in each state for responding so promptly and effectively to Louisiana's request. Thanks are due to each agency for their input and excellent cooperation.

J. R. Bond
Louisiana Geological Survey

ABSTRACT

A nationwide survey of water-source heat pumps (Hawaii and Alaska not included) was conducted by the Louisiana Geological Survey, Department of Natural Resources, in August 1981. Forty-one states responded to the questionnaire requesting information about the use of heat pumps, the disposal or reuse of processed water, problems with supply or return wells, and the development of guidelines, regulations, or legislation.

Most of the states indicated that heat pumps were in use, although 12 of the 41 states reported that the number of installations was unknown, and almost half of the responding states had 100 or fewer installations. Twenty-three states reported ground water as the exclusive water source for heat pumps. Return to aquifer and release to surface appeared to be equally popular methods of dealing with the spent water; however, the use of a closed system to recycle spent water was limited. Approximately half of the states mentioned problems with the return or supply wells. Thirteen states reported that they either had or were developing guidelines, regulations, or legislation.

Although they are an increasingly popular means of heating and cooling buildings, water-source heat pumps represent a new technology, and information about them was limited or unavailable in some states. Hence, the findings of this survey should be viewed as conservative.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to present the results of a survey conducted by the Louisiana Geological Survey, Department of Natural Resources (DNR). Forty-one states responded to a letter and questionnaire (Appendix A) requesting information by mid-August 1981 on the use of water-source heat pumps, method of disposal or reuse of the processed water, problems, and information on guidelines, regulations, laws, policy procedures, and other relevant information and comments.

A water-source heat pump is a system which includes a source of water at a temperature higher or lower than the air temperature of the structure to be heated or cooled, a heat exchanger, pumps, and a place or process which disposes of, stores, or recycles the water after it has passed through the heat exchanger. Such systems are beginning to replace conventional heating and cooling technology in parts of the country where they are reportedly more economical. The Louisiana Geological Survey was seeking information about the most utilized sources of water (water well or public supply) and the means of processing the spent water (return to aquifer, release to surface water, or recycling via storage in a tank or closed well underground). Because the Office of Conservation, DNR, has regulatory authority over return wells as Class V wells under the Underground Injection Control (UIC) Program, the state was particularly interested in any problems other states had with this method of disposal. Like other states with UIC delegation, Louisiana has three years to assess ground-water contamination potential and adopt whatever regulatory programs it deems necessary. The state was interested in learning whether other states had enacted legislation or adopted regulations or guidelines for return wells and water-source heat pumps in general.

Comments by letter and answers to the questionnaire were assembled, by state agency and by state, and are summarized in this report. Letters from agencies in several states that supplement replies to and comments in the questionnaire are included in Appendix B. Copies of guidelines, policy statements, laws, or regulations provided by several states are included in Appendix C. Unfortunately, some legislation, reports, and documents were too long to be reproduced. These papers are mentioned in the section "Summary of Replies," and copies may be obtained by directly writing to that state. The section "Summary of Nationwide Findings" presents the overview.

The combination of the summary and the information in the appendixes provided input and ideas to Louisiana, which had recently completed its own inventory and assessment of water-source heat pump use in the state. The results of the Louisiana study and the consultant's recommendations for regulation of water-source heat pumps in Louisiana, based on his findings in the state and the information from other states summarized in this report, are in a separate report which was prepared for the Department of Natural Resources. This report may be published at a later date; information about Louisiana in that report is summarized in the following section.

METHOD OF INVESTIGATION

The Louisiana Geological Survey wrote to the conterminous 48 states requesting information on the utilization of water-source heat pumps. The letter and questionnaire (Appendix A) were sent to several agencies in each state who were identified, by a telephone survey, to have interest and/or responsibility for the use of heat pumps and disposal practices. This information was important in evaluating Louisiana's needs and also aided in the assessment of heat pump use, disposal methods, and the development of the consultant's recommendations.

Replies from 41 states, including Louisiana and several agencies in some states, were received. Because of the differences in responsibilities and in experience and expertise, replies from the several agencies in the same state varied and thus required careful evaluation. In several instances, follow-up letters were sent or telephone calls were made to replying agencies in order to avoid any misunderstanding.

SUMMARY OF REPLIES

Forty-one states responded to the Louisiana Geological Survey's letter and questionnaire. The number of replies, as well as the importance of their content and suggestions, provided Louisiana with information that was invaluable in the effort to assemble guidelines and recommendations for the wise use of water-source heat pumps in the state. In its letter requesting information from each state, the Louisiana Geological Survey offered to share the results with other states. Hopefully, this effort will encourage more interstate communication and interstate transfer of technology.

The comments and answers are presented in this section by state and by agency in each state. For the sake of brevity, some replies were edited slightly and paraphrased. It is hoped that this did not change the meaning of the reply. If additional information on the activity or plans of an agency in a state are needed, the address of the state agency is given.

The comments vary by state and, in some instances, by agencies in the same state. These variations were caused primarily by a difference in experience and expertise, responsibilities, and changes in state policy and attitudes as the use of heat pumps increases.

The reader should keep in mind that the comments are based on replies that reflect conditions as of the period August-October 1981. An asterisk

has been placed by those agencies that have or share regulatory responsibility for heat pumps and/or activities that affect heat pump utilization. The reader should also refer to the documents in Appendix C, which includes policy statements, rules, guidelines, and laws. All offer some excellent ideas.

ARIZONA

Department of Water Resources*
99 E. Virginia Avenue
Phoenix, AZ 85004

Less than 100 heat pump supply wells were known to be in use in Arizona. Although no problems were reported, there was concern about the possibility of thermal pollution and an increase in total dissolved solids; however, this concern was minimal because of the limited number of systems in use.

Arizona, a water appropriation regulatory state, regulates and permits water use through the Department of Water Resources (Appendix B). Injection wells are the responsibility of the Bureau of Water Quality Control:

Bureau of Water Quality Control*
Department of Health Services
1740 West Adams
Phoenix, AZ 85007

CALIFORNIA

Water Resources Control Board
P.O. Box 100
Sacramento, CA 95801

As of September 1981 (Appendix B), the use of ground-water heat pumps was rare, thus, little or no information had been assembled on their utility. Legislation specifically regulating water-source heat pumps had not yet been considered necessary. Such regulations would probably encompass the expertise and regulatory responsibilities of several state agencies.

Chapter 10 of the (California) Porter-Cologne Water Quality Control Act (January 1981) states in part (Article 3, Section 13750) that "every person who hereafter intends to dig, bore, or drill a water well or a cathodic protection well or who intends to deepen or reperforate any such well, or to abandon or destroy any such well, shall file with the department a notice of intent . . ." This notice provides the state agency the opportunity to review a proposed operation prior to installation.

COLORADO

Department of Natural Resources*
Division of Water Resources
Room 818
1313 Sherman Street
Denver, CO 80203

As of October 1981, eight ground-water source installations returned water to the subsurface, and four installations discharged onto the surface. Although no problems were noted, requests for supply wells were denied "a couple of times because the proposed wells were near hot springs and there was a fear of decreasing their flow." Permits are usually approved unless the use of the well may have an adverse effect on other water needs. The Colorado Department of Natural Resources regulates the use of ground-water heat pumps by requiring permits to drill all wells. A disposal permit must be obtained from the Department of Health.

As of September 1981, the following state agency planned to publish in four to six weeks a pamphlet describing heat pumps and their potential use in Colorado:

Department of Natural Resources
Colorado Geological Survey
715 State Centennial Building
1313 Sherman Street
Denver, CO 80203

CONNECTICUT

Connecticut Health Department*
79 Elm Street
Hartford, CT 06115

The Health Department is involved with heat pumps in that the water used must meet quality standards and a "separating distances requirement" pertaining to public water-supply wells as per the Public Health Code of the State of Connecticut.

Department of Environmental Protection*
Water Compliance Unit
State Office Building
Hartford, CT 06115

The Department of Environmental Protection regulates all ground-water and surface-water discharge. As of September 1981, about 20 installations that returned water to the subsurface were in use and 10 installations discharged onto the surface. The state's applicant guidelines for heat pump discharge is included in Appendix C.

Reportedly, a heat pump system pumping 700 gallons per minute developed problems with iron bacteria and was pumping sand. Sand chlorination and filters were used to solve these problems.

DELAWARE

Office of Sanitary Engineering*
Department of Health and Social Services
Division of Public Health
P.O. Box 637
Dover, DE 19901

The Office of Sanitary Engineering reported that state regulations require well permits for construction and that water must be returned to the aquifer.

Department of Natural Resources
and Environmental Control
State of Delaware
P.O. Box 1401
Dover, DE 19901

The Department of Natural Resources and Environmental Control stated that guidelines and regulations were in use. At the time of the survey, eight applications were waiting for approval by the Board of Health. Approval by the Board of Health is necessary when public water is available in order to ensure that there is no cross connection between the public supply and the ground-water source for the heat pump.

Seven installations had been approved. Six of these injected into the subsurface; however, in one instance the injection well would not disperse the return water into the aquifer, and the contractor constructed a drain field so that the return could seep into the subsurface.

Department of Health and Social Services*
State of Delaware
Division of Public Health
Office of Sanitary Engineering
P.O. Box 637
Dover, DE 19901

The Department of Health and Social Services reported that 10 systems were in use and returned water to the aquifer. It also stated that regulations require well permits for construction and that the water must be returned to the aquifer.

FLORIDA

Department of Environmental Regulation*
State of Florida
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, FL 32301

The Department of Environmental Regulation reported that no state agency has the responsibility of ground-water heat pumps. However, this agency is

responsible for preventing ground-water pollution and consequently has control of injection/return wells.

This agency reported that, in some cases, the supply well and injection/return well were too close, which tends to reduce the efficiency of the system. In some cases, the return well had been opened to dispose of waste water and hazardous waste.

St. Johns River Water Management District
P.O. Box 1429
Palatka, FL 32077

In a letter dated August 13, 1981, the St. Johns River Water Management district reported that ground-water heat pumps "were rapidly increasing throughout the district and in some areas constitute[d] as much as 30% of total ground water used by an individual county" (Appendix B). A recent report from this district entitled "Annual Water Survey, 1979" stated that 180 million gallons of ground water per day was used for 16,000 heat pumps in one county. Most of this water was discharged onto the surface. This district also reported that discharge from the systems was contaminating "shallow supplies" and the "resources integrity [had] been diminished due to the large concentration of users." (Included in Appendix B with this district's letter is page 25 from St. John's River Water Management District Technical Report No. 10.)

South Florida Water Management District
P.O. Box V
West Palm Beach, FL 33402

The South Florida district "does not regulate wells - Regulatory programs in ground [are] confined to water use - not water pumped."

Northwest Florida Water Management District
Route No. 1, Box 3100
Havana, FL 32333

The Northwest Florida district reported "some subsidence associated with large municipal wells injecting into shallow strata" (Appendix B). The district also stated that because of the surface geology most of the water discharged onto the surface "is returned indirectly through percolation; therefore, consumptive use will probably never be a concern."

Southwest Florida Water Management District
5060 U.S. Highway 41, South
Brooksville, FL 33512

The Southwest Florida district reported 5000 heat pump systems that returned water to the aquifer and another 2500 installations that discharged water onto the surface. This district includes a 16-county area. Reportedly, some returned air-conditioned water had caused the aquifer to build up heat in excess of 105° F. This buildup in isolated areas was not considered a widespread problem.

Suwannee River Management District
Route 3, Box 64
Live Oak, FL 32060

The Suwannee district reported 75 installations that returned water to the aquifer and 25 installations that discharged water onto the surface (Appendix B). The only problem had been the placement of supply and return wells close to each other so that efficiency losses resulted from a reduced thermal gradient.

Department of Water Resources*
State House
Boise, ID 83720

The Department of Water Resources is responsible for regulating ground-water use, but has no specific guidelines, regulations, or legislation relating to heat pumps. However, some ground-water heat pumps using low-temperature geothermal water could be subject to some provisions of the state's geothermal law. There are adequate state rules and regulations for disposal wells. As a western state, Idaho has had very strong water-use appropriation laws, but to date the state has not required separate permits for domestic heat pumps.

Idaho Office of Energy
State House
Boise, ID 83720

In its reply to the questionnaire, the Idaho Office of Energy wrote that "although numbers were not available, ground water source heat pumps were in use and either returned water to the subsurface or onto the surface."

Department of Health and Welfare
Division of Environmental and
Water Quality Board
State House
Boise, ID 83720

The Department of Health and Welfare estimated that less than 100 installations were in use; these installations discharged water to the surface. It is possible that some heat pumps using high-temperature water could be subject to some provisions of the state geothermal law. The agency was also of the opinion that adequate regulations and rules for disposal wells already exist. As a western state, Idaho has strong water appropriation laws that do not require separate permits for domestic "space" heating.

EG & G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

According to EG&G Idaho, the use of heat pumps in Idaho will increase (Appendix B). Several institutions, including schools, had installed water heat pumps, and several other schools were considering the possibility.

ILLINOIS

Environmental Protection Agency*
State of Illinois
2200 Churchill Road
Springfield, IL 62706

The letter from the Illinois Environmental Protection Agency explained that because an inventory was underway as of August 5, 1981, the number of heat pumps was unknown (Appendix B). The agency expected to complete the inventory in 1 or 1-1/2 years.

Illinois State Water Survey
605 East Springfield Avenue
P.O. Box 5050, Station A
Champaign, IL 61820

The State Water Survey provided a rough estimate of 10 to 40 installations returning water to the aquifer, 5 to 10 installations using a closed type of system, and 30 to 60 installations discharging water to the surface.

INDIANA

Indiana State Board of Health*
P.O. Box 1964
Indianapolis, IN 46206

The Stream Pollution Control Agency is responsible for regulating the impact of heat pumps on ground-water and surface-water quality. The number of heat pump installations and problems with them had not been inventoried by this agency.

Indiana Department of Natural Resources*
Division of Water
Room 605, State Office Building
Indianapolis, IN 46204

This department estimated that, as of September 1981, 100 installations returned water to the subsurface and 400 discharged water onto the surface.

IOWA

Iowa Natural Resources Council*
Henry A. Wallace State Office Building
Des Moines, IA 50319

The Natural Resources Council reported that the exact number of installations was unknown. The only problems encountered were the plugging of return wells and inadequate spacing between wells, which caused "some interferences between wells." As the use of heat pumps increases, these problems may become more common.

Iowa Natural Resources Council Rule 455A applies to the supply and return of injection wells, and a permit is required to store, divert, or withdraw water. The following are sections 3.1(4) and 3.1(6) of Rule 455A that apply, for the most part, to heat pump operations.

> 3.1(4). Under storage or disposal. A permit for the diversion of water or any material from the surface directly into any underground water course or basin shall not be granted except upon proof provided by the applicant that the requested diversion is fully safe, will not contaminate the aquifer utilized and is approved by the Iowa Water Quality Commission.
>
> 3.1(6). Closed cooling systems. A permit shall not be granted for the withdrawal of ground water for use solely as a coolant in a closed system without returning such ground water to the aquifer from which it came unless applicant demonstrates compelling reasons for not returning the water.

Department of Environmental Quality*
Henry A. Wallace State Office Building
Des Moines, IA 50319

This department will probably have co-responsibility for regulating heat pump operations.

Iowa Geological Survey
123 North Capital Street
Iowa City, IA 52242

The Iowa Geological Survey had been studying thermal contamination and reported thermal problems when return wells were used (Appendix B). The Iowa Extension Service was preparing a brochure on the use and design of ground-water heat pumps.

KANSAS

Department of Health & Environment*
Forbes Field
Topeka, KS 66620

The Kansas Department of Health and Environment, along with the state's Bureau of Oil Field and Environmental Geology, will be responsible for regulating ground-water heat pumps. Guidelines were being developed and an inventory of wells was to begin in August 1981.

This department reported (August 1981) the following types of disposal activities: 60 installations returning water to aquifer, 4 installations returning to a closed system or swimming pools, and 20 installations discharging water to the surface.

The major problems associated with heat pump installation were that return wells were not being constructed properly and were not capable of handling the return flow. Many plugged due to particulate matter and fine sand. Another problem was incrustation due to iron and manganese in the water. Because of poor development, many supply wells pumped fine sand.

LOUISIANA

Louisiana Geological Survey
University Station, Box G
Baton Rouge, LA 70893

In its inventory and assessment, the Louisiana Geological Survey learned that about 300 water-source heat pumps were in use as of October 1981. Of this total, no more than 10 heat pumps were injecting the waste product into the subsurface, and 2 or 3 were using the closed-loop system. The remainder discharged onto the surface and into swimming pools, ponds, sewers, ditches, and so on. Louisiana has no law, regulation, or rule limiting or controlling the use of water. Recommendations were made for the development of guidelines that would apply to water use and waste disposal.

Department of Natural Resources*
P.O. Box 44396
Baton Rouge, LA 70804

As stated in a letter dated April 12, 1982, from the Legal Division of the Department of Natural Resources (DNR), the Office of Conservation (DNR) has jurisdiction over subsurface injection, and the Office of Environmental Affairs (DNR) has jurisdiction over surface discharge from heat pumps (Appendix B). In April 1982, Louisiana received primacy delegation for the UIC program. The Attorney General of Louisiana rendered a legal opinion that fluid from a heat pump installation is a waste product (Appendix B).

Department of Health and Human Resources*
P.O. Box 3776
Baton Rouge, LA 70821

This department, through the provisions of the Sanitary Code of Louisiana, can take action to regulate or eliminate activities that may endanger health.

MAINE

Department of Environmental Protection*
State House Station 17
Augusta, ME 04333

This agency was to be responsible for regulating water-source heat pumps. No installations were known to exist in Maine.

MARYLAND

The John Hopkins University
Applied Physics Laboratory
John Hopkins Road
Laurel, MD 20810

The Applied Physics Laboratory provided general information on the use of heat pumps in Maryland and stated that many eastern states are now having to write regulations for heat pumps (Appendix B). The university suggested the development of a manual for architects, builders, and users of heat pump systems.

MASSACHUSETTS

Department of Environmental Quality
Engineering*
1-11 Webster Street
Boston, MA 02110

The Department of Environmental Quality Engineering, along with the Division of Water Pollution, reportedly will regulate the use of water-source heat pumps based on legislation recently passed. As of September 1981, 38 installations were in use, all of which use ground water and return water to the subsurface through leaching.

MICHIGAN

Water Resources Commission
Chairman
Executive Office
Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909

Although water-source heat pumps were reported to be in use, an inventory had not been made. The water or waste from the installation was reportedly returned to the aquifer or discharged on the surface. No problems were noted.

The Water Resources Commission issued a policy statement on heat pump practices (Appendix C) and stated that heat pump facilities with a heat exchange capacity or 120,000 Btu per hour or less will not be required to have a discharge permit, provided no chemical additives are used in the system. Systems with a heat exchange rate greater than 120,000 Btu per hour or systems with a smaller rate that propose to use chemical additives must file for a discharge permit.

MINNESOTA

Minnesota Pollution Control Agency
1935 West County Road B2
Roseville, MN 55113

As of September 1981, the number of ground-water heat pumps in Minnesota was unknown. Recent legislation allowed the installation of up to 210 systems with the reinjection to the supply aquifer through a program administered by the Department of Health. Permit applications for discharging to the surface are under the control of the Pollution Control Agency. Aside from these systems, ground-water injection in general is prohibited through separate regulations of the Pollution Control Agency and the Department of Health.

The Minnesota Department of Natural Resources must approve the issuance of a water appropriation permit if the supply well yields 10,000 gallons or more per day. Minnesota's rules for heat pump use are in Appendix C.

There had been no attempt to identify problems associated with the use of water-source heat pumps.

MISSISSIPPI

Department of Natural Resources
Bureau of Land and Water Resources
P.O. Box 10631
Jackson, MS 39209

This department reported that it had not yet (August 1981) inventoried the use or impact of water-source heat pumps.

MISSOURI

Department of Natural Resources*
P.O. Box 176
Jefferson City, MO 65102

Included in Appendix B is a letter from this department dated August 18, 1981, that summarizes the use of heat pumps in Missouri. Missouri House Bill No. 1614 (1978) permits only single residential heat-pump installations.

MONTANA

Department of Natural Resources
and Conservation
Energy Division
32 South Ewing
Helena, MT 59601

At the time of the survey, the utilization of heat pumps was "relatively new" in Montana (Appendix B) and the market was "not large enough" for

problems to have developed. Closed-loop systems were in the experimental stage, and emphasis was on developing interest in ground-water heat pump systems primarily as an energy conservation goal.

Of the 10 installations using ground water and known to exist, 6 returned water to the aquifer, 2 stored water in a tank underground, and 2 discharged onto the surface. In addition, there were 2 closed-loop systems, and 2 installations used public water supply and discharged onto the surface.

The state's regulatory responsibility by category is as follows:

Water-use permits---------- Department of Natural Resources and Conservation

Discharge permits---------- Department of Health and Environmental Sciences

Return or injection permits-- Department of State Lands

Montana Bureau of Mines and Geology
Montana College of Mineral Science
and Technology
Butte, MT 59701

Replies indicated that potential problems with surface disposal may increase stream temperature and adversely affect fish. No problems had yet been noted.

NEVADA

Department of Environmental and
Natural Resources
Division of Environmental Protection
Capital Station
Carson City, NV 89712

The Division of Environmental Protection regulates discharge to the subsurface and surface. The Division of Water Resources (Office of the State Engineer) regulates water rights and withdrawal permits. There are no regulations that specifically apply to water-source heat pumps.

Some wells were used as "noncontact" cooling water for commercial buildings and returned water to the same aquifer. Some geothermal wells were used to heat houses and commercial buildings by use of "in well heat exchanges or flow through heat exchanges" with return to the same aquifer or discharge to a storm drain.

NEW JERSEY

Division of Water Resources*
Department of Environmental Protection
P.O. Box CN 029
Trenton, NJ 08625

The Water Allocation Office of this state agency has the responsibility for regulating water-source heat pumps. As of September 1981, there were 79 "cooling return wells" registered with the state. The agency believed that there were more, but they had not yet classified them as to use or method of disposal.

NEW MEXICO

Health and Environmental Department
P.O. Box 968
Santa Fe, NM 87503

The State Engineer appropriates water rights in New Mexico. Few systems (11) were reported to have been installed. Specific laws and regulations for heat pumps had not been developed. A major problem seemed to be the short life of return wells.

NEW YORK

Department of Environmental Control
50 Wolf Drive
Albany, NY 12233

As of September 1981, no state agency had specific responsibility for regulating heat pumps. Consequently, the number of heat pumps and associated

problems were not reported. The reporting agency stated that persons in New York City used heat pumps in summer and that "suspected contamination was caused by pumping and not returning [water] causing drawdown and salt water intrusions."

NORTH CAROLINA

Department of Natural Resources
and Community Development*
P.O. Box 27687
Raleigh, NC 27611

The Division of Environmental Management, Ground Water Section, is responsible for regulating heat pumps. Legislation had been passed requiring "prior permission." Although 100 installations were estimated to be returning water to the aquifer and 500 discharging onto the surface, no problems had yet been noted.

NORTH DAKOTA

State Department of Health*
Missouri Office Building
1200 Missouri Avenue
Bismark, ND 58505

As of August 1981, 30 ground-water source heat pumps were in operation, all of which returned water to the aquifer. One installation discharged water onto the surface. Although no problems associated with heat pumps had been noted, the State Department of Health was in the process of evaluating this possibility. This department requires information for single-family units under existing water well standards and that wells be built in conformance with state water-well regulations. Additional regulations were being developed.

OHIO

Ohio Environmental Protection Agency*
361 E. Broad Street
P.O. Box 1049
Columbus, OH 43216

The Ohio Environmental Protection Agency will probably regulate return wells, but had not yet inventoried the installations. Ohio's proposed policy on the use of return wells is in Appendix C. Reported problems were inadequate supply well yield in some areas, inadequate capacity of return wells used by more than one or two homes, and clogging of return wells.

Department of Natural Resources
Division of Water
Fountain Square
Columbus, OH 43224

This department has issued a brochure on the utilization of ground water for heating and cooling that is available upon request.

OKLAHOMA

Water Resources Board*
P.O. Box 53585
Oklahoma City, OK 73152

Regulations were in use. The Water Resources Board, as of September 1981, required a permit for the "initial well to take ground water," regardless of use.

Oklahoma State Department of Health*
Environmental Health Service
P.O. Box 53551
Oklahoma City, OK 73152

The State Department of Health, as of September 1981, required only notification of the installation of injection wells; it will eventually require permits under the UIC program to prevent contamination of potable water supplies.

Some heat pump installations had resulted in cross connnections between potable water and water of questionable quality, thus creating a potential health hazard. This agency reported some problems with injection wells that were not recharging the water into the formation, but instead were flooding the area.

OREGON

Water Resources Department
555 13th Street
Salem, OR 97310

No laws, regulations, or guidelines relating specifically to heat pumps had been developed. Legislation was passed in 1979, but funding limitations prevented implementation (Appendix C). This legislation was pertinent to geothermal resources and required considerable hydrogeologic data. The number of heat pump installations was unknown, but one problem was reported: A parking lot flooded due to the faulty construction of a return well.

PENNSYLVANIA

Commonwealth of Pennsylvania*
Department of Environmental Resources
P.O. Box 2063
Harrisburg, PA 17120

The Department of Environmental Resources will be responsible for the ground-water quality protection aspects of heat pump systems (Appendix B). About 588 heat pump installations were in use. Reportedly, most residential systems used injection wells. The only likely problems were scaling and clogging, especially in areas which used ground water high in calcium, iron, and magnesium.

This department's report, "Ground-Water Heat Pumps in Pennsylvania," presents an excellent summary of the utilization of heat pumps (Appendix C). The sections on economics, regulating concerns, and conclusions are recommended reading for officials of other states and persons concerned with heat pumps.

SOUTH CAROLINA

Department of Health & Environmental Control*
2600 Bull Street
Columbia, SC 29201

It was estimated that about 500 water-source heat pumps are installed per year. Most of the systems (95%) used ground water. Details on problems were not yet available.

SOUTH DAKOTA

Department of Water and Natural Resources*
Joe Foss Building
Pierre, SD 57501

No problems were reported since ground-water source heat pumps had not "caught on" in South Dakota. This state was still assessing the need for and the extent and type of regulatory controls.

South Dakota Geological Survey
Science Center, University
Vermilion, SD 57065

No research had been done in South Dakota, but some efforts were made to study the geothermal potential in western South Dakota where water temperatures exceed 100°C. Several institutions, including a school in Chamberlain and a hospital in Pierre, had large geothermal projects. Details on these installations were not yet available.

TENNESSEE

Department of Public Health*
Cordell Hull Building
Nashville, TN 37219

The Department of Public Health is responsible for waste water discharge. Although no exact count was available, it was estimated that 300 new heat pump wells are drilled each year; most reportedly discharged onto the surface.

The Tennessee Valley Authority has a program providing assistance to persons wanting to install ground-water heat pumps. However, few loans had been made because of the agency's stringent regulations regarding ground-water supply and water quality.

Department of Conservation*
Division of Water Resources
4721 Trousdale Drive
Nashville, TN 37219

The Department of Conservation is responsible for registering water wells that yield 50,000 gallons or more per day and for licensing contractors and pump installers. The agency stated that there is a need for a comprehensive regulatory program, but at that time had insufficient information to design such a program. However, this agency will endeavor to monitor the situation through the state's requirement that licensed drillers must report the drilling of water wells.

TEXAS

Department of Water Resources
1700 N. Congress Avenue
P.O. Box 13087
Austin, TX 78711

The letter from the Department of Water Resources outlines the use of heat pumps in Texas (Appendix B). The department reported that "those

systems which have been located and analyzed do not pose any threat to the environment, nor have any complaints or problems been reported."

UTAH

Utah Water Research Laboratory
Extension Service
Utah State University
Logan, UT 84322

A well permit is required for a ground-water heat pump system. To acquire the permit (water right), the homeowner must file an application with the Utah Division of Water Rights and receive approval of the application.

Utah State University had done some research into the use of heat pumps in the state, evaluated the utility of these installations, and published some excellent reports related to Utah's geohydrology, including "Ground Water Heat Pump Equipment Selection Procedures for Architects, Designers and Contractors (March 1980)" and "Ground Water Heat Pump: The Interaction of Flow Rate, Aquifer Temperature Changes and Well Spacing (June 1981)."

Division of Water Rights*
200 Empire Building
231 East 400 South
Salt Lake City, UT 84111

The Division of Water Rights, which has regulatory responsibility for permitting water wells, reported that about 75 to 100 heat pump installations returned water to the subsurface and one or two discharged onto the surface. The only reported problem was increased water temperature.

VERMONT

Agency of Environmental Conservation*
Department of Water Resources and
Environmental Engineering
Montpelier, VT 05602

The installation of ground-water heat pumps was just beginning as of August 1981, and at that time there were no known specific references to heat pumps in state statutes, regulations, or guidelines (Appendix B).

Four installations discharged water to the surface and two had a closed-loop system.

VIRGINIA

State Water Control Board*
P.O. Box 11143
Richmond, VA 23201

This agency had assumed responsibility for preparing statewide regulations for heat pumps. No information on the utilization of heat pumps was available.

Hampton Roads Water Quality Agency
1436 Air Rail Avenue
Virginia Beach, VA 23455

The Hampton Roads Water Quality Agency originally intended to complete a task entitled "Criteria Development for Ground Water-Air Heat Pumps," but had modified its plans when the responsibility of preparing regulations was assigned to the State Water Control Board (Appendix B).

WASHINGTON

Department of Ecology*
Mail Stop PV-11
Olympia, WA 98504

The Department of Ecology reported that 47 installations returned water to the aquifer and 31 discharged water onto the surface. The only problems, which were unverified, were associated with injection wells. This department's letter of August 7, 1981, explains in detail the topics of concern and emphasizes a relevant thought: "Both the product suppliers and the well drillers conclude that one does not know the heating/refrigeration business nor does the other know the well drilling business. Further, they have not

gotten together to discuss the topic" (Appendix B). The standard operating procedure for water-source heat pumps is given in Appendix C.

Washington State Energy Office
400 E. Union Street
Olympia, WA 98504

The State Energy Office reported 5 installations that discharged onto the subsurface, 175 to the surface, and 1 large district heating system that used public supply water and injected into the subsurface.

This agency published the proceedings of a symposium held on September 24, 1980. It is entitled Geothermal Symposium--Low Temperature Utilization Heat Pump Applications, District Heating. Because of the size of the document, it was not possible to include it in this report.

WEST VIRGINIA

Department of Natural Resources*
Division of Water Resources
Ground Water/Hazardous Waste Branch
1201 Greenbriar Road
Charleston, WV 25311

There were no known water-source heat pumps in West Virginia. The Department of Natural Resources was developing regulations and assessing methodology necessary for obtaining state primacy delegation for the UIC program.

WISCONSIN

Department of Natural Resources*
P.O. Box 7921
Madison, WI

The Department of Natural Resources has the responsibility of approving ground-water heat pump supply wells. According to this department's reply, return wells were generally prohibited. The following is an extract from legislation passed in 1981 by the Wisconsin legislature:

(4) Ground water heat pump project. (a) Approval. Until July 1, 1984, the Department of Natural Resources may approve the installation and operation of not more than 60 ground-water heat pump systems which inject circulated water into the ground water of the State notwithstanding the requirements of sections 1.11 and 144.025 and chapters 147 and 162 of the statutes if:

1. The ground water heat pump system has an alternative means of disposing of the circulated water.

2. The ground water heat pump system serves a building not larger than 30,000 cubic feet, and

3. No more than 3 ground water heat pump systems are approved in any county.

4. Any injection well used to inject circulated water into the ground water of the State is constructed by a well driller registered under chapter 162 of the statutes.

(b) Monitoring. The Department of Natural Resources shall monitor ground water heat pumps approved under this project. The Department may rescind its approval of the operation of a ground water heat pump system if it determines that the injection of circulated water into the ground water is harmful to the waters of the State. If approval is rescinded, the ground water heat pump system may not inject circulated water into the ground water of the State.

(c) Design; implementation; exemption from rule-making requirements. The Department of Natural Resources, with the cooperation of the Wisconsin Geological and Natural History Survey and the Department of Administration, shall design and implement this project. Notwithstanding the requirements of chapter 227 of the statutes, the Department of Natural Resources is not required to promulgate rules to design, implement, administer or enforce this project.

(d) Study; reports. The Department of Natural Resources shall conduct a study to assess the environmental impact of the utilization of groundwater heat pump systems. The Department of Natural Resources shall report its interim findings to the legislature on or before July 1, 1982, and July 1, 1983, and shall file its final report and recommendations on or before July 1, 1984.

Geological and Natural History Survey
University of Wisconsin - Extension
1815 University Avenue
Madison, WI 53706

This state agency reported 130 installations using ground water that discharged onto the surface; in addition, 45 installations returned the water to the subsurface by seepage.

State Engineer's Office*
Barrett Building
Cheyenne, WY 82002

All water use in Wyoming is controlled by the State Engineer's Office. Any individual wishing to utilize a heat pump must go through the state's ground-water appropriation permitting procedures. Contamination problems by injection or return wells would be a concern of the Department of Environmental Quality.

Wyoming Geothermal Assessment Group
Department of Geology
University of Wyoming
Laramie, WY 82071

At the time of the survey, heat pumps were basically new in Wyoming. Heat pump use was reported to be so slight that any potential problems either had not occurred or had not been publicized.

Department of Environmental Quality
Water Quality Division
Equality State Bank Building
Cheyenne, WY 82002

The Department of Environmental Quality does not regulate or administer the use of heat pumps, but does regulate the disposal of geothermal fluid.

SUMMARY OF NATIONWIDE FINDINGS

At the time this survey was conducted in the fall of 1981, it was impossible to accurately inventory water-source heat pump systems nationwide or to assess problems associated with their use and the need for their regulation. States reporting few or no installations may have been presenting the true situation, or their answers may have reflected the fact that most states did not require registration of or permits for all or part

of these systems; therefore, these states may have had no means of obtaining an accurate count. Similarly, some state agencies may have been unaware of problems with heat pumps because there was no specific agency to which such matters were routinely reported or because the installations had not been in use long enough to develop problems. Therefore, the following summary of nationwide findings is probably an underestimation of the true utilization of water-source heat pumps in the nation and the problems associated with their use.

Whenever several agencies within a state reported different numbers, the largest numbers were used. States were grouped according to the number of systems reported: unknown, less than 100, 100 to 999, or 1000 or more systems. The information was further subdivided according to source of water supply, method of disposal, reported problems associated with these alternatives, and regulation of their use.

INVENTORY

Seven states did not reply to the letter and questionnaire: Alabama, Arkansas, Georgia, Kentucky, Nebraska, New Hampshire, and Rhode Island. (Alaska and Hawaii were not contacted.)

Of the 41 states responding, 35 reported that water-source heat pumps were utilized in their states, 5 were unsure (Maryland, Mississippi, Nevada, Virginia, and West Virginia), and 1 reported none (Maine).

Of the 35 states reporting some utilization of water-source heat pumps, 16 reported less than 100 installations (Arizona, California, Colorado, Connecticut, Delaware, Idaho, Illinois, Kansas, Massachusetts, Montana, New Jersey, New Mexico, North Dakota, Utah, Vermont, and Wyoming); 6 reported between 100 to 999 (Indiana, Louisiana, Pennsylvania, North Carolina, Washington, and Wisconsin); 1 reported more than 1000 (Florida); the remaining 12 states reported that the numbers of installations was unknown.

SOURCE OF WATER AND METHOD OF DISPOSAL

Of the 35 states reporting some utilization of water-source heat pumps, 8 made no attempt to break down the systems by water source and disposal method: Arizona, California, Oregon, Oklahoma, Pennsylvania, New York, South Carolina, and South Dakota. Of the remaining 27 states, only 4 (Idaho, Louisiana, Montana, and Vermont) reported the use of public supply water as the source for systems, a source less frequently used than ground water. The exclusive use of ground water was reported by 23 states.

Of the 27 states reporting the method of processing or storing spent water, only 6 reported the use of a closed system whereby the spent water was stored in or recycled from an underground well or tank (Idaho, Illinois, Iowa, Minnesota, Montana, and Vermont). However, in all six states these systems were less commonly used than those systems which returned the water to the surface or to an aquifer.

Of these 27 states reporting on the method of processing or storing the spent water, 11 states reported return to the aquifer by injection well as being the most common method in use: Colorado, Connecticut, Delaware, Florida, Kansas, Massachusetts, New Jersey, New Mexico, North Dakota, Texas, and Utah. In a few cases, return to aquifer by leach field was mentioned. Ten states reported release to surface water as the most prevalent practice (Idaho, Illinois, Indiana, Louisiana, Montana, North Carolina, Tennessee, Vermont, Washington, and Wisconsin), and six reported that roughly equal numbers utilized surface disposal and return to aquifer.

PROBLEMS ASSOCIATED WITH WATER-SOURCE HEAT PUMPS SYSTEMS

Of the 35 states reporting some utilization of water-source heat pumps, 17 reported one or more instances of problems with the return or supply wells, and 18 reported no problems, but with the qualification that this matter had not been investigated, that it was too early to tell, or that this

information was unknown. Florida, which reported the most water-source heat pumps (approximately 5000 of which return water to the aquifer and 2500 of which return water to the surface), had the most problems to report.

Problems reported in connection with supply wells included inadequate spacing of wells; capacity of wells not sufficient to supply the system; deterioration of water quality in the supply aquifer due to saltwater intrusion; conflict with other water usage in areas of scarce ground water; and scaling, plugging, or sanding up of the supply well.

Problems reported in connection with return wells include the following: 1) plugging of the return well (very common) and the possibility of ground-water contamination if chemicals are used to solve this problem; 2) insufficient capacity of the return well to serve the system; 3) thermal pollution of ground water when the supply and return wells are too closely situated in the same aquifer; 4) ground-water deterioration when supply well pumps water of quality that is inferior to that of the return well aquifer; 5) and the use of return wells for disposal of other waste water, including hazardous waste. This alternative is more costly than discharge to the surface.

Although not specifically requested in the questionnaire, problems with other aspects of water-source heat pumps were mentioned or are known from Louisiana's study of these systems.

Water sources from public supply: This alternative is generally cost-prohibitive unless a closed system is used to recycle water.

Processed water released to surface: This water is lost from the aquifer and is thus a waste of a valuable natural resource which may be needed in the future for more important uses. This water may cause mosquito control problems, damage neighboring property, or cause thermal pollution of surface waters.

Processed water recycled in an underground tank or sealed well: Initially, this is the most expensive system to construct, but may be at least equally cost-efficient in the long run; the most serious question that remains to be answered is whether these systems are thermally efficient after several years of operation.

Installation of water-source heat pumps systems: Because water-source heat pumps are composed of pieces of existing technologies and are not new, unique entities, owners of these systems may not realize the most efficient systems for their money. Thus far there has been little communication between the water-well contractors who drill the wells and the heating/refrigeration people who install the heat exchangers.

Regulatory fragmentation: The fragmentation mentioned above carries over into the regulation of such systems and complicates the enactment and enforcement of regulatory programs.

REGULATION OF WATER-SOURCE HEAT PUMP SYSTEMS

Water-source heat pump systems are being installed in increasing numbers, and it is likely that in states where these systems are major users of ground water some action will be necessary--if it has not already been taken--to minimize misuse of an important natural resource. In the questionnaire, states were asked if they had or were developing guidelines, regulations, or legislation for water-source heat pump systems. This question revealed itself to be ambiguous because most states have some regulations and legislation that cover part of these systems, although they may not be specific to water-source heat pump systems. To further complicate the issue, different agencies usually regulate supply wells, surface discharge, and return wells. Although the information was not specifically requested, several states mentioned that they had acquired or were seeking regulatory authority over injection wells (Class V) under a UIC program and would be developing regulations for this aspect of water-source heat pumps if they were determined to be a potential source of ground-water contamination.

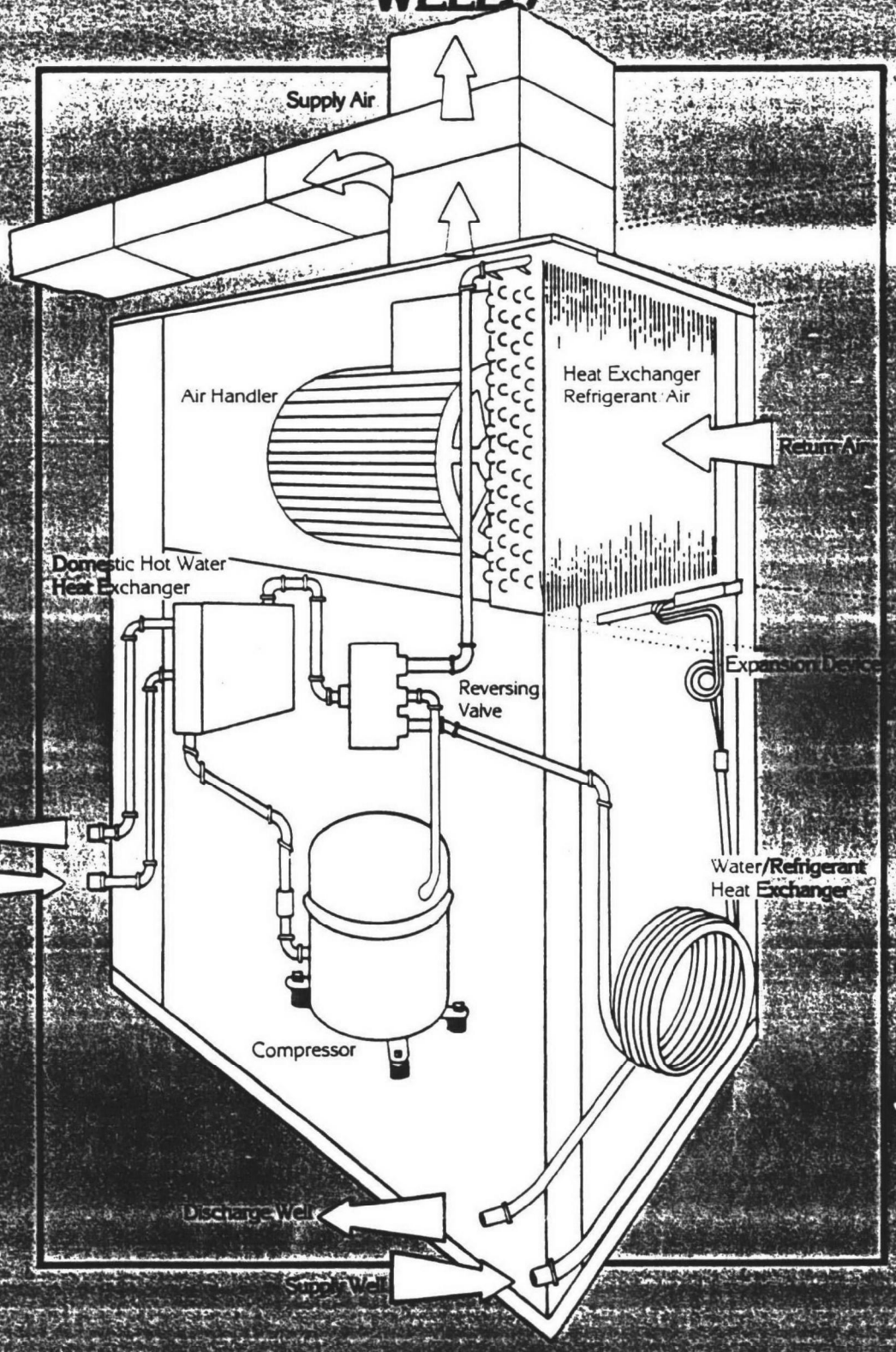
The regulatory agency and the aspect of the system registered, permitted, regulated, or prohibited are mentioned in the section "Summary of Replies." The 13 states that mentioned having or developing guidelines, regulations, or legislation specific to water-source heat pump systems were Connecticut, Delaware, Missouri, Michigan, Minnesota, Massachusetts, Ohio,

Oregon, Pennsylvania, North Carolina, North Dakota, Washington, and Wisconsin. Part of Wisconsin's legislation is excerpted in the section "Summary of Replies," and relevant documents from Connecticut, Michigan, Minnesota, Ohio, Oregon, Pennsylvania, and Washington are given in Appendix C.

SECTION 3.2.7

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Understanding Heat Pumps, Ground Water, and Wells - Questions and Answers for the Responsible Consumer
AUTHOR: (or INVESTIGATOR)	National Water Well Association
DATE:	1983
FACILITY NAME AND LOCATION:	Not applicable
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	This is a consumer-oriented document designed to inform persons about heat pump systems. Information is presented in a question and answer format. The report provides a table summarizing groundwater heat pump use and effluent disposal regulations by state.

UNDERSTANDING HEAT PUMPS, GROUND WATER AND WELLS



Questions and Answers for the Responsible Consumer

Prepared by the
National Water Well Association
in cooperation with the
ground water heat pump industry.

Kevin B. McCray, Editor

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National Water Well Association
500 W Wilson Bridge Road
Worthington, Ohio 43085

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INTRODUCTION

Nearly half of the energy used in the residential and commercial sectors in the United States goes for space heating. This represents one-sixth of the total U.S. energy use and one-fourth of the total oil and natural gas consumption.

Costs of heating and cooling homes continue to rise and many projections indicate that these costs will continue to rise for years to come. Consumers, therefore, are reconsidering alternatives that they may have rejected in cheaper energy times.

Today, many consumers are in an excellent position to realize energy savings through the use of ground water heat pump systems, especially in areas that have adequate supplies of underground water available through the use of wells. Ground water heat pumps have been found to be particularly efficient in areas that have an extreme variation in outdoor air temperatures—the areas that use the most energy for space conditioning.

Since ground water heat pump systems are still relatively new in the minds of many consumers, these same consumers are unfamiliar with the many types of systems and their relative advantages and disadvantages. Consumers, through no fault of their own, typically know little about:

- State regulations
- Life cycle cost effectiveness
- Ground water
- Reputable water well contractors
- Reputable heating/air-conditioning contractors.

This publication was prepared to:

- Help consumers select the most economical and environmentally safe system.
- Help consumers understand the feasibility of using these systems to meet their heating and air-conditioning needs.
- Help increase awareness of ground water resources.
- Address potential problems of system design and operation, such as scaling, corrosion, pipe clogging.
- Assist consumers, construction companies, water well contractors, pump installers and heating/air-conditioning contractors in complying with regulatory standards.

This publication does not, and should not, answer all questions a cautious, responsible consumer might have about installing a ground water heat pump system. Because of the characteristics of ground water and individual home construction, it is impossible for any one publication to answer all questions that must be asked. This publication is intended only to help you understand and to help you ask the questions you need answered.

We hope you find it useful.

The National Water Well Association

WHAT IS A HEAT PUMP?

Essentially, a heat pump is a device that moves heat from a relatively cool area to another, warmer area. A refrigerator is a type of heat pump.

In its cooling mode a heat pump works like an ordinary air conditioner, extracting heat from inside a building and pumping it outdoors. But unlike an air conditioner, the heat pump can be reversed. During cold weather, a heat pump can absorb heat from outdoors or ground water and transfer it to the inside air.

HOW DOES A WATER-TO-AIR HEAT PUMP OPERATE?

The operation of a water-to-air, or ground water heat pump simply involves taking thermal energy (heat) from ground water and transferring it into the space being conditioned during the winter months. Summer cooling is provided when the system puts excess heat from the structure back into the ground water. This is possible because the temperature of ground water remains fairly constant throughout the year—never freezing in winter or warming in summer.

The heating cycle begins when the ground water is piped through tubes to a heat exchanger. Surrounding these tubes is a container filled with a liquid refrigerant (Freon®).* The Freon®, absorbing heat from the ground water, forms a cool gas (10 to 30 F cooler than the ground water). The gas is then directed to a compressor, which compresses this gas to a hot, denser gas (an average of 180 F and 245 pounds per square inch pressure for most models). The hot gas then flows to another heat exchanger, where the heat from the Freon® gas is released to air and moved throughout the house. After this release of heat, the Freon® condenses to a liquid and flows through an expansion device, which reduces the pressure and consequently lowers the temperature again. Finally, the refrigerant reenters the first heat exchanger and the cycle is repeated.

For home cooling, the above process is reversed. The compressor sends the hot, dense gas directly to the water. The refrigerant is cooled by this process. The now liquid Freon® enters an expansion device, which further lowers its temperature and pressure. The cool liquid refrigerant flows to the second heat exchanger, where it absorbs heat from the air in the house. In exchange, cooler air is released and moved through the house. The warmed refrigerant returns to the compressor to repeat the cycle.

*Freon® is a registered trade name of the E.I. Dupont De Nemours Co. Although other fluids (ammonia, nitrogen) can be used, Freon® is the most common.

Most of the heat pumps installed today are reversible, meaning they can provide cooling as well as heating. This is made possible by using a device called a refrigerant reversing valve, which permits the flow of refrigerant to be reversed. Some units may also be equipped to provide hot water heat as an alternative to hot air. These units are equipped with a small heat exchanger between the refrigerant reversing valve and the compressor, which provides hot water for domestic needs.

COOLING MODE

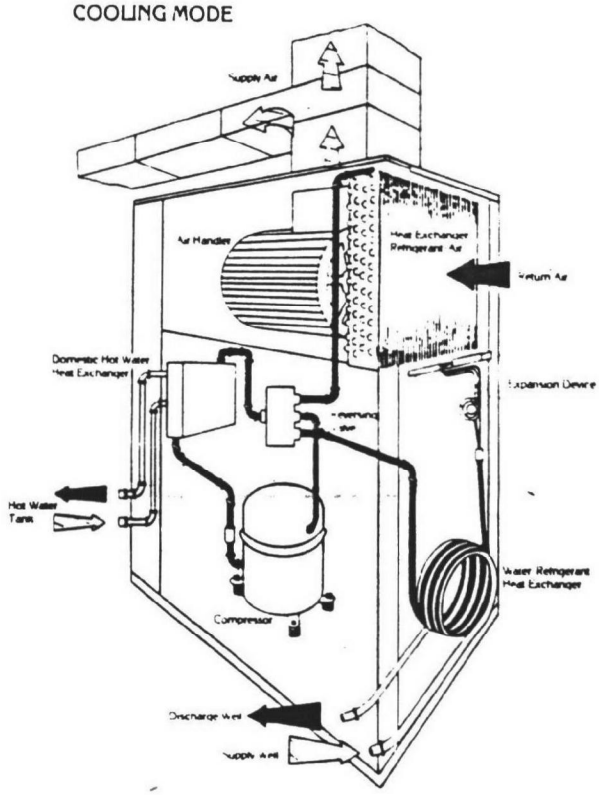


FIGURE 1. Cooling mode

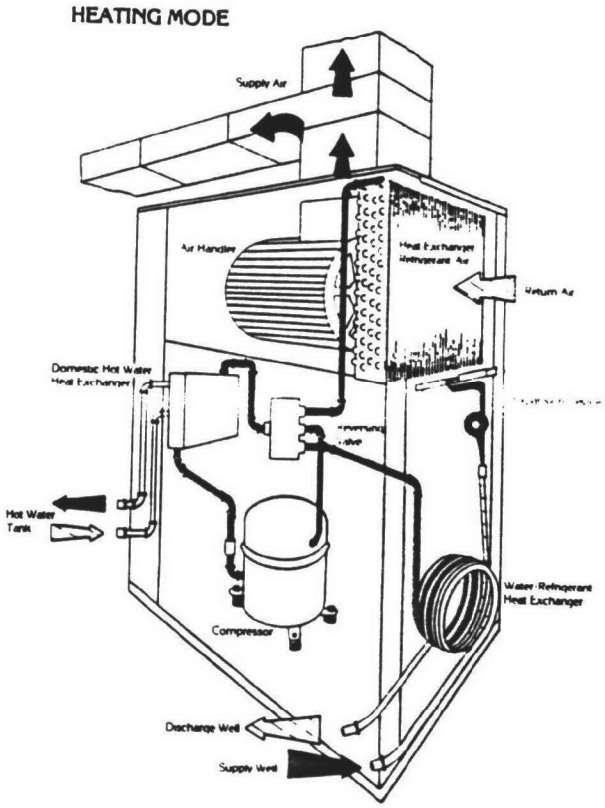


FIGURE 2. Heating mode

WHAT IS GROUND WATER?

Ground water is the water which fills pores and cracks in underground rocks and soil. Like petroleum, uranium or cobalt, ground water has economic value. But unlike other economic resources and minerals, ground water is part of the endless hydrologic cycle. Over 93 percent of the water supply in the United States lies underground, yet most of our current water supply comes from surface sources such as lakes, rivers and streams.

Ground water is replenished by nature depending on the local climate and geology and is variable in both amount and quality. When rain falls, the plants and soils take up water. Some of the excess water runs off to streams, and some percolates down into the pores and cracks of the subsurface rocks. Ground water does not flow in veins, domes or underground rivers or lakes. A water well that extends into the saturated zone will fill with water to the level of the water table—the top of the zone in which all of the openings of the rocks are filled with water.

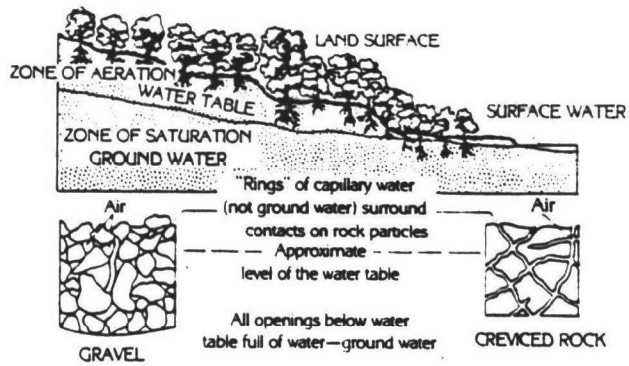


FIGURE 3. How water occurs in the rocks

WHY USE GROUND WATER?

Ground water is attractive as a potential low temperature energy source in applications such as residential and commercial space conditioning. By using a heat pump, ground water can serve as a heat source (for heating) and a heat sink (for cooling).

The temperature of the ground water is nearly the same year-round, regardless of the temperature extremes on the surface. Thus, it is warmer than the outside air in winter and cooler in summer. Since heat pump capacity and efficiency vary significantly with the heat source/sink temperature (or temperature difference between the source/sink and conditioned space), a ground water heat pump system offers considerable advantages over the more widely used air-to-air heat pump. Water will hold five times more heat than an equal weight of air and its heat content does not vary with its temperature. Air yields very little heat at temperatures below 25 F and will accept very little heat in the cooling cycle at temperatures above 85 F.

WHAT ARE THE ADVANTAGES OF GROUND WATER?

Ground water has often been preferred over surface water for development in homes or industry. Its many advantages include: low development and treatment costs; relatively constant yield and supply; constant chemical quality; sediment-free nature; constant temperature; no evaporation losses; and minimal area requirements for development. Many of these advantages, especially ground water's constant temperature, are directly applicable in considering the use of ground water as a heat source.

The demand for ground water development will increase as our population, industry and per capita needs for water increase. Ground water is often preferred by industry for

cooling and processing because of its constant cool temperatures, low cost and sediment-free nature. Small and mid-sized communities may prefer ground water for their requirements due to its low development, expansion and treatment costs.

HOW IS GROUND WATER OBTAINED?

A modern water well is not what most of us think of when wells are mentioned—a wooden bucket cranked up from a dark hole in the ground, or the old-fashioned pitcher pump that can still be found in some rural areas.

The modern water well is either drilled with a cable tool percussion rig, a rotary rig or a jetting rig. A complete, modern well system includes casing, pump and pressure tank. In some cases, filtration or chemical treatment is required where the mineral content of the ground water is unacceptable. In considering the well construction cost, you should know that the actual drilling is typically the cheapest part of the well.

A well should be located on the highest ground practicable. It should certainly be on ground higher than nearby sources of pollution. The well casing should terminate above ground and the ground surface at the well site should be built-up when necessary so that surface water will drain away from the well in all directions. A well should be located so that it will be accessible for pump repair, cleaning, treatment, testing and inspection. The top of the well should not be within a basement nor under a building with no basement. When adjacent to a building, the well should be at least 2 feet outside any projection, such as overhanging eaves.

The design and construction of a well should be adapted to the geologic and the ground water conditions existing at the site of the well.

In selecting the type of well to be constructed, these objectives should be attained: 1) the well should be adequate in diameter and depth to obtain the water available from the water-bearing formation in which the well is completed, 2) the well should be designed to leave no unsealed opening around the well which could conduct surface water, contaminated ground water or undesirable ground water vertically to the intake portion of the well, and 4) the materials that are to be a part of the permanent well should be durable. Your water well contractor can refer to well logs, records of other wells in the area, to tell him what he might expect to encounter in constructing your well. At the completion of your well he should provide you with your own well log, which should tell you, among other things, data on unsuccessful drilling, the well's actual location, its diameter, assembled order of each size and length of casing and liners, complete description of well screen, grouting depths, water levels, pumping test data and a geologic record of formations penetrated. The record should also include results of mineral analysis and bacteriological tests taken immediately after well disinfection.

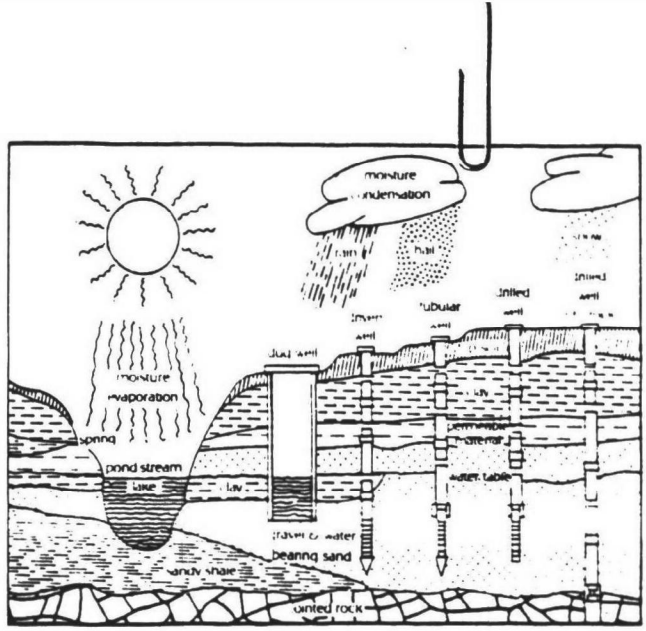


FIGURE 4. Typical cross section of underground strata, showing various types of well construction. Note that drilled well penetrating into rock formation does not require casing below bottom level of sand-and-gravel formation

A casing lines the well shaft, supporting the walls of the well and serving to keep out possible surface contaminants. The well pump is the heart of the system, moving water up from the aquifer to the faucet. Two main types of domestic electrically powered pumps are now being sold: submersibles and jets. Reciprocating pumps are also available, but are considered obsolete except for special applications. The submersible pump is placed inside the well and attached to the discharge pipe. A jet pump is generally used for shallow well applications. Usually the pump itself is not submersed in the well, but rather it is located in a clean, dry location where it won't be subjected to freezing air temperatures. Your drilling contractor or pump installer will be able to recommend the pump that best meets your needs. Submersible pumps are generally preferred for deep well applications due to their greater efficiency.

The pressure tank receives water the pump has moved. As water is pumped into the pressure tank the air at the top of the tank is compressed. When you turn the faucet on, the compressed air expands, forcing water out of the tank and into your pipes. Whenever the pressure drops below a set pressure, more water is pumped into the tank. A good pressure tank cuts pumping costs and promotes longer pump life. For ground water heat pumps, the more storage capacity, the longer the heat pump will run during its cycle, resulting in a more efficient operation.

IS THERE ENOUGH GROUND WATER AVAILABLE?

A 1976 study done by the National Water Well Association concluded that over 85 percent of the continental United States had sufficient shallow ground water resources to use the ground water heat pump for residential heating and cooling.

While ground water receives a continuous supply of geothermal energy from the earth's interior, it is also a natural solar storage facility. Heat energy from the sun is absorbed by surface water which moves through the earth's crust to the water table. This energy is stored in shallow ground water aquifers—bodies of rocks that contain usable water supplies.

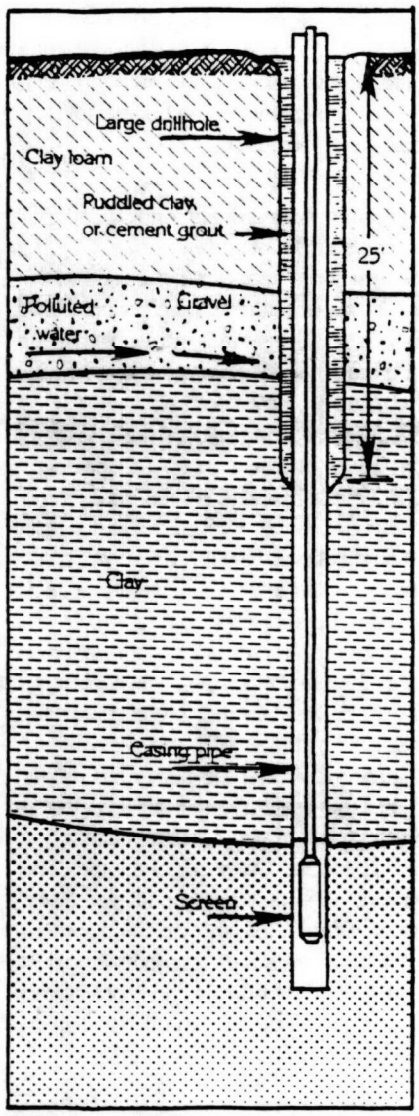


FIGURE 5. When the borehole is drilled oversize (as in rotary drilling), the empty space between casing and borehole must be sealed with a cement or clay grout. Otherwise, polluted surface or ground water may enter the water supply

WHAT IS THE TEMPERATURE OF THE AVAILABLE GROUND WATER?

The temperature range of shallow ground water in the U.S. ranges from 44 F in the north-central areas to approximately 80 F in Florida and southern Texas. In North America, ground water heat pumps can operate efficiently at ground water temperatures as low as 39 F, with equipment currently being constructed. Higher temperature ground water will, of course, put less demand on the system and make it more efficient.

In the extreme South, where the cooling cycle predominates, ground water temperatures average about 72 F. It leaves the ground water heat pump at about 85 F. Ground water heat pumps have been used for many years in Florida.

In the North, where the heating cycle is crucial, ground water temperatures average about 52 F. There is less flexibility available in severe northern climates for lowering the ground water temperature before freezing occurs. Some heat pump units are designed to operate with a very small temperature drop in the water to avoid freezing damage with supply water as cool as 39 F.

There is a potential risk of changing the ambient temperature of the aquifer where recharge or aquifer volume is limited. A ground water heat pump usually raises the temperature of the water by no more than 10 F. This water is therefore usually returned to the original aquifer with no change in water quality and only a modest temperature difference.

In the fall of 1979, the Research Facility of the National Water Well Association was awarded a grant from the U.S. Environmental Protection Agency to ascertain the environmental impact of residential ground water heat pump systems. The most significant objective of this project was the determination of the thermal impact on various types of aquifers if water that has passed through a heat pump is returned underground.

The project used a computer model to determine any thermal impact that might be expected as a result of the return of heat pump discharge water into the water supply aquifer. To limit a nearly infinite number of combinations of variables, the aquifer characteristics, well design and well spacing were kept constant for the nine evaluated test cities.

To verify the reliability of the computer simulations, the data were compared with a carefully monitored field installation located near Columbus, Ohio.

Houston, Texas, the southern most location, has the largest air-conditioning requirement and the smallest heating requirement of the test cities.

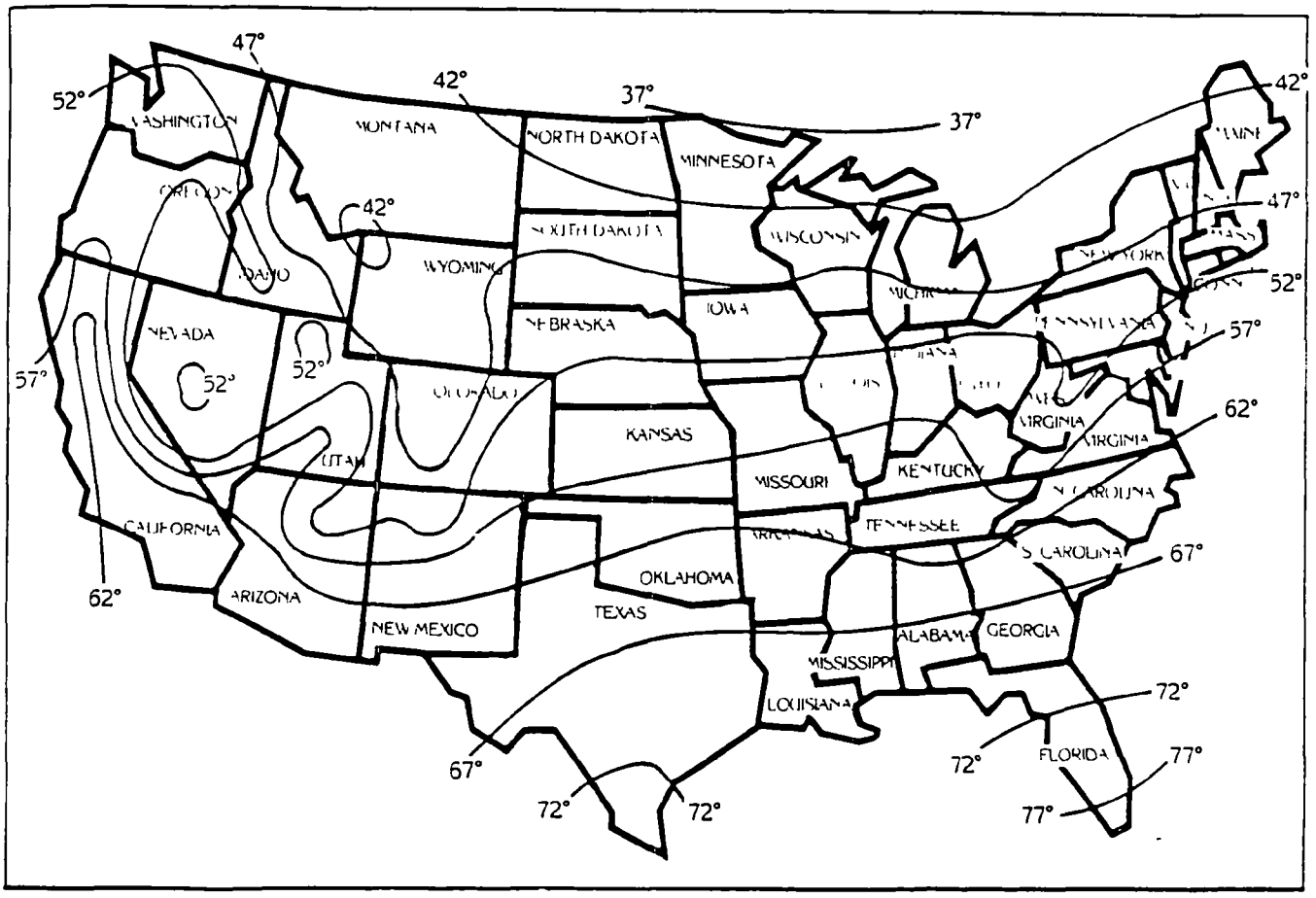


FIGURE 6 Average temperature of shallow ground water F (Popular Science)

The results found that a thermal front arrives at the production well 100 feet from the return well before the end of the third year, but it is not until the seventh year that the temperature at the production well has increased a full one degree Fahrenheit. At the end of the air-conditioning season, after 20 years of operation, the temperature at the return well is 83.3 F and at the production well it is 68.6 F. The initial water temperature was 66 F. Although the thermal front has migrated as far as 200 feet from the return well, the maximum extent of a one degree temperature change is 125 feet.

Concord, New Hampshire, the most northern location, has the largest heating requirement and a very small air-conditioning requirement. Of the nine locations studied, the greatest amount of heat would be removed from the model aquifer at Concord.

The thermal front arrives at the supply well before the end of the third year of operation. However, the temperature at the return well never changes by as much as one degree Fahrenheit during the 30 years of simulated operation. The original ground water temperature was 47 F. At the end of the heating season, after 20 years of operation, the temperature at the return well is 43.2 F and at the supply well it is 46.5 F. A change of one degree Fahrenheit never extends beyond 60 feet from the supply well.

The system in Columbus, Ohio, establishes equilibrium after five years of operation and remains constant for the remainder of the 20-year simulation. A small cold front develops around the return well in the heating season and it is replaced by a small warm front that develops during the air-conditioning season. No permanent net aquifer temperature change of any significance occurs.

Based on the simulations, measurable changes in aquifer temperatures can be expected to occur if ground water used by a heat pump is returned underground. However, the changes appear to be quite small and migration of the thermal front is somewhat limited. The temperature changes that do occur appear to have minimal effect on the water chemistry of most aquifer systems and there are no other environmental effects readily apparent.

It should be recognized that varying factors related to aquifer characteristics could have a significant impact on the results obtained. For example, if the thickness of the aquifer is 50 feet, one-half the thickness used in the simulation, the thermal front will expand at twice the rate described above. No set rule of thumb can be established for well spacing or maximum density of heat pump use. Each location must be examined on the basis of its own characteristics, according to the NWWA report.

A serious problem could develop in extremely hot or cold environments where increased ground water withdrawal may be required to meet heat exchange demands. In areas with moderate climates, the threat of thermal pollution is nearly eliminated by the balancing of recharged warmer water in the summer with cooler water in the winter. In areas like the Gulf Coast region where air conditioning is required nearly three-fourths of the year, a definite possibility exists for an increase in aquifer temperature, especially in areas where the aquifer being recharged has low permeability.

HOW MUCH WATER DOES A GROUND WATER HEAT PUMP REQUIRE?

In order for a ground water heat pump to operate at its specified heating and cooling capacity and efficiency, the proper ground water flow rate through the water to-refrigerant heat exchanger must be maintained. The ground water aquifer, well and pumping system must be able to supply the required flow rate

The water flow requirement of a ground water heat pump is dependent on its sizing (which varies over a wide range for individual home applications), its design, water flow per Btu/hour of heating (which varies over a wide range for different manufacturers) and the temperature of available ground water (which varies from 44 F in the north central states to 80 F in the extreme southern states) The requirements of heat pumps sized to provide 50,000 Btu/hr space heating output (typical sizing for an average modern home) can range from 5 to 15 gpm (7,200 to 21,600 gallons per day), depending on the design of the specific equipment. Such heat pumps can require even higher water flows during the summer if equipped with ground water heat exchangers for space cooling, and an additional water flow of 1 to 3 gpm (1,440 to 4,320 gallons per day) can be required if a separate ground water heat pump is used for water heating in the home. The required water flows for heat pumps are therefore much larger than 300 to 400 gallons per day required for domestic water supply systems.

The consumption of ground water heat pumps supplying 75, 20 and 15 million Btu/year of space heating, hot water heating and space cooling, respectively, can range from 500,000 to 2,000,000 gallons per year, depending on the characteristics of the specific equipment and installation.

Brevard County, Florida, has more than 16,000 ground water heat pump units in place, capable of pumping a combined total of 180 million gallons of water daily—three times more than the city of Orlando s total daily water use Volusia County, Florida, has 1,346 ground water heat pump systems, with a 6 16 million gallons per day capacity

The water flow requirement per ton varies with the water temperature and the manufacturer's choice of design As a very general rule of thumb, a minimum flow of about 2.5 to 3 gpm for every 12,000 Btu per hour (ton) of heating and cooling will be needed. One manufacturer says that if the ground water temperature is 55 F, the company s 3-ton (36,000 Btu) unit has a flow rate of 2.5 to 3 gpm/ton If the temperature is 50 F the required flow rate for this equipment is 5 gpm Forty-five degree water must flow at the rate of 10 gpm If the home relies on ground water for other domestic needs as well the system should be designed to handle peak water consumption

Water use restrictions are more stringent in western states. These states adhere to the prior appropriation system of water law When disputes over water use arise, priority is given to parties having senior water rights Many western states have also specified preferred uses that are given priority over other senior water rights. Eastern states generally follow riparian water law which specifies that the water flowing on or under one s land may be used as long as it is put to reasonable use Generally, a riparian landowner is not subject to quantity limitations.

Thus, ground water heat pump users are more likely to be subject to water quantity limitations in the western states However, these limitations may only apply to commercial applications since domestic use of ground water heat pumps may be considered a preferred use, exempt from most water use restrictions As yet, few states have actually defined the status of ground water heat pump systems in their statutes Their status is therefore subject to interpretation of state regulatory agencies. Most state statutes describe domestic use in similar language.

Even if your well couldn t produce adequate water, you might possibly be able to use a ground water heat pump For installations where low well yields prohibit conventional design, a freeze-protected underground water storage tank immediately adjacent to the water supply well can be used to limit well pump cycling The tank is usually buried for architectural suitability and to avoid excessive heat loss or heat gain to the atmosphere Any watertight tank with an appropriate volume is suitable Tank volume varies with heat pump water flow requirements Because of their low cost and water-holding capacity, septic tanks are often used for this application

The heat pump extracts heat energy from the water in the tank until the water temperature is lowered to a predetermined limit (for instance, 40 F) A temperature sensor then signals the well pump to begin adding warmer ground water to the tank, thus displacing the colder water which is returned to the aquifer. The well pump continues pumping warmer water into the tank until a higher selected temperature is reached

Use of a storage tank system in this manner can reduce the water well pump operating time, particularly for a reversible heat pump during spring and fall periods of frequent shifting between the heating and cooling modes However, the surface area of a small underground tank is inadequate to extract large quantities of heat from the surrounding earth, and such tanks do not significantly

reduce the maximum water well flows required for space heating with most heat pumps during severe winter weather

In some situations during the spring and fall, the heat pump can often operate solely from the water in the tank, since the house is heated at night and cooled in the daytime A general rule for sizing the storage tank is one gallon per square foot of living space to be conditioned.

HOW MUCH ADDITIONAL WATER DO I NEED FOR DOMESTIC USE?

The question of how much water you and your family will need for all of your purposes is also a determining factor in the cost of your complete well system

The capacity required of the water system depends upon the water-using fixtures and the number of people and/or animals consuming the water The most important consideration is the demand requirement. This means the amount of water required in a given period of time In a home, for instance, most of the water is used in the morning shortly after everyone awakes and in the evening around the dinner hour Motels and hotels have similar demand periods

Peak periods usually last from 30 minutes to two hours During this time, water systems must meet the demands of those using the system This means the combination of the well, the storage tank and the pump must produce the water continuously Special or emergency demand required for firefighting purposes should also be planned for farm installations For home installations, the demand period lasts for about one hour

If the rate of flow required during the demand period exceeds the maximum rate at which water can be drawn from the well, the difference must be made up in storage capacity This must be accomplished so the user will continuously obtain water under pressure.

Water Uses	Peak Demand Allowance for Pump	Individual Fixture Flow Rate
	gpm Column 1	gpm Column 2
Household Uses		
Bathtub or tub-and-shower combination	2.00	80
Shower only	1 00	40
Lavatory	50	20
Toilet—flush tank	75	30
Sink, kitchen—including garbage disposal	1 00	40
Dishwasher	50	20
Laundry sink	1 50	60
Clothes washer	2.00	80
Irrigation, Cleaning and Miscellaneous		
Lawn irrigation (per sprinkler)	2.50	50
Garden irrigation (per sprinkler)	2.50	50
Automobile washing	2.50	50
Tractor and equipment washing	2.50	50
Flushing driveways and walkways	5 00	100
Cleaning milking equipment and milk storage tank	4 00	80
Hose-cleaning barn floors, ramps, etc	5 00	100
Swimming pool (initial filling)	2.50	50

TABLE 1

WHAT ABOUT WATER PUMPS AND PIPING SYSTEMS?

Choosing a proper well pump is very important. Two main factors will determine the proper size for the pump—water system demand in gpm and depth from the pumping level to the level of use. In practice, pump installers prefer to oversize a well pump somewhat rather than to undersize it to allow for increased demand in the future. An oversized well pump will be more rugged and will compensate for friction loss in the pipes, fittings and elbows and heat exchanger. Skilled contractors can size the pump to precisely meet the demands of the system for maximum efficiency.

The pipes that deliver ground water to the heat pump and back to the recharge structure should be sized for the required water flow and the lowest friction loss. If smooth pipe, such as copper or plastic, is used the friction loss will be lower than that for steel pipe at any given size. Plastic is attractive in many installations due to its lower cost, low friction loss and resistance to both corrosion and incrustation.

Water supply lines from the well to the building need not be insulated if protected from freezing by burial below the local frost line. Freeze protection may be assured by using pitless adapters on the well when possible or other freeze protection means above the frost line. Where long runs of horizontal pipe are required from the supply well to the building, they should be insulated with at least 1/2-inch thick water-resistant insulation suitable for underground use, together with placement below the frost line to minimize heat loss and loss of efficiency. Return lines need not be insulated, but they must be placed below the maximum anticipated frost depth. Supply and return pipe lines should be separated enough to prevent heat exchange from taking place between the two. Many times the well drilling contractor or pump installer has installed the offset pipe just below the frost line where the temperature of the earth may be 33 to 36 F. This can be determined by checking the water temperature at the well and in the house. If the difference is greater than three degrees, a new offset pipe should be buried at least 8 feet in depth. If you ignore the seasonal differences in water temperature, however slight, it will sabotage your installation.

Copper pipe should not be run directly to the unit. Plastic pipe is recommended for noise reduction and insulation qualities. If hose is used, it should be capable of handling the pressure. Flow valves should be installed where they will not be heard. On the return side, the discharge should be allowed to fall by gravity as much as possible to help reduce pumping costs and pressure drop.

Most of the controls and protective devices necessary for efficient and safe ground water heat pump operation are provided by the manufacturer and are located within the heat pump enclosure. Usually the only control that the contractor must install, connect and adjust is the room temperature thermostat that has been supplied or recommended by the manufacturer. If a water storage tank is installed, the contractor must also install the tank temperature control. Most of the electrical connections are self-contained and prewired with the heat pump unit. Most heat pumps require a 220-volt, 60 hertz power supply from a separate circuit breaker and the main circuit box. Current, an important factor, will often vary from manufacturer to manufacturer. Individual manufacturer's ratings should always be consulted.

To avoid corrosion, be certain that copper and aluminum wires have not been wired together. All connections should be checked to make certain they are secure. Proper disconnections and fuses are essential. A disconnect switch should be placed near the unit and the well pump should have its own fused disconnect as well.

HOW CAN I LEARN IF MY WELL WILL SUPPLY ENOUGH WATER?

The best source for this information is a qualified, professional water well systems contractor. In selecting such a person or firm, you will be putting your trust in a person who has the knowledge and equipment to properly construct, develop and test your well. He is also familiar with state and federal requirements concerning well location in regard to septic tanks, drain fields, surface water and other wells.

In most cases, the water well contractor has many years of experience in the area in which he operates. He has made a large investment in sophisticated equipment. In some instances, the contractor himself may be a geologist or hydrologist, or may retain such a scientist on his staff. If not, he has many other sources of technical information at his disposal. First and most important among these technical information sources is his file of well logs—records of your well or other wells drilled in the area. These will help advise you of the approximate depth of your planned well, and can help predict the quality of the water you can expect. However, a drilling contractor cannot accurately predict what quantity or quality of water a new well will yield. No one can.

Most domestic wells are drilled less than 200 feet deep. Formations can vary in permeability, and therefore in yields. Even though a neighbor's well yields 15 gpm, the well in question may not produce that amount for several reasons. The construction of the two wells may not be the same: perhaps the well screen openings or slots are of different size or the screen is of a different length. Construction alone does not affect well yield. If a well is not

properly developed, the yield will suffer Yet another important item to consider is the presence of other wells in the area If a neighborhood already has a substantial number of wells drawing from a low-yielding aquifer, the addition of more high-demand wells might cause problems for all concerned parties

Before you make a financial commitment with a contractor ask him the following questions on well construction

• What will be the well's finished diameter and depth?* This can affect the cost of the well and the amount of water it can produce

• How much and what kind of well casing will be required?* Local sanitation codes may dictate how much steel or plastic protective casing must be used The final casing length will depend on the depth of the well and geologic conditions at the site

• If a well screen is required, what kind will be used? This will depend on the kinds of geological formations found in your area Screen selection is very important and you generally get what you pay for

• How will the well be disinfected to ensure high-quality drinking water (if being used for domestic use in addition to heat pump use)?

• After the well is drilled, how will it be developed to produce an optimum amount of water?

• How will the well be sealed?

• Will the contractor furnish an accurate well log or record when the work is completed? A good well log provides detailed information on all aspects of your well's construction It will be essential years later if repairs or maintenance are required

• Will further treatment in the home be necessary after the well is completed? Water treatment equipment can range from a simple filter to expensive water conditioning systems Find out in advance how much water treatment is likely to be required in your area

Ask a prospective contractor to itemize his cost estimates as follows drilling—cost per foot; casing—cost per foot, cost of other materials (drive shoes, screens, seals, etc), cementing, developing, pumping equipment, test pumping, and water treatment equipment

When you need a water well, or work done on your present well, consult your local water well contractor first He is the best qualified individual If you do not know a local contractor, contact local agricultural agents, suppliers of well equipment, neighbors or the National Water Well Association, 500 W Wilson Bridge Road, Worthington, OH 43085, (614) 846-9355

The contractor you select should consider all relevant factors when designing and testing a well for ground water heat pump use A well supplying a ground water heat pump must be able to produce an adequate supply of water for an extended period of time, perhaps as long as 20 out of 24 hours for up to 10 days at a time If the water demand is not only for the heat pump, but may also include the dishwasher, shower or water softener backwash at the same time, the total household demand may double the demand of the ground water heat pump alone Many existing wells may not be properly developed This means that the well screen was set in an inadequate aquifer or it was set too shallow in a good aquifer When in doubt, have the well drilling contractor perform a pumping test to qualify or disqualify the well If a water problem is to occur it most likely will happen during the months of January and February when the demand on the well is the greatest

Therefore, testing becomes a very important part of completing the well The usual methods of bailer testing or pumping into a bucket are now inadequate Insist that your contractor conduct a three-part test to establish the maximum flow and the specific capacity of the well Specific capacity is the yield of a well expressed in gallons per minute of flow for each foot of difference between the static water level (depth to the water in a well that has not been pumped for at least 24 hours) and the pumping level (the depth to the water in a well while the pump is running) The three parts to a proper well test are constant rate test, recovery test and step test If your contractor follows these procedures, you can be confident that the yield figures your contractor determines will be accurate Remember, once a well is drilled and developed the safe yield of the well is fixed. If a well is producing, for example, 5 gpm it cannot be forced to produce 10 or 20 gpm by adding a larger well pump The yield of a well is controlled by the permeability of the aquifer and not the size of the pump Also, well screens are a must for sand and gravel geology to maximize yields and prevent the pumping of sand Well yields may drop over time due to incrustation This can be minimized through proper maintenance

MUST THE WATER BE TREATED OR SOFTENED BEFORE IT PASSES THROUGH THE GROUND WATER HEAT PUMP?

Poor water quality containing high concentrations of iron, calcium, magnesium, salts and other dissolved solids may cause scaling and incrustation in the heat exchanger piping. Corrosion of the water side heat exchanger by aggressive water," which appears to be a greater problem than incrustation, is inhibited by the

*A contractor cannot always determine in advance the depth at which an adequate water supply will be found Neighboring wells offer some assistance but no definite assurance

formation of an oxide or hydroxide film Any ground water constituent that prevents the formation of this film or removes it will cause degradation of the metal Hydrogen sulfide is the most common corrosive agent with the water-side heat exchangers Although the cupro-nickel alloy (No 706) heat exchanger is more resistant than the copper variety to mechanical erosion and corrosion by brackish waters, neither metal shows acceptable resistance to dissolved hydrogen sulfide Concentrations as little as 0 5 parts per million are known to cause corrosion of the metals The use of a stainless steel heat exchanger will help deal with this problem

Chemical incrustation has not been a significant problem in existing installations of ground water heat pumps Every new, modified or reconditioned water well, including pumping equipment, should be disinfected before being placed into service The well and pumping equipment should be disinfected with a chlorine solution made up of one part household bleach (sodium hypochlorite 6 percent) and two parts water. Two quarts of this solution should be poured into the well for each 100 gallons of water in the well. Biological incrustation, if encountered, is likely to be a problem throughout the entire domestic water supply system If bacterial infestation and subsequent blockage of the heat exchanger is a chronic problem, water treatment at the well before the water passes through the heat exchanger would be required. Due to the large volume of water used, conventional treatment would substantially increase system operating costs. A periodic maintenance program or chemical feed at the well can minimize this perplexing problem if it appears However, in some states regulations may prohibit the return of the water to the aquifer if it has been chemically treated. Contact your local authorities to be safe

Strongly acidic water can cause deterioration of copper tubing. Ideally, the pH level of the ground water should be between six and eight, and the hardness reading (on the standard 0-30 scale) no higher than 10 Many ground water heat pump manufacturers design their equipment to reduce the effects of poor quality water, and most manufacturers provide optional features for applications that require special considerations.

One way to prevent scale and increase resistance to acid deterioration is to use cupro-nickel instead of copper tubing, and it is now the industry standard. The cupro-nickel expands and contracts with temperature changes, and its surface tends to flake off mineral deposits and scale with each cycle In addition, the cupro-nickel alloy is corrosion resistant to nearly all ground water However, while the cupro-nickel alloy is more resistant than copper to mechanical erosion and corrosion by brackish waters, neither metal shows acceptable resistance to dissolved hydrogen sulfide. Concentrations as little as 0 5 parts per million are known to cause corrosion of the metals and stainless steel may be required

When installing a ground water heat pump in a house with a water softener, be sure that the unit s water supply has been brought off the incoming water pipe at a point where it is not using softened water This is to avoid depleting the softener s salt supply because of the high amounts of water used to operate the heat pump

Considering these factors, it is not necessary to circulate your ground water through your home s water treatment equipment before it enters the heat pump, but have your water analyzed by a laboratory before making your investment.

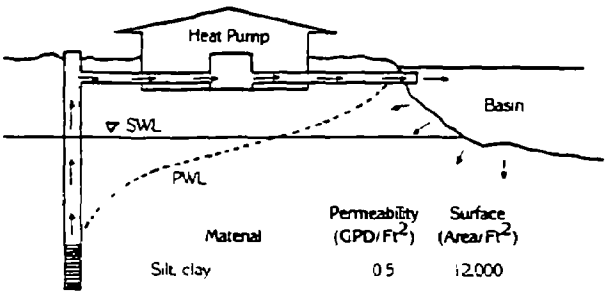
Even in areas where ground water is not of drinking water quality ground water heat pump applications are possible The heat pump can merely 'borrow the ground water for a time and return it to its original source, withdrawing (or adding) only heat in the process, not the pollutants.

If the practice of using polluted water for ground water heat pump applications is employed, it is crucial that the ground water be returned through a properly constructed return well to its original source This practice is essential to avoid unnecessary pollution of drinkable water.

WHAT DO I DO WITH THE WATER AFTER IT HAS BEEN USED BY THE HEAT PUMP?

A ground water heat pump does not consume any water in the heat exchange process If eight gallons of water go in the heat pump, eight gallons of water will come out. Thus, you will need a method to discharge this water

Typical methods of discharge include returning the water to the aquifer from which it was extracted, secondary use of the water, such as industrial process applications or agricultural uses, evaporation and/or seepage ponds; and discharging to sewers, ponds, streams, rivers, lakes or the land surface Naturally, it would be desirable to have



Material	Permeability (GPD/Ft^2)	Surface (Area/Ft^2)
Silt, clay	0 5	12000
Very fine sand	16 0	375
Fine-medium sand	300 0	20

FIGURE 7 Recharge basins

plumbing installed to allow for secondary use of the discharge water, if this is permitted, such as for lawn and garden watering when the ground conditions warrant it.

Most sewer systems cannot handle the large volumes of water which ground water heat pumps can produce (up to 10,000 or more gallons per day). Sewer lines may backup. Tile fields will become overloaded. While ponds could be attractive and have multiple uses, they consume large amounts of land area, which would restrict their potential use in more densely populated areas. Discharge to the land surface may create bogs, accelerate pollutant-leaching into ground water and form icy areas in the winter. In addition, surface discharge in some areas may accelerate sinkhole activity. Disposing of the water to a stream, river or lake may be effective, but your local government may have specific regulations dealing with this issue. If the ground water used in the heat pump was of poor quality, discharging it to higher quality water will contaminate those sources. Also, heating ground water may raise the temperature which would be harmful to surface water dwelling creatures. Check with your local authorities before making your decision.

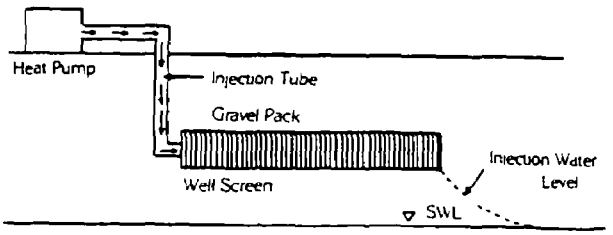
In close quarters, care must be taken so that the discharge doesn't infringe on a neighbor's property. Often, local ordinances prohibit any kind of discharge, and although variances can sometimes be obtained, they can be costly and time-consuming.

The disposal methods preferred by the National Water Well Association, from a water conservation standpoint, are secondary use of the water and returning the water to the production aquifer.

When returning the water to the original aquifer from which it came, the water should remain in a closed system. There are several methods for returning the water to its aquifer. They are: using a single well for supply and disposal; using two wells and alternating withdrawal and disposal between the wells in winter and summer; and using two wells, but not alternating their function.

• **Single well**—For return of water in a supply well, approximately 100 feet of vertical separation is required for every 12,000 Btu of heating or cooling produced per hour. A typical domestic heat pump unit, with a 60,000-Btu capacity, would require 500 feet of separation in the well from the point of disposal to the point of supply. If 100 feet of vertical separation is needed, it probably would be unadvisable to use this system. Higher drilling and pumping costs could make this system impractical in many areas. Also, local regulations may restrict the use of a single well for both potable water and return.

• **Alternating two wells**—This method could take advantage of any temperature variations which may exist in the ground water from this process. In winter, a return well injects cooler water back into the aquifer. In summer, the return well (now acting as a supply well) could withdraw this cooler water from the aquifer for more efficient cooling. The second well could be used in a similar way for warmer water. Alternating supply and return may also be beneficial as a preventive maintenance measure. This alteration in each well helps prevent clogging of the well screen, a common problem. This method of design is rarely practiced, probably due to its larger initial investment. The system would require an additional pump (one per well) and more piping compared to other systems.



Material	Permeability (GPD/Ft^2)	Well Screen Length—(Ft)
Silt, clay	0.5	12,000
Very fine sand	16.0	375
Fine-medium sand	300.0	20

FIGURE 8. Horizontal disposal well.

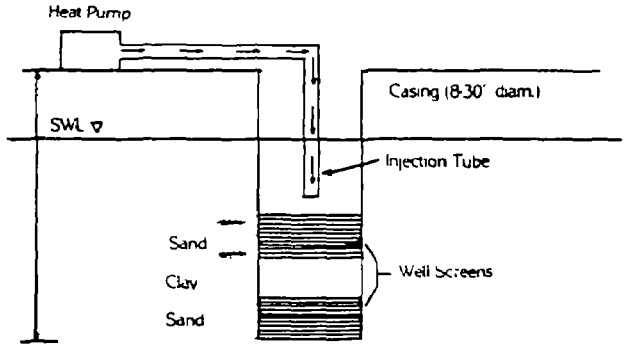


FIGURE 9. Shallow, large-diameter wells.

• **Two well system (non-alternating)**—A general rule to follow is to drill the return well to the same aquifer at the same depth as the producing well. Return wells in sand and gravel aquifers must have a screen to help prevent incrustation and facilitate water movement. Water is always returned below the water level to reduce precipitation of dissolved solids on the well casing.

If a return well is drilled, it must be placed far enough from the supply well to prevent an overlapping thermal effect between the two wells. Raphael G. Kazman, in his report, Use of Twin Wells and Water-Source Heat Pumps for Energy Conservation in Louisiana, created a table for use by the project engineer or designer to approximate the needed spacing between the production and return wells. These wells alternate their roles. The well used for

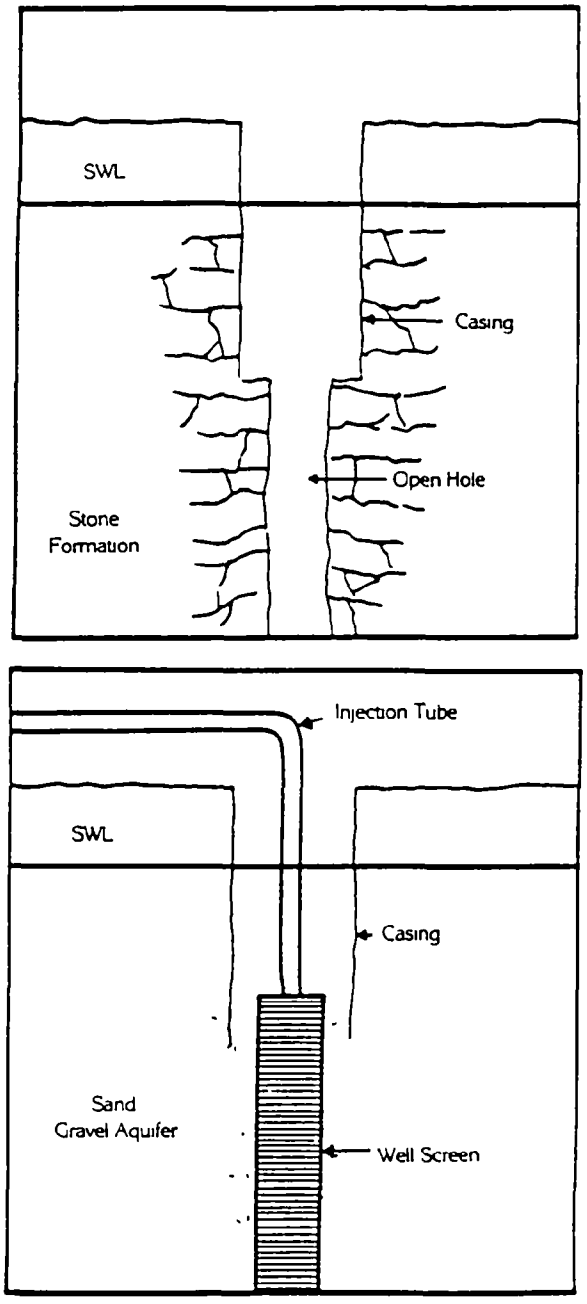


FIGURE 10. Well recharge small-diameter disposal wells

production in the summer is used for return in the winter and vice versa. Kazman reported that if each house in an entire housing development were equipped with twin wells and heat pumps, the return water of one property owner might be pumped by his neighbor The studies he conducted indicate that to maintain the same well discharges without danger of interference with neighbors, the spacing between the twin wells must be increased, possibly as much as 20 percent or more. To minimize interference and short-circuiting between neighboring sets of twin wells, the summer well should always be located on the street side of any lot and the winter well should be drilled in the backyard, he says

Two wells, even in the same aquifer, keep the temperature difference separate, if properly spaced, because underground water flows so slowly The spacing of the supply and return wells is dependent upon several variables, among which are· 1) selection of the optimum ground water heat pump based on available well capacity and operating cost, 2) the length of the critical season of operation (overall duration of the heating season in the North, air-conditioning season in the south), 3) the actual number of days that the heat pump will be called upon to operate and the percentage of time during those days that it will actually be in operation 4) the aquifer characteristics *permeability, thickness and specific* capacity Spacing the supply and return wells at least 100 feet apart is best for most locations For good aquifer conditions, this spacing might be less, while greater spacing may be necessary for poor aquifer conditions. The return well has to be constructed as well as, or better than the supply well—it is not just a dumping hole Theoretically, an aquifer will accept the same amount of water that it will yield In reality, however, it will only accept 75 to 80 percent of its yield in return Therefore, an aquifer that will yield 18 gpm will only accept approximately 14 gpm and the remaining 4 gpm will run out on the ground The contractor and homeowner should be concerned about the possible plugging of the return well by deposits of sand or high amounts of iron being present in the ground water Air dissolved in the water can also induce corrosion.

It should be noted, however, that in aquifers with low permeabilities, gravity feeding of return water may not provide sufficient pressure to allow infiltration into the aquifer

If the discharge water is returned to an aquifer other than the supply aquifer and the two aquifers are separated by a thickness of low-permeability material, interference should be minimal or nonexistant. Supply and return aquifers must be chemically compatible to assure that mixing of the two water types does not result in precipitation of salts or hydroxides from solution, which might lead to eventual plugging of the aquifer surrounding the return well.

Local policies vary widely concerning the use of return wells. Several states, including Wisconsin and Minnesota, do not allow any type of underground injection or return at this time. Several others have adopted a general policy to discourage this type of disposal method. On the other hand, Oregon encourages return of this water Many of the other states have some form of permit or notification procedure Enforcement is often lax, however particularly for small domestic systems. Regulatory agencies commonly have statutory authority to regulate these systems but no formal program. More than one-third of the states have no permit or notification requirements.

Regulations for return of water to surface water generally correspond to the federal National Pollutant Discharge Elimination System standards Disposal to a leach field and septic tanks is generally not a problem, but

is usually not recommended However, many states require that septic tanks be spaced a certain distance (generally around 50 feet) from a well Disposal to sewers is regulated on the state level in only four states The state of Minnesota, for example, had forbidden for many years the use of any type of return well However, the law was amended in late 1981 to allow the construction of a minimum number of return wells Provisions of the law said that the wells must withdraw from and return to the same aquifer, the wells must be constructed so as to allow for inspection of water quality and temperature, the system must be constructed as a completely closed system which is sealed against the introduction of foreign substances and the owner must agree to allow inspections by the health department The law does not allow for a domestic supply well to be used in conjunction with a ground water heat pump

Meanwhile, officials of Satellite Beach, Florida, rescinded in early 1982 an ordinance that required homeowners with ground water heat pumps to also have a return well In March 1981 the council had approved a law requiring the return well But council members said the cost was prohibitive to homeowners

Again, the point is check with your local officials

WON'T I BE IN DANGER OF DEPLETING MY PROPERTY'S GROUND WATER SUPPLY, NOT TO MENTION MY NEIGHBOR'S, IF I HAVE A GROUND WATER HEAT PUMP INSTALLED?

Most problems regarding heat pump dewatering have stemmed from improper determination of well yield Domestic wells are normally designed to produce enough water for household use only, which is usually 300 to 400 gallons per day Ground water heating may require 10,000 gallons of water or more per day in extremely cold weather. An adequate water well design for household usage may not be sufficient to also sustain a heat pump

Uncontrolled overpumping and overdevelopment of the ground water may cause problems such as aquifer drawdown and well interference. Aquifer drawdown indicates that more water is being withdrawn from the aquifer than is being replaced and usually manifests itself by smaller yields and lower water levels in wells Pumping a well usually creates a cone-shaped depression of the water table (the two-dimensional surface representing the top of the ground water), with the lowest point on the cone being the well location where the water is being pumped With overpumping, two or more closely spaced wells may see an overlapping of their individual cones of depression This is called well interference and also is reflected by lower well yields, as some of the available ground water must now supply two or more wells instead of one

The way to prevent water level declines is not to pump water to waste when the well is used to supply water to the heat pump, but to use it and then return it to the aquifer through a return well

The spent water, which may have been used in the summertime to remove heat from the interior of a building, will be warmer than the native ground water In the winter on the other hand it is cooler that the source of ground water

The spent water, if returned too close to the production well, will break through or shortly appear in the production stream Thus, if the volumes pumped during each season are nearly equal, the temperature of the ground water will not change significantly even after a decade or more of operation.

Where the water is returned into the same producing aquifer by way of the supply well or a second well, no aquifer drawdown or well interference will occur

Management of the heat balance within an aquifer is essential in urban areas where heat transfers between several users may have to be coordinated Spacing of private domestic wells is likely to depend on property boundaries rather than the hydrologic characteristics of the aquifer under development Random installation of ground water heat pumps could lead to thermal interference through improper well spacing Efficiency of the heat pump system would be considerably reduced where a sufficient amount of interference exists.

Through careful planning and analysis of the aquifer prior to housing construction, it is possible to avoid the problem of well interference Production and injection wells can be spaced for optimum dissipation of thermal energy within the aquifer Well spacing should be based on the heating and cooling load for the proposed number of residential units to be built at a given location, as well as the hydrologic properties of the aquifer to ensure the efficient utilization of ground water for the operation of ground water heat pumps.

Thus, it is crucial that the well yield be correctly and accurately determined by a qualified contractor

HOW EFFICIENT ARE GROUND WATER HEAT PUMPS? HOW DO THEY COMPARE TO OTHER HEATING METHODS?

The efficiency of a heat pump is measured by the number of units of heat energy output (Btu) obtained for each unit of heat energy input (kilowatt) This is called the Coefficient of Performance (COP) The COP is a measure of heat pump efficiency; the higher the COP, the more efficient the heat pump By precise definition, the COP is the heating output divided by the electrical energy input, which can be written as. COP = H_p/E for the heating mode.

The COP of a heat pump is more than one because the heat energy in pumps exceeds the input electrical energy it consumes. Energy efficiency ratio (EER), an alternative measure of cooling performance, is defined as the Btu per hour of useful cooling per watt of electrical power input. The EER is equal to the COP (a dimensionless index of performance) multiplied by 3 412.

Conventional heating systems generally have lower accepted COPs than ground water heat pump systems Some average seasonal COPs of those systems under ideal circumstances are listed below

Electrical resistance furnace	1.0
Natural gas furnace	0.80
Coal furnace	0.60
Fuel oil furnace	0.70

In other words, a conventional natural gas furnace system, for every 100 Btu of energy it consumes, produces 70 Btu of heat, or has an efficiency of about 70 percent if properly maintained. Heat pumps, on the other hand, normally have COPs greater than one An air-to-air heat pump typically has a COP of 1 5 to 2 0. The fact that heat pumps typically have COPs greater than one seems to contradict the laws of nature since more energy comes out of the heat pump than we put in. Actually, this is not the case because a heat pump merely uses electrical energy to transfer 'free' thermal energy from the outside air or from ground water

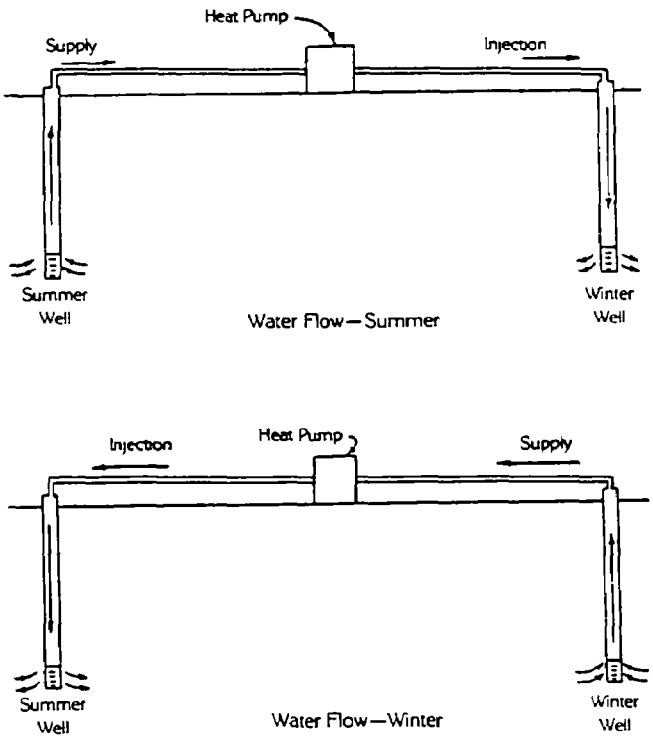


FIGURE 11 Schematic diagram of water source heat pump wells

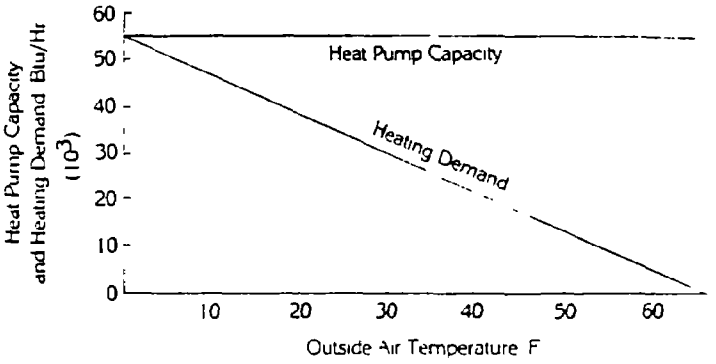


FIGURE 12. Hypothetical heating load vs. outside air temperature ground water source heat pump

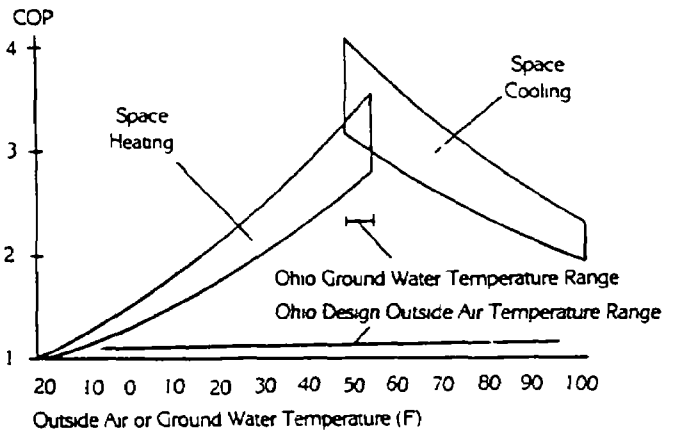


FIGURE 13 Typical heat pump performance trends

Ground water has been called 'nature s most efficient energy storage system " In addition to the advantage of high specific heat, which was discussed earlier, ground water s temperature varies little with the seasonal weather changes It is warmer than the air in winter and cooler than the air in summer Therefore, the heat pump output is also relatively constant year round It is for this same reason that the performance of the air to-air heat pump varies more than that of a ground water heat pump system since the temperature of the air source is dependent upon outside weather conditions When air source heat pumps operate in extreme temperatures they consume large quantities of electricity in order to operate effectively and must often rely upon a back up heating method (such as electrical resistance strip heating) during the winter to provide a comfortable home temperature Ground water heat pumps under operating conditions are about 25 to 75 percent more efficient than air-to-air heat pumps operating under optimal conditions *

An example of the efficiency of the ground water heat pump is thus illustrated. An average house of 2,000 square feet of living area requires about 360,000 Btu per day for heating. Using a ground water heat pump with 45 F ground water and an outside air temperature of 20 F, it requires about 28 8 kilowatt hours (kwh) per day to heat the home to 68 F, while the usual energy requirement for an electrical resistance heating system would be 108 kwh per day For every kilowatt hour of energy put into the system, you would be getting 3 6 times the Btu per hour out. Thus, the ground water heat pump s COP is 3 6

In the cooling mode, reversing ground water heat pumps are often rated on the basis of an energy efficiency ratio (EER). EER also represents output divided by power input, which makes the high number desirable. EER ratings for air to-air heat pumps fall between 6 8 and 9 0 Ground water heat pumps can reach EER ratings of 13 or more

The following chart compares the COPs of the various systems and also shows the relationship between the energy input (what you buy) and the energy output of the system The energy output of the system is the energy input multiplied by the COP Note that the average COP of a ground water heat pump is significantly higher than the air to-air heat pump

System	COP	Energy Input	Energy Output
Electrical resistance	1 0	100	100
Fuel oil	70	100	70
Propane	75	100	75
Natural gas	80	100	80
Air-to-air heat pump	1 5	100	150
Ground water heat pump	2.8	100	280
Reversing ground water heat pump	3.2	100	320
Direct cooling	20 0	100	2,000

*Computer simulations conducted for the U S Department of Energy study Ground Water Heat Pumps An Examination of Hydrogeologic Environmental Legal and Economic Factors Affecting Their Use determined that the ground water heat pump uses 20 to 60 percent less energy for heating than the air source heat pump

The higher the COP the lower the annual operating cost of the system will be In comparison, 100 Btu of energy will produce 320 Btu of heat from a reversing ground water heat pump but only 75 Btu from a natural gas furnace. This reduction in annual operating costs offsets the higher initial costs of a ground water heat pump system

A computer simulation by the National Water Well Association of currently available ground water heat pumps located in nine cities throughout the United States predicts annual COPs ranging from 2.2 in Concord, New Hampshire (where 94 percent of the energy load was for heating), to 2 9 in Birmingham, Alabama (where approximately 50 percent was for heating and 50 percent for cooling) In Concord, only 10 percent of the total energy consumed by the ground water heat pump system was used for supplemental electric strip heat whereas an air to-air heat pump required 40 percent for the same purpose By simulating a heat-only ground water heat pump and using direct heat-exchange cooling (with ground water) energy requirements were reduced 30 percent compared to the reversible cycle ground water heat pump This is a result of sizing to full heating design load rather than cooling load. With this strategy, the use of supplemental electric strip heat can be substantially reduced or eliminated. However, some suggest that the use of supplemental electric strip heat, which will probably only be needed for a few days a year, should be less expensive than greatly increasing the size of the heat pump system

HOW RELIABLE ARE GROUND WATER HEAT PUMPS?

A properly designed ground water heat pump system is reliable because it is never exposed to extreme operating conditions. Air-to-air heat pumps are calculated to last 10 years because of their exposure to the outdoors.

The compressor is an important part of any heat pump Its main function is to pump refrigerant vapor (Freon®) from a relatively low suction pressure to a higher delivery pressure The suction and delivery pressures are a function of the heat pump design and ground water temperature A large difference between the suction and delivery pressures will force the compressor to work harder for the same flow rate This requires more electrical input and places higher mechanical stresses on crankshafts, bearings and valves.

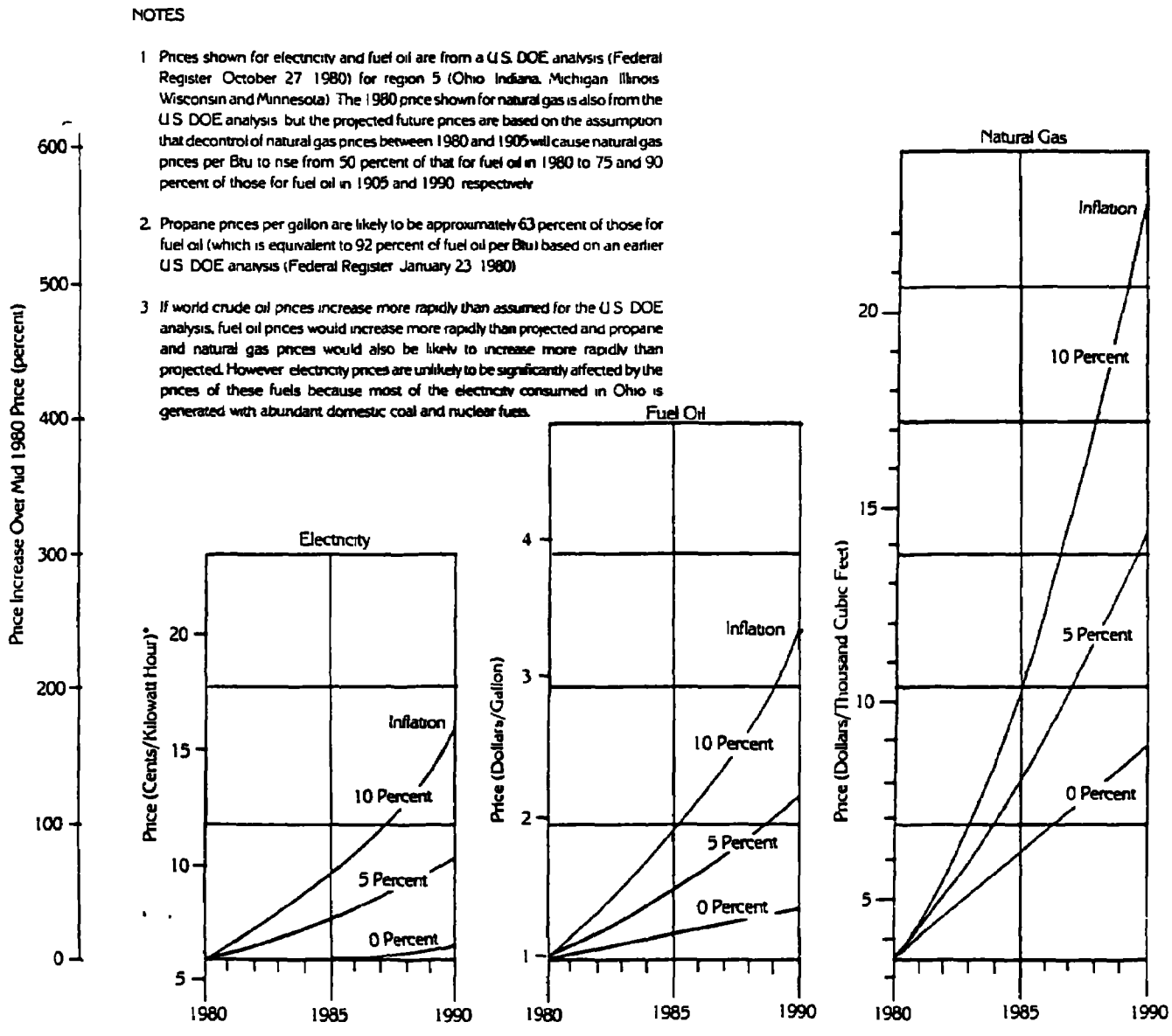
High stresses often caused compressor failures in the earliest heat pump models In recent years, however compressors with better bearings and improved valving have

been developed. Improved motor insulation has also been developed, and better motor cooling methods are being used In short, compressors are more rugged and are protected by better controls There should be a fail-safe control system to ensure that the compressor is turned off if water pressure fails. Without this it is possible to freeze and subsequently destroy the heat exchanger

The extra durability of today s heat pumps has lessened the requirement for numerous protective devices and reduced the number of parts that can cause problems. For example, 20 years ago heat pumps had many relays, today, most have only three

According to some manufacturers, systems with a thermostatic expansion valve for refrigerant metering are preferable to those with capillary tube metering because they are adjustable for optimum operation under various conditions

The reliability of ground water heat pumps has clearly improved, as evidenced by a preventive maintenance and service program conducted by the American Electric Power Co in which detailed maintenance reports were shared by individual heat pump manufacturers between 1961 and 1976 The findings showed that heat pump annual maintenance trendline values declined in each five-year



*Night off peak power is likely to be available at 40 to 60 percent of prices shown.

FIGURE 14 Projected future Ohio residential energy price trends

interval from 1957 to 1976 for service both in and out of warranty

Compressor failures constituted the major percentage of maintenance costs for individual components of the heat pump, followed by fans, refrigerant leaks and flow controls Today, some ground water heat pump manufacturers will offer compressor guarantees of 10 years Most offer at least a five-year guarantee

Yet another indication of improved ground water heat pump reliability is its sales volume history Shortly after 1952, the year ground water heat pumps were first made commercially available sales were slow but increased steadily until about 1963 Then as a result of a high number of heat pump failures in the 1950s models, sales growth nearly came to a standstill The ground water heat pump industry hung tough and worked to improve its product The industry corrected its faults and as a result, ground water heat pump sales have risen sharply since the early 1970s and continue to grow

IF GROUND WATER HEAT PUMPS ARE SO TERRIFIC, WHY DIDN'T PEOPLE USE THEM LONG AGO?

The basic principle of the heat pump was first proposed by Nicholas Carnot in 1824 This theory was advanced 30 years later when Lord Kelvin proposed that refrigerating equipment could be used for heating Because of cheap, readily available fossil fuels, the heat pump remained a researcher s curiosity until the mid 1930s when several manufacturers designed custom systems using the heat pump principle for comfort heating. Following the delays caused by World War II, commercial production of heat pumps began in 1952 and production and use has continued to grow since

THEN WHY AM I JUST NOW LEARNING ABOUT GROUND WATER HEAT PUMPS?

Most homes have natural gas, fuel oil, or propane space and hot water heating systems Much of this equipment is relatively inefficient, primarily because these fossil fuels were abundant and cheap when it was installed Subsequent fuel price increases have significantly increased the cost of heating with these systems

The Arab oil embargo of the early 1970s finally made America realize that it had to reduce its energy consumption and costs When gasoline was 35 cents a gallon (and fuel oil about the same), and electricity was a penny to 2 cents a kilowatt hour, it didn t make much difference in energy savings to a homeowner whether he installed an oil furnace natural gas furnace, air to-air heat pump or ground water heat pump, except that ground water heat pumps cost more to install Now with residential heating oil at $1 21 or more per gallon, natural gas at over $4 50 per thousand cubic feet and electricity at 6 5 cents per kilowatt hour it makes an important difference to every energy consumer *

In addition according to the National Water Well Association there has been a general ignorance about ground water Many mistakenly believed ground water resources were limited. Also, many believed ground water heat pumps were only able to utilize ground water of 60 F or warmer; ground water contained chemicals which would promote corrosion or scaling of the heat exchanger ground water flowed in underground rivers or veins, requiring a water witch to locate them Of course, as we have already shown and explained, all of these beliefs were false

The reason air to-air heat pumps are so widespread is not that they are better—they are not. It is simply because the air is right there, surrounding us We are not really sure the ground water is there, unless we see it flow from the well

*Some homeowners might therefore benefit from investing in modifying existing equipment to increase its efficiency or replacing it with one of the more efficient systems now available—the ground water heat pump—especially if the existing equipment is near the end of its useful life (which is usually about 20 years for furnaces)

I HAVE A 20-YEAR-OLD HOUSE. CAN A GROUND WATER HEAT PUMP BE RETROFITTED?

Retrofitting ground water heat pumps is certainly possible However, each application must be surveyed and information reviewed before making the final determination of materials and methods. It is possible that under certain pre-existing conditions the necessary revisions for retrofitting will make the use of a ground water heat pump less economically attractive to the homeowner

The University of Dayton (Ohio) Research Institute studied a one and one-half story brick house built within the Dayton city limits in 1934 that had its natural gas gravity-flow furnace replaced with a 2 1/2 ton ground water heat pump The total energy consumption rate for the household was reduced to less than one-third of the previous rate

The supply well for the project was drilled within a few feet of the house to a depth of 40 feet. The water, after it passes through the heat pump, is discharged into the city

storm sewer via an access drain in the basement of the house

The total cost of the conversion was about $6,800. This included the well and pump system cost of about $1,250, upgrading the electrical service from 90 to 200 amps, ductwork and main system installation. Included in this was the non-trivial cost of removing the old furnace.

The COP for the ground water heat pump in this house was calculated to be 2.8. The natural gas furnace that the heat pump replaced had a COP of 0.7.

Here are some key factors that a homeowner should have assessed by a qualified heating, air-conditioning, ventilation contractor.

- The building must be inspected for such elements as insulation type, amount and quality of insulation, window and door area; presence of good storm windows and storm doors; attic spaces for excessive heat loss. Recommendations should be made to provide a lower heat transfer between the occupied space and the exterior.
- Determine the total heating and cooling load under existing conditions and the heating and cooling load when recommendations are completed.
- The building site and surrounding geologic conditions must be assessed to determine if adequate supplies of acceptable quality water can be made available and to determine if adequate and proper effluent disposal (return of the ground water) can be arranged, preferably by use of a return well. A qualified water well contractor will need to assist here in most cases.
- Inspect the existing air distribution system. Is it adequate in size? Is there distribution to all occupied areas? Check the return system. Will there be only one large return? If so, the air distribution system will short-circuit and modifications must be made.

Since ground water heat pumps circulate warm air at lower temperatures than conventional gas and electric furnaces, a larger volume of air must be circulated at lower velocity to provide the same total comfort requirement. This calls for larger air ducts than conventional furnaces require. A conventional furnace delivers air that's about 120 to 140 F. A heat pump delivers air at only about 100 to 110 F, so it must move a larger volume. You need about twice the normal-size ducts, or double the number, to accommodate the flow with a larger fan turning at fewer rpm. A faster fan with the same ducts won't do; the efficiency would drop, the noise would increase and the room would seem drafty. Suppose that a duct must deliver 2,000 cfm of air. This means that the supply diameter should be approximately 18 inches. The approximate rectangular duct choices are 8 x 40, 10 x 30, 12 x 24, 14 x 20 and 16 x 17 inches. The proper return duct diameter is 22 inches, and the rectangular choices for the return are 12 x 36, 14 x 30, 16 x 26, 18 x 23 and 20 x 20 inches. Your contractor will have access to tables that will enable him to select the proper size ductwork for your application. The heat from any heat pump decreases in unit cost as the required temperature of the air is lowered, thus the importance of properly sized ductwork.

Coming up with the proper air distribution system in retrofit applications may be more difficult than in new construction because the consumer and installer are forced to live with much of what is already installed. The consequences of an undersized system can be noisy air ducts and diffusers, drafty rooms, reduced heat pump performance and unsatisfied customers. Some systems will require no modifications except for new supply and return fittings for the new equipment. Others may require the addition of several supply and return branches in order to assure satisfactory performance. Additionally, there will no doubt be some systems that the contractor may choose not to work with. Remember, any air conditioning or heating system is only as efficient as its distribution.

While a heat pump can equally well heat water for floor or baseboard heating, it is not satisfactory to do summer cooling through the floor or baseboard units. If these methods are chosen for winter heating, summer air conditioning will still require a system for circulating cooled and dried air.

- Check for the possibilities of removing existing heating and cooling equipment and installing the ground water heat pump in conjunction with the existing ductwork with a minimum of revisions. Do not use existing ductwork if major restrictions or connections to new equipment prevent a smooth air flow to and through the system.
- Select the proper heat pump equipment for the job. A proper equipment selection can only be made by calculating the design heat loss from the house. The oversized unit will require a greater water flow and a larger electrical supply. In short, indiscriminate oversizing of a ground water heat pump may be an expensive and inefficient proposition.

After determining heating and cooling load requirements and equipment space available, select the equipment for supply and return duct connections. Mate directions with the existing building supply and return ductwork if it is to be used. Make sure equipment is accessible for service and adjustments. Equipment should be sized to provide continuous air flow to the space with a minimum amount of drafts. A lower outlet and duct velocity is preferred.

Effective insulation of the structure should be your first aim because it will reduce your operating costs with an efficient heating system. Trying to make a poorly insulated house comfortable with a ground water heat pump will only result in the unhappiness of all concerned. If you first do not reduce the heat loss to the lowest practical levels, you will not succeed in achieving the lowest cost of operation.

Retrofit equipment can come in several configurations, which is helpful to the homeowner. These are the unitary, split-system and add-on designs.

The unitary design format, probably the most popular, features the entire unit, in either a vertical or horizontal configuration, contained in a single cabinet requiring only sheet metal, water piping, electrical and condensate drain connections.

In split-systems the Freon® to-air heat exchanger and blower are located in one enclosure and the compressor and Freon®-to-water heat exchanger in another. The air

handling portion of the split-system can be either horizontal or vertical. Since the air handling section is smaller than a complete unitary system of the same capacity, greater freedom of location is possible. Additionally, the compressor section of a split-system can be located in a spot convenient for water piping and service. These systems are also useful where noise isolation is critical.

The add-on system is similar to the split system in that there are two major components. The Freon® to-air heat exchanger, however, is placed in the air stream of the existing forced air furnace. Generally, these systems are sized from one-half to two-thirds of the design heating capacity of the structure. This is primarily due to the lower air moving capabilities of the existing unit and air distribution system. The existing furnace can be retained for use when full capacity heating (due to very cold weather) is needed. Add-on systems are less expensive in initial cost than a full-sized unitary heat pump. However, through part of the heating season, the existing furnace will be operating. The economic trade-off associated with the add-on system should be outlined for you, the customer.

CAN THE GROUND WATER HEAT PUMP BE USED FOR OTHER THAN HOUSEHOLD HEATING?

Ground water heat pumps are used to heat and cool warehouses, shopping malls, office buildings, hospitals, aircraft hangers, greenhouses, barns—just about any type of properly constructed and insulated structure that needs efficient, economical heating and cooling.

Another means of utilizing ground water heat pump units for residential heating and cooling is distinct heating systems. This involves a centralized distribution of ground water to multiple end-users. Each end-user would use individual heat exchangers and compressors for its own heating and cooling needs. Common piping may be installed to deliver the ground water to service. Costs for obtaining, pumping, maintenance and disposal of the ground water can be mutually shared by all end-users.

IS GROUND WATER HEAT PUMP-CONDITIONED AIR ADEQUATE FOR THE COLDEST WINTERS AND HOTTEST SUMMERS?

Yes, if the equipment is properly sized for the structure and its heating and cooling loads. Again, remember that a ground water heat pump is different from an air-to-air unit. Ground water temperatures remain nearly constant year round, they show little if any effect from air temperature changes. That is the advantage of the ground water heat pump. The compressor does not have to work harder (although it does work longer) when the temperature reaches extremes, unlike that of an air-to-air heat pump.

WHAT HAPPENS ON A 0° FAHRENHEIT DAY WHEN MY HEAT PUMP OR WELL PUMP FAILS?

What would you normally do? Wouldn't you get it repaired? Of course you would. We are not being flippant here. It's just that this is a common objection given to the use of ground water heat pumps and one that, when examined, is unfair.

Natural gas furnaces fail, electricity goes off (all furnaces require electricity to operate), snowstorms make it impossible for fuel oil trucks to make deliveries, and so on. In other words, failures can and do occur with any home heating and/or cooling system. With a temporary failure you could rely upon some other heating method, such as a wood burning stove or electric space heating unit until your heat pump unit or well pump is brought back on-line. This is no different than what you would do with any other system.

Ground water heat pumps are highly reliable when properly designed and installed. Because of the way they are constructed, they have fewer problems than their air-to-air cousins. If you have a heat pump regularly inspected and serviced by qualified industry professionals you are less likely to have to be cold in the middle of January.

WILL VARIATION OF THE WATER TABLE AFFECT THE PERFORMANCE OF MY GROUND WATER HEAT PUMP?

It could, but not necessarily. If the water table declines it is only a problem for you if it declines below your well pump's operating level. If it drops below that mark you must have the pump reset to prevent it from running while dry and subsequently burning out, leaving your home without water and your ground water heat pump without a water source. Another alternative would

be to have the well drilled deeper

If the water table rises, you must make certain that your return well will not overflow and spill out onto the surrounding ground.

Remember, your ground water heat pump will have no consequential appreciable effect on the water table level if the supply well is properly designed, constructed, developed and tested, and if a return well of similar standards is incorporated

However, if the system is designed for possible water discharge into sewers, streams or some other surface facility, the water available for recharge may be reduced and result in the lowering of the water table under certain hydrologic conditions

WHAT ABOUT HUMIDITY IN MY HOUSE DURING THE WINTER AND DEHUMIDIFICATION IN THE SUMMER?

Because the ground water heat pump only needs to heat the air it circulates to about 110 F as opposed to 140 F for more conventional home heating systems, the air is subsequently not as dry as that found in conventional methods. Thus, a pleasant humidity level is maintained in the home during the dry winter months.

Water cooling with the ground water heat pump is very efficient, and provides the amount of dehumidification we expect from conventional air conditioning during the humid months of summer

WHAT IF THERE'S A REFRIGERANT LEAK? WON'T IT BE HARMFUL TO MY FAMILY OR OUR PETS AND COULDN'T IT CONTAMINATE MY GROUND WATER SUPPLY?

It is unlikely that ground water heat pumps themselves could cause ground water pollution The units do, however, contain refrigerants and oils. It is conceivable, by a worst-case perspective, that a rupture in the plumbing or an event causing a pressure loss in the system could allow the Freon® and/or oil to enter the ground water system

While the presence of a small quantity of oil in ground water may make the water undrinkable for a brief period, the Freon® poses no risk.

The Freon® Products Laboratory of E.I. Dupont De Nemours and Co has explained the company's findings concerning health risks from exposure to Freon® 12 and Freon® 114, two refrigerants commonly used in heat transfer systems

"Sufficient evidence is now available to indicate that double-wall heat exchangers are not necessary and that the health hazard in the event of leakage (of Freon® 12) is negligible, according to Dupont.

The solubility of Freon® 12 in water decreases as the temperature increases. For example, the solubility at 140 F is about one-third that at 70 F The amount of Freon® 12 dissolved in water depends upon the pressure of the product supplied to the water and is not affected by the pressure of other gases that might be present, such as air. Since Freon® 12 is not very soluble in water, it dissolves very slowly when the pressure is increased

Long term tests using rats and dogs determined that no tissue damage occurred in either group of animals fed substantial quantities of Freon® 12. The Dupont study concluded that "The health hazard from the use of Freon® 12 in direct coils for heating water seems extremely slight."

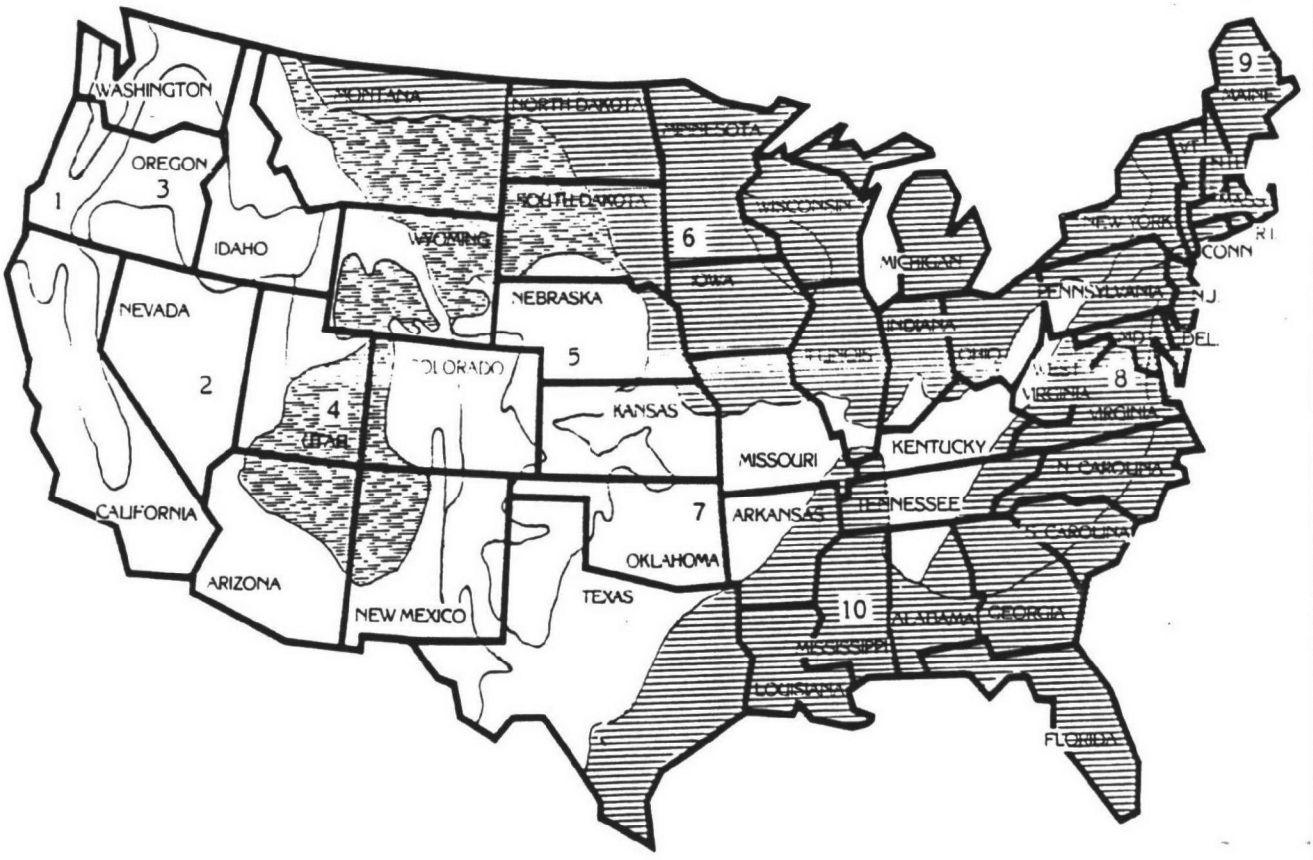
Animal ingestion studies with Freon® 114 in relatively large amounts show no effect, according to Dupont. Additional studies found that the solubility of Freon® 114 in water is very low

In short, there is little health risk or ground water contamination risk from the heat pump system's refrigerant. In addition, the likelihood of a leak is very low, because the refrigerant does not mix with the water at any point.

HOW MUCH MONEY CAN I SAVE USING A GROUND WATER HEAT PUMP?

We have intentionally waited to answer this question We wanted to make certain that you read and understood all that came before this question before you started thinking about the savings a ground water heat pump can provide

To properly evaluate the economics of a ground water heat pump system, its initial cost (equipment and installation) and its annual operating costs must be considered. The initial cost of the ground water heat pump system is higher than that of conventional systems, but its lower annual operating costs and maintenance requirements, ability to produce heating as well as cooling



Ten Major Ground Water Regions	Average Well Depth	Cost to Drill Average Well	Range of Depths	Pump Cost At List 10 GPM	Drop Pipe Cost at List 160' Plastic	Total Well Cost Range 1978 NWWA Water Survey
#1 Western Mountain Ranges—6"	250	$3,770	100-500	$470	$140	$2,000-5,000
#2 Alluvial Basins—6"	400	$6,188	200-1,000	$610	$245	$2,600-7,000
#3 Columbia Lava Plateau—6"	200	$3,042	50-1,000	$470	$105	$1,550-6,000
#4 Colorado Plateau—6"	300	$4,029	110-500	$610	$175	$2,000-5,000
#5 High Plains (Ogallala Aquifer)—4"	300	$1,458	50-500	$610	$175	$1,250-5,000
#6 Glaciated Central Region—4"	150	$1,680	50-300	$386	$85	$1,250-3,750
#7 Unglaciated Central Region—4"	200	$2,058	100-400	$470	$105	$1,550-4,000
#8 Unglaciated Appalachians—6"	250	$2,600	200-500	$470	$140	$2,350-6,000
#9 Glaciated Appalachians—6"	100	$1,385	50-200	$360	$52	$1,150-3,750
#10 Coastal Plain—4"	75	$640	25-250	$360	$42	$1,250-3,250

Average Cost for Well and Pumping System for 10 GPM $2,400-$2,800
Average Cost for Cased Well Only $1,600-$2,000
Average Well Depth Is 200 Feet

Source Data: DOE. CS 20060—5,120'

Exhibit II

FIGURE 15. Regional well data and water system cost

make it economically attractive.

How much money you ultimately save will depend on your house, your family's lifestyle, where your house is located, the temperature of your ground water supply, the type of equipment you select, the water discharge method you select and other variables, including interest rates and available tax incentives

Based on U.S. Department of Energy projections of energy costs, a gas heating/cooling system is the most economically attractive of current system choices in most parts of the United States. However, the ground water heat pump, with no well costs included, has an economic advantage over all other systems evaluated (including conventional air to-air heat pumps, electrical resistance heating/electrical cooling systems and oil heating/electrical cooling systems) in eight of the nine test cities of the study (Houston, Texas, is the exception).

With the cost of a return well included, payback of incremental first costs for installation of a ground water heat pump system is usually achieved within an eight-year life cycle period. The shortest payback periods are indicated for northern climate installations. Using the air-to-air heat pump or the electric heating/electric cooling system as the alternate choice, payback periods range from two to 10 years. Using the oil heating/electric cooling system as the alternate, payback periods range from one to more than 10 years.

Let s look at some actual installations and the savings that have been realized.

A 2,880-square foot, two-story, four-bedroom house with basement located near Decatur, Illinois, had a ground water heat pump installed that utilized 54 F ground water During the 1980-81 heating season it cost the homeowners $173 43 to power their ground water heat pump In comparison, the heating costs using the following alternative methods in Decatur would have been #2 fuel oil—$620, propane—$555, electric resistance—$415, air to-air heat pump—$245, natural gas—$235

An average house (1,200 square feet) located in Northwood, North Dakota, required 39 million Btu of energy from the ground water for space heating during the 1981 calendar year The resident s electrical energy cost was approximately $220 to operate the heat pump and water pump for that year Equating this system s operation cost to conventional heating systems', this cost compares to $471 with electric resistance, $550 with propane and $675 using fuel oil heating (natural gas isn t available) On the other hand, a larger house (2,500 square feet) located in Lanmore required 77 million Btu of energy from the ground water to space heat the house on an annual electric operation cost of approximately $325

The Butler Rural Electric Cooperative Inc. of Hamilton, Ohio, decided to replace the 100-kw electric boiler and 30-ton chiller with a water to-air exchange via air handling equipment it had been using in its 6,600-square foot office facility with a ground water heat pump system The results of this project are listed below

	Office Facilities Only 6,600 Square Feet	
Heating Degree Days 79-80 5,340 Degree Days 80-81 5,045	1979-80 Old Equipment 100-Kw Boiler 30-Ton Chiller	1980-81 New Equipment 4 4-Ton Ground Water Heat Pumps and Well Pump
Total kwh to heat and cool	117,555	36,502
Average kwh per month	9,796	3,042
Average kwh per day	322	100
Total cost per year	$6,347 97 Average @ 0.054 kwh	$2,190.12 Average @ 0 06 kwh
Average cost per month	$ 528.99	$ 182.51
Average cost per day	$ 17.39	$ 6 00
Average cost per square foot	$ 961	$ .332
Total kwh to heat area	71,415	26,683
Total cost to heat area	$ 3,856.41	$ 1,600 98
Average cost per square foot to heat area	$ 584	$ 242
Total kwh to cool area	46,140	9,819
Total cost to cool area	$ 2,491.56	$ 589 14
Average cost per square foot to cool area	$ 377	$ 089

TABLE 2

The important factor to you is what the unit costs to be installed and how long it will take for the unit to pay for itself and subsequently show a real savings to you.

If you want a ground water heat pump system and don t have a water well, the cost of installing a well (and the cost of a return well, if that is the water discharge method selected) must be considered in your total cost estimate

Let s take a 150-foot well, a typical depth in many parts of the country And let s take a moderately high drilling price of $10 per foot, which includes the cost of the well casing. So, we are now talking about $1,500 With the addition of the pumping system, the pressure tank and the plumbing up to the house, another $700 has been spent.

A return well will cost approximately the same amount as the supply well if it is constructed to switch roles with the companion well If it is not built to take full advantage of the aquifer system, then the cost of the well pump can be deducted—approximately $500.

Ground Water Heat Pump Compared to Other Systems

Make a Comparison of Net Cost per Million Btu/Hour of Usable Heat

A. **Electric resistance heat**

$$\frac{1{,}000{,}000 \text{ Btu}}{(3{,}413 \text{ Btu/kw} \times 100 \text{ percent efficiency})} = 293 \text{ kw} \times _____ ¢ \text{ per kwh} = \$ _____$$

B. **Natural gas**

$$\frac{1{,}000{,}000 \text{ Btu}}{100{,}000 \text{ Btu/therm} \times 75 \text{ percent efficiency*}} = 13.33 \text{ therms} \times _____ ¢ \text{ per therm} = \$ _____$$

(*Assumes spark ignition, automatic flue damper & proper sizing)

C. **Propane gas**

$$\frac{1{,}000{,}000 \text{ Btu}}{91{,}800 \text{ Btu/gallon} \times 75 \text{ percent efficiency*}} = 14.5 \text{ gallons} \times _____ ¢ \text{ per gallon} = \$ _____$$

(*Assumes spark ignition, automatic flue damper & proper sizing)

D. **#2 Fuel oil**

$$\frac{1{,}000{,}000 \text{ Btu}}{140{,}000 \text{ Btu/gallon} \times 70 \text{ percent efficiency*}} = 10.2 \text{ gallons} \times _____ ¢ \text{ per gallon} = \$ _____$$

(*Assumes flame retention burner, automatic flue damper & proper sizing)

E. **Air-to-air heat pump (with demand defrost)**

$$\frac{1{,}000{,}000 \text{ Btu}}{(3{,}413 \text{ Btu/kw} \times \text{average COP of } 1.75)} = 167 \text{ kw} \times _____ ¢ \text{ per kw} = \$ _____$$

F. **Ground water heat pump**

$$\frac{1{,}000{,}000 \text{ Btu}}{(3{,}413 \text{ kwh} \times \text{average COP of } 2.75^*)} = 107 \text{ kw} \times _____ ¢ \text{ per kw} = \$ _____$$

(*Includes cost of pumping water and auxiliary heat)

Compare Energy Costs as Follows.

Highest Cost per Million Btu ÷ Lowest Cost per Million Btu =
_____ How Much More You Can Expect to Pay for Higher Cost Energy.

Now a heat pump· Say you have a 2,000-square foot house and you need 60,000 to 80,000 Btu for heating. The system will cost anywhere from $1,900 to $4,700 The total cost of a ground-water heat pump system, therefore, can run between $5,600 and $8,400 Average initial costs for conventional heating systems are lower Some of these with the cost of a cooling system included, are listed below

Air to-air heat pump	$3,500
Natural gas furnace	$2,500
Electric resistance	$1,500
Electric furnace	$2,500
Propane	$2 700

Thus, the ground water heat pump is expensive According to a market survey conducted in 1980 (Scherrer) of 65 respondents in the ground water heat pump industry, the most significant barrier to the increased use of these systems is the high initial cost.

But, let s look more closely at the potential savings question

Cost-effectiveness is the key that convinces most homeowners to select a high-efficiency heating system Consumers are typically willing to invest in energy saving devices where there is a proven energy-savings and the incremental cost is affordable.

The cost-effective economics of the ground water heat pump should be understood. The accompanying table gives an illustration of the cost-effectiveness of the ground water heat pump You could calculate comparison costs for your area by making the appropriate data substitutions

It is important that the cost of pumping the water from your well be included in the total operating cost of your complete ground water system. When all elements of the system are properly sized, mated and installed, this cost will be minimal, but it is nonetheless a factor that you must be aware of

HOW DOES MY UNIT'S COP AFFECT MY PAYBACK PERIOD?

The higher the COP the lower the operating cost; therefore the larger the savings which subsequently gives an accelerated payback schedule.

TABLE 3
Types of Energy Sources and Heat Content with Present-Day Operating Costs

Type of Energy	Units	Gross Heat Content	Usable Heat Content	Fuel Cost	Cost—10,000 Btu
#2 Fuel oil	gallons	140,000 Btu/gal	84,000 Btu/gal *	1 20/gal	14 29¢
Propane gas	gallons	91,000 Btu/gal	54,600 Btu/gal *	71.38¢/gal.	13 07¢
Natural gas	therms	95,000 Btu/th	57,000 Btu/th*	35¢/th	6 14¢
Electricity (resistance)	kwh	3,413 Btu/kwh	3,413 Btu/kwh	4 192¢/kwh	12 28¢
Electricity (A/A heat pump standard model)	kwh	6,826 Btu/kwh	6,826 Btu/kwh**	4.192¢/kwh	6 14¢
Electricity (A/A heat pump efficiency)	kwh	8,533 Btu/kwh	8,533 Btu/kwh***	4.192¢/kwh	4 91¢
Electricity (W/A heat pump)	kwh	10,500 Btu/kwh	10,500 Btu/kwh****	4 192¢/kwh	3 99¢
Coal (Pocahontas)	ton	12,000 Btu/lb	5,000 Btu/lb*****	$125/ton	12.50¢

*Based on 60 percent efficiency
**Based on COP of 2 (200 percent efficiency)
***Based on COP of 2.5 (250 percent efficiency)
****Based on COP of 3 11 (311 percent efficiency)
*****Based on 38 percent efficiency

A/A = Air-to air heat pump
W/A = Water-to-air heat pump

TABLE 4

Efficiency*, Percent	Fuel Consumption per Million Btu: Natural Gas, Cu. Ft.	Propane, Gallon	Fuel Oil, Gallon	Wood**, Cords
35	—	—	20 6	—
40	2.422	27 3	18 0	0 104
45	2.153	24 3	16 0	0 093
50	1.938	21 9	14 4	0 083
55	1.762	19 9	13 1	0 076
60	1.615	18 2	12 0	0 069
65	1.491	16 8	11 1	—
70	1.384	15 6	10 3	—
75	1.292	14 6	—	—
90	1.077	—	—	—
95	1.020	—	—	—

Electrical Power Consumption per Million Btu

Heating (kw-hr)			Cooling (kw-hr)		
	Heat Pumps			Heat Pumps	
Electric Resistance Equipment	Air Source	Water Source	Air Conditioner	Air Source	Water Source
(100 percent)*	(1 7)*	(3 4)*	(2 2)*	(2.2)*	(3 2)*
293 1	172 4	86 2	133 2	133 2	91 6

*Ohio seasonal efficiency or COP (see text)
**Soft wood (8,000 Btu/lb)

HOW WILL HAVING A GROUND WATER HEAT PUMP AFFECT THE VALUE OF MY PROPERTY OR MY ABILITY TO SELL IT?

As consumers become more and more energy-savings conscious, they will demand that a house have an energy-efficient heating and/or cooling system such as the ground water heat pump If your house has such a system, it will make it all the more attractive to a prospective purchaser, should you decide to sell The less it costs to live in your house, the more buyers can afford to spend to purchase it from you. Many bankers are now seeing energy-saving devices as the key to qualifying homeowners for mortgage loans.

COULDN'T I USE THE GROUND WATER HEAT PUMP TO PRODUCE HOT WATER FOR BATHING AND COOKING?

Many ground water heat pump systems come with domestic hot water generation options. When equipped with an auxiliary heat exchanger, a ground water heat pump can provide some hot water heating with approximately the same COP as that obtained in providing space heating. When equipped with an auxiliary heat exchanger, a heat pump operating in its cooling mode can provide some hot water heating without adding to the power consumption required for space cooling

The water heating attachment uses an electric water heater connected to a second heat exchanger coil on the heat pump A small pump recirculates the tank water around the heat exchanger to maintain a constant temperature of 120 to 160 F When the heat pump is not in use or cannot supply enough hot water, electric resistance heat supplements the system Small air to-air heat pumps are also available to heat water economically

WHAT IF I CAN'T USE A WELL?

Water-to-air heat pumps, as the term suggests can be adapted to water supplies other than wells, such as a freshwater lake or a stream

Another alternative to a well system would be a closed-loop, earth-coupled system.

The closed-loop heat pump system requires only that the heat exchanger be buried in contact with moist earth In using closed loop exchangers, there is no depletion of the aquifer, since no water is withdrawn from the ground. The earth-coupled exchanger is filled one time with potable water or other heat exchanger fluids, therefore, it does not contaminate the heat pump by precipitating out minerals from the soil

Two general types of earth-coupled systems have been used with water-to-air heat pumps. The first type is a vertical heat exchanger. The second type is the earth-coil or horizontal heat exchanger A serpentine length of plastic pipe buried 4 to 6 feet below the earth s surface is called an earth-coil or ground loop

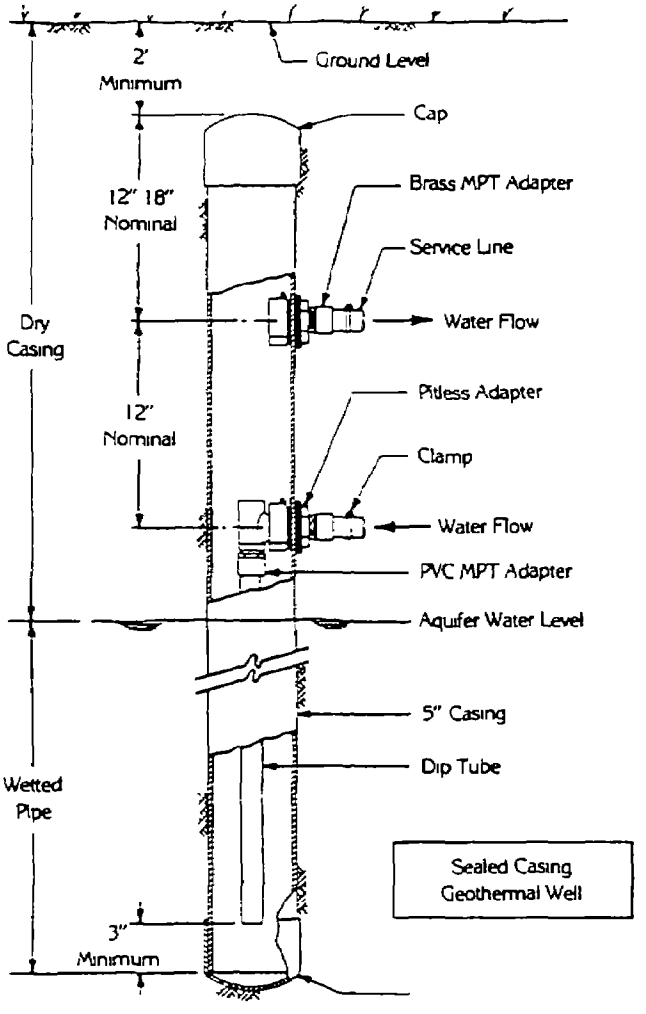


FIGURE 16 Sealed casing geothermal well

Both horizontal and vertical earth-coupled exchangers utilize low-wattage circulator pumps to send water from the heat pump out through the continuous closed-loop to exchange heat with the earth and back to the heat pump

The vertical heat exchanger is constructed by a water well drilling contractor The water from the heat pump is circulated to the bottom of the well and exchanges heat with the water in the well surrounding the pipes as it rises to reenter the heat pump This flow is achieved by means of a low wattage inexpensively operated circulation pump Vertical heat exchanger wells are filled only once and do not draw water from the earth.

The horizontal serpentine earth-coil has two plastic exchanger pipes in a single trench 6-inches wide and 6-feet deep. In the case of a double layer design, the trench is partially backfilled after laying the first pipe, then completely backfilled after the second. In urban areas, earth coils can be layed out in a curved pattern around the boundary of a lot. Heat exchange will drop to only 10 to 20 percent of normal performance if the soil around the pipe becomes dry When multiple pipes are to be buried in the same trench, the horizontal or vertical separation required between pipes is 2 feet. The length of the earth-coil required will vary with the climate For example, in Oklahoma, where many of these systems have been installed, approximately 300 linear feet of wetted pipe or 450 linear feet of dry pipe per nominal ton of heat pump cooling capacity is required.

In the northern U.S where heating is clearly dominant and cooling is of minor importance, 10 to 25 percent of propylene glycol USP should be used in the closed loop vertical heat exchanger to prevent freezing of the water in the heat pump exchanger

With a properly sized heat pump, duct system, water piping and water pump, the midwinter COP according to advocates of the earth-coupled heat pump, averages from 2.8 in northern climates to 3 2 in the middle U S Their performance is reported to be higher in autumn and spring

Another popular heat pump system common in commercial buildings makes use of recycled water in a closed loop. The water temperature in the closed water source heat pump must be maintained within a narrow degree range. Therefore, a cooling tower is required for cooling the water in the summer, and a boiler is required for heating the water in the winter The requirements of the boiler and cooling tower reduce the overall operational efficiency of this type of heat pump system

WHAT ABOUT SOLAR ENERGY AND GROUND WATER HEAT PUMPS?

The ground water heat pump has the unique ability of being able to take advantage of future advances in solar collection and heat storage technologies. Because the ground water heat pump is a water-to-air heat pump, it can easily be expanded to accept improved solar collectors and more efficient thermal energy storage. Where use of a well is not possible, a water-to-air heat pump could be combined with a closed cycle system whereby water in a storage tank could be heated by solar collectors. The water in the tank would not need to be heated beyond the 50 to 70 F range through the use of solar panels. When the cost-effectiveness of these efficiency-augmenting accessories justifies their use, the ground water heat pump can be used as a dual-source solar assisted heat pump that obtains heat from both the ground water and the solar collectors. It has not been demonstrated that the solar energy gained can even come close to paying for solar collectors at the present price of $25 to $75 per square foot or more.

WHAT LAWS AND REGULATIONS SHOULD I BE AWARE OF WHEN CONSIDERING THE USE OF A GROUND WATER HEAT PUMP?

Federal, state and local regulations impose restrictions and mandate various requirements for well construction, ground water use and quality and effluent disposal, but they will not significantly obstruct the implementation of ground water heat pumps in the long-run.

The Safe Drinking Water Act of 1974 was enacted by Congress to ensure that public water systems are adequately supervised by the states. This act requires the federal Environmental Protection Agency to adopt regulations for state underground injection programs. Heat pumps which use return wells or discharge water in a manner which could affect drinking water supplies may be subject to regulations as a Class V well discharge system. States are required to participate in inventory and impact assessments of all Class V wells. This may include heat pump return wells, depending

TABLE 5

Summary of Ground Water Heat Pump Use and Effluent Disposal Regulations by State**

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Alabama	No permit needed to use water for H P under domestic category	Simple permit required by Water Improvement Commission. Well regulated as Class V well under Underground Injection Control Program (UIC)	Theoretically covered by NPDES—however this system usually not equipped to consider small domestic use so in most cases could just discharge without a permit	Not a problem if discharge to land owned by H P user	A loophole in regulations—this type of discharge is allowed—if tank is big enough and far enough from well	Would probably be allowed almost anywhere—although in many areas would be cost prohibitive
Alaska	No problem to obtain water rights	No mechanism to require a permit or to prevent this type of injection well				
Arizona	No problem to obtain water use—falls into domestic category—no permit needed	Will be regulated by rule as Class V well under UIC when the state obtains primacy				
Arkansas	No permit needed for water use of this type	Permit required by Dept. of Pollution Control and Ecology as Class V well under UIC				

*If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama.

**Small-scale domestic heat pump utilization only.

TABLE 5
(Continued)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
California	32 counties out of 58 total require permits for all wells—no real problems though	At present, there are no regulations. In the future, may be regulated by the regional water quality control boards and through UIC				
Colorado	No permit needed for a well that has a yield less than 15 gpm	Permit required by state engineer				
Connecticut	Diversion permit required for use of more than 50 000 gpd	Permitted as Class V well under UIC				
Delaware	No problem to use water—would be classified as a domestic well—no permit required	State policy is to encourage reinjection. Wells will be permitted through UIC as Class V well				
Florida	A permit would be required for this volume of water use—but not a serious problem in most parts of state	Permit required by Dept. of Environmental Regulation as Class V well under UIC				
Georgia	No permit needed for use less than 100,000 gpd	Reinjection of cooling water is allowed in state. No permit is required for this				
Hawaii	Classified as a domestic well—so no problem to obtain water use	A regulation exists that requires permission for disposal wells and wastewater disposal—however not enforced at present				
Idaho	No permit needed for domestic use—except in critical ground water area—need a permit for any use more than 13 000 gpd	Permit will be granted if water quality remains the same	No problem except in critical ground water areas where recharge back to the aquifers would be required			
Illinois	Domestic use classification—no permit needed	Heat pump return wells are unregulated. The state EPA has the jurisdiction to permit them but has chosen not to do so at the present time				
Indiana	Domestic use—no permit needed	Conventional and cooling water recharge wells not regulated—though Stream Control Board has theoretical authority. Permitting regulations currently being considered	Board of Health permit—no special problem to obtain			

*If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama

TABLE 5
(Continued)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Iowa	No permit needed for domestic use	The state is not administering the UIC Heat pump wells must be registered with U S EPA Users are encouraged to consult with Iowa Geological Survey before construction				
Kansas	A water appropriation permit would be needed	No regulations at present but will probably require a permit as Class V well of UIC				
Kentucky	Private use—no permit required	Will probably be regulated as Class V well under UIC				
Louisiana	No permit required	Permit required as Class V well of UIC				
Maine	No permit needed for this type of water use	Permit required by Water Bureau of Dept of Environmental Protection				
Maryland	A permit would be needed for use of this type	Permit required at county level One county has banned heat pumps				
Massachusetts	No permit needed for this type of water use	Registration will be required with the Division of Water Pollution Control as Class V well under UIC				
Michigan	No permit needed for this type of water use	No permit required by Water Resources Commission as long as heat pump has a heat exchange rate less than 120,000 Btu/hour or has no chemical additives				
Minnesota	No permit required	Permit required by Dept of Health. Drinking water well may not be used as supply well Water must be reinjected to same aquifer in a closed system. No other type of disposal allowed				
Mississippi	No permit required	Permit required as Class V well of UIC				
Missouri	No permit needed	Permit required by Dept of Natural Resources unless heat pump is limited to single family residence or is limited to eight or fewer single family residences with a combined injection/withdrawal rate of 600 000 Btu/hour				
Montana	Certificate of water right is needed—no serious problem to obtain	Class V well of UIC				
Nebraska	No permit needed	Permit required as Class V well of UIC New regulations possible in summer of 1983				

*If no information is provided in this column regulations pertaining to this type of discharge are similar to those in Alabama

TABLE 5
(Continued)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Nevada	Permit would be required	Not regulated at this time but probably will be in the future				
New Hampshire	No permit needed	Notification required Wells regulated as Class V wells of UIC				
New Jersey	No permit needed	Permit requires wells 5 feet apart and water returned to same aquifer				
New Mexico	Permit needed for use of this magnitude	Regulated under New Mexico s existing ground water regulations on a case-by-case basis				
New York	No permit needed	Dealt with on an ad hoc basis by Division of Water, Dept. of Environmental Conservation. May require a discharge permit if a unit presents a possible thermal pollution problem				
North Carolina	No permit required	Recharge well requires a permit as a Class V A well under the state s UIC				
North Dakota	Standard appropriation permit needed	Registration required as Class V well of UIC				
Ohio	No permit needed for domestic use	No permit required. The state EPA has recommended construction and operation procedures				
Oklahoma	No permit needed for domestic use	Will be treated as Class V well of UIC for permitting purposes				
Oregon	Less than 15 000 gpd—no permit required	Permit and report required by Water Resources Dept. as low temperature geothermal well				
Pennsylvania	No permit needed	No regulations. The state is not adopting the UIC and the U.S EPA has no plans to regulate heat pumps. Bureau of Water Quality Management suggests returning water to its original source				
Rhode Island	No permit needed	Approval will be required as Class V well of UIC	RIPDES may require a simple permit			
South Carolina	No permit needed	Pending legislation will designate heat pump wells as Class V B wells. Wells will not need permits but will be reported. Construction standards are being considered.				
South Dakota	No permit needed	Will be regulated as Class V well under UIC				

*If no information is provided in this column regulations pertaining to this type of discharge are similar to those in Alabama

TABLE 5
(Continued)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Tennessee	No permit needed for water use less than 50 000 gpd	Heat pumps will be regulated by UIC Proposed rules exclude domestic heat pumps from permit requirements Commercial and industrial heat pumps will be permitted by rule as Class V well of UIC				
Texas	No permit needed for water use	Authorized by rule as Class V well of UIC				
Utah	Permit needed for use of any type	Class V well of UIC				
Vermont	No permit needed	Probably will be regulated as Class V well under UIC				
Virginia	No permit needed	Currently considering regulations that would require a general national pollutant discharge elimination system permit for small heat pumps and a specific NPDES permit for large units				
Washington	Permit needed for use of more than 5,000 gpd	Discharge permit not required on single family residence Anything larger requires permit from Dept. of Ecology				
West Virginia	No permit needed	Return wells are Class V wells under UIC However, there are no plans to require permits at this time				
Wisconsin	No permit needed	Reinjection of water allowed only by permit through experimental program running through 1984				
Wyoming	No permit needed	Permit required to recharge water				

*If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama

upon your state s interpretation of the Safe Drinking Water Act.

At the state level, well construction requirements vary considerably. Concern on this level is more a matter of cost than of limitation; the expense involved in meeting such requirements can rule out the feasibility of heat pump utilization. Where water-use restraints exist, usually in the form of permit requirements, they are not serious deterrents to heat pump use. However, some areas do completely ban the use of ground water heat pumps

The disposal of effluent to a return well is uncontrolled in some states and prohibited in others. Where this disposal method is forbidden, heat pump selection may be limited. Alternative disposal methods are available, however, and are generally subject to less regulation than are return wells. Since other disposal methods, such as discharge to land, surface water, or sewers, are usually possible (if not advisable), state limitations on return wells should not hinder heat pump use.

Some local controls on well construction, ground water use and quality and waste disposal may adversely affect ground water heat pump use. Most local regulations, however, will not seriously impede the widespread use of this equipment.

We suggest that you always contact appropriate local officials before making a financial commitment to a ground water heat pump

WHAT ABOUT ENERGY TAX CREDITS THAT I MIGHT RECEIVE IF I INSTALL A GROUND WATER HEAT PUMP?

At the time this was written, there was no federal tax credit available to homeowners for having installed a ground water heat pump (Revenue Ruling 81 304) While you may have heard of someone that made such a deduction by perhaps having described his unit as "geothermal equipment," "solar water unit" or 'solar heat extractor,' and apparently had the deduction approved by the Internal Revenue Service, that is not correct. According to the IRS, essentially what has happened is that the IRS has not caught this deduction. Ground water heat pumps, despite whatever other title that might be given to them, simply do not legally qualify for energy tax credits currently being offered by the federal government. Legislation has been introduced into both the House and Senate to amend the tax codes to specifically include ground water heat pumps for energy tax credits

Despite the federal government's position, several states such as Michigan, Ohio, Indiana, Idaho, North Dakota and South Dakota, for example, have granted tax credits to homeowners using ground water heat pumps. Typically, these credits provide that there will be no increase in the property tax valuation on the property, there is no sales tax assessed on the equipment and some states will offer income tax credits

It is best to check with your state s taxation or energy offices to be certain

I HAVE AN AIR-TO-AIR UNIT INSTALLED AT MY HOME NOW. CAN I CONVERT IT TO A WATER-TO-AIR UNIT?

Such a conversion is possible by trained professionals For several years the Fred Rosenau family of North Dakota had been living in a home equipped with an air to-air heat pump system.

The major disadvantage of using an air-to-air heat pump in North Dakota is that air temperatures are often too low for economical use in the winter when heat is needed and too high in the summer when cooling is needed Rosenau noted that as soon as the outside air temperature reached 0 F (-18 C), his air to-air heat pump would no longer kick in, forcing him to rely on a more expensive electric resistance backup system.

Rosenau was familiar with the concept of using ground water as the source of energy in a heat pump system So a year and-a-half ago, with the help of B Simek of Simek Refrigeration in Fullerton, he decided to convert his air-to-air heat pump to water

Rosenau had a couple of advantages when he started the project. Nine hundred feet from his house there was an old test well which was producing 72 F (22 C) water. Rosenau also owns his own backhoe and was able to lay the pipe from the well to the house himself

Simek states that the heat pump conversion itself was not difficult and was essentially a matter of replacing the air evaporator with a water exchanger This summer, however, the new condenser unit failed, apparently due to a manufacturer s defect. Although the part will be replaced by the company without charge, the malfunction has resulted in several months of downtime

All in all, Rosenau and Simek have been pleased with the operation of the converted heat pump system During the winter months, Rosenau estimates that the air-to-air heat pump (and necessary backup system) would have cost between $4 and $5 a day to operate. With the water to-air system, it cost Rosenau less than $2 a day to heat his 1,880-square foot home, plus a basement apartment, between November 1980 and May 1981 The backup system was never needed, even with the thermostat set at a constant 70 F (21 C). Essentially what needs to be done is to replace the air evaporator with a water exchanger This is a procedure that would be beyond the abilities of the average homeowner

We do not recommend such a change, despite the invalidate any warranties or responsibilities presently charged to the manufacturer We strongly urge that you use equipment only as it was designed.

MY HEATING, AIR-CONDITIONING CONTRACTOR SAYS THAT HE DOESN'T WANT ANYTHING TO DO WITH GROUND WATER HEAT PUMPS.

Part of this attitude may be a result of the problems found in the early designs of the 1950s As has been explained, those problems have been eliminated.

Your contractor may also not totally understand ground water as a heat source or a heat sink. Most HVAC contractors have been installing air-to-air heat

pumps, and ground water heat pumps are something new to many of them Most of us are skeptical of something new until it has been proven to us As more and more homeowners demand ground water heat pumps, more and more HVAC contractors will educate themselves to the advantages and the savings of the ground water heat pump

Ground water heat pump installations usually require the combined talents of a water well systems contractor and an HVAC contractor While it may be difficult to find firms with both skills, they are in fact growing in number Local heating equipment suppliers or the National Water Well Association can put you in contact with a firm in your area

WHY AREN'T THE MAJOR HEATING AND AIR-CONDITIONING EQUIPMENT MANUFACTURERS PROMOTING THE WIDE-SPREAD USE OF GROUND WATER HEAT PUMPS?

They are slowly coming around to the promotion of the ground water heat pump You must understand that they haven't really been promoting the use of the air-to-air heat pump for that many years They have made significant financial commitments to air to-air heat pump equipment and are perhaps somewhat reluctant to cut into what has proven to be a profitable product line Manufacturers are now realizing that in most parts of the nation adequate ground water yields are available to operate residential and small commercial building heat pump units. Meanwhile, existing smaller ground water heat pump manufacturers have had a chance to establish their product line and to thrive

Presently, the ground water heat pump industry is in its infancy: In 1981, it is estimated that only 30,000 systems were sold in the United States. Partly for this reason, manufacturers are reluctant to adopt even the most obvious and well-tried innovations For example, most manufacturers design ground water heat pump units for optimal efficiency in the cooling mode Increased consumer demand could encourage more manufacturers to incorporate existing design innovations for greater efficiency in the heating mode This can increase efficiency by approximately 33 percent in cold northern climates

I LIVE IN THE CITY. CAN I USE A GROUND WATER HEAT PUMP?

Ground water heat pumps can be installed in some urban and suburban areas if they utilize dedicated water systems not interconnected with the domestic water or sanitary systems For example, the city of Hilliard Ohio, adopted legislation in 1982 that would not prohibit using wells for ground water heat pumps, but would establish controls to protect the domestic water supply of others in the city. The legislation would permit the city engineer to turn off the ground water heat pump systems if the domestic water supply would become threatened

Water-to-air heat pumps could be adapted for use in an urban setting One way would be to integrate heat pump use with city water supplies Water could be piped in, run through the heat pump and returned to community storage, since the water is in no way contaminated on its way through the heat pump Or it might pass through the heat pump before being metered or used inside the house The 'borrowed' water in either scenario would be metered and priced at reduced levels

Yet another idea is to link several houses, all the apartments in a building or an entire community into a network of ground water distribution and return.

A condominium project in downtown Columbus, Ohio, utilizes ground water heat pumps. Wells were drilled and permits obtained from city officials to allow the discharge of the ground water into the city storm sewers.

In short, it is technically feasible to use a ground water heat pump in a city or a suburb However local government restrictions or local ground water conditions may limit its use Check with your appropriate authorities

HOW SHOULD A GROUND WATER HEAT PUMP BE SELECTED?

Select your unit only with the cooperation of a qualified, dependable heating and air conditioning contractor in conjunction with a qualified, dependable water well systems contractor Ground water heat pumps come in many different types and sizes Climate and building design are crucial factors to be considered in determining which ground water heat pump will operate most efficiently and economically to meet your particular heating and/or cooling needs

Choosing a ground water heat pump unit that is smaller than the heating load calls for will mean that the unit cannot supply enough heat during the coldest part of the winter

choosing a unit that is larger than required will cause the unit to stop and start frequently throughout the winter, which reduces system efficiency The heat pump should, therefore, be sized as close to the calculated heat load as standard sizes permit.

After the heating load calculations have been completed and the heat pump is sized this information should be shared by the contractor with the manufacturer from whom the heat pump is being selected. Some manufacturers may even require a set of construction plans of the house so they can perform the heat load calculations and size the unit themselves. In either case, the contractor and the manufacturer should be in close contact so the proper equipment can be selected Your particular situation may even cause the contractor to recommend that two or more smaller heat pumps be installed, which is called zoning Or some other design alternative may be suggested.

The Air-Conditioning and Refrigeration Institute (ARI) has published **A Standard for Ground Water Source Heat Pumps.** ARI develops and establishes equipment and application standards and certified performance of heating and cooling products.

The purpose of the standard, according to ARI, "is to establish, for ground water source heat pumps definitions and classifications, requirements for testing and rating, specifications, literature and advertising requirements: performance requirements, safety requirements, and conformance conditions

The standard applies to factory-made residential, commercial and industrial units. The current ARI ground water source heat pump definition says that a unit "consists of one or more factory-made assemblies which normally include an indoor conditioning coil with air moving means, compressor(s) and refrigerant-to-water heat exchanger(s), including means to provide both cooling and heating functions. When such equipment is provided in more than one assembly, the separated assemblies shall be designed to be used together, and the requirements of the rating outlined in the standard are based upon the use of the matched assemblies."

Once the heat pump has been selected, the proper distribution system must be designed.

Equipped with the knowledge you have gained from this book you will be better able to select your contractor, understand the equipment and its performance, and better appreciate your energy savings.

WHEN SHOULD I DECIDE AGAINST A GROUND WATER HEAT PUMP?

Obviously, if you live in an area with inadequate or poor quality ground water that can t be used with a ground water heat pump, you already face the most serious limitation Also, if other heating and/or cooling methods appear to be more efficient on the long term basis than the ground water heat pump, then ground water equipment may not be for you.

If you live in a northern climate and can survive summer without cooling, or in a southern climate that erases the need for winter heat, you would not need the more costly reversing ground water heat pump A single-cycle heating or cooling ground water heat pump may be for you, and still be more cost-effective than an air to-air heat pump

WHO MAKES GROUND WATER HEAT PUMPS?

There are ground water heat pump manufacturers throughout the United States, Canada and Europe. Some companies are large and some are small.

To contact ground water heat pump manufacturers, write or call the companies listed in this booklet.

WHAT SHOULD I LOOK FOR IN SELECTING A MANUFACTURER?

More than likely, you won't be selecting a manufacturer. You ll be selecting a distributor or installer that has already made a product line decision. Ask him what led him to that company Using the knowledge you have obtained from this book, assess his answers and the product literature he makes available to you

WHAT'S THE FUTURE MARKET OF THE GROUND WATER HEAT PUMP?

In 1976 ground water heat pump sales were approximately 10,000 units. In 1980 that figure was estimated at 30,000 units.

The Air-Conditioning and Refrigeration Institute found that 48 percent of all new houses with central air conditioning built in the United States during 1978 had heat pumps (of all types) That figure grows each year

In 1979, **Air Conditioning, Heating and Refrigeration News,** a trade magazine, reported that its market research found that the ground water heat pump market would grow 30 to 35 percent annually

Ground water heat pumps are often most cost-effective for new homes, since the retrofit of water pipes and heating

ducts is very costly Further, the new home market is very large The National Association of Home Builders estimated in 1981 that approximately 20 million new family units will be required in the United States during the 1980s.

Nevertheless, retrofitting represents the greatest potential for energy savings on a statewide basis, and it becomes increasingly cost effective as energy costs rise The retrofit market also is large Approximately 600,000 or 5 percent of all homeowners, are expected to replace their heating systems each year

The National Water Well Association has estimated that the market could grow to upwards of 750,000 units a year, based on the following reasoning There are approximately 12 million existing domestic water wells in the United States, of which approximately 600,000 need rehabilitation each year By 1985 approximately half of these homeowners will use that opportunity to retrofit their house or business with ground water heat pumps, accounting for a 300,000 unit market, according to NWWA. In addition, there are about 400,000 new houses constructed each year that use ground water supplies and could potentially also use a ground water heat pump NWWA Executive Director Jay Lehr predicts that by 1990 75 percent of all new houses in the U.S built on quarter-acre lots or larger will be heated by ground water heat pumps.

WHY IS THE NATIONAL WATER WELL ASSOCIATION SO ACTIVELY PROMOTING THE USE OF A HEATING AND COOLING SYSTEM?

Like all Americans, the National Water Well Association is concerned about America s dependence upon foreign energy resources We believe that we all should do what we can to decrease our energy consumption while maintaining the comfort of our standard of living. Besides, why should we burn a precious chemical resource such as petroleum?

And of course, the use of ground water and water wells and water well equipment is in the interests of those members of the international ground water industry we represent. The ground water heat pump is but a part of those interests.

HOW CAN I GET MORE INFORMATION ON GROUND WATER HEAT PUMPS FOR MY SPECIFIC APPLICATIONS?

While you may contact the manufacturers that we have listed in this book, we suggest that you contact your local heating and air-conditioning contractor If he can t help you contact local HVAC suppliers, electric cooperatives, HVAC trade organizations or the National Water Well Association for a list of contractors in your area who are familiar with ground water heat pumps

For even more information, review the catalog of materials available on ground water heat pumps from NWWA and place your order today

The following materials are suggested for more information on ground water, wells and heat pumps·

To order, contact the National Water Well Association/ 500 W Wilson Bridge Rd./Worthington, OH 43085/ 614-846-9355
When You Need a Water Well. $ 50
America s Priceless Ground Water Resource · 1977. $ 50
Heat Pump Anthology II · 1982. $6.25
Ground Water Heat Pump Installation in Michigan · 1983 $5
Water Source Heat Pump Handbook · 1983. (Call for price)

Additional reading:
Standard for Ground Water Source Heat Pumps 1982. Air Conditioning and Refrigeration Institute, 1815 North Fort Myer Dr Arlington, VA 22209 $4 50

Guidebook to Water Source Heat Pumps 1981 National Conference of State Legislatures, 1125 Seventeenth St., Ste 1500, Denver, CO 80202.

WATER-SOURCE HEAT PUMP MANUFACTURERS

This list of water-source heat pump manufacturers is as complete as possible prior to date of publication Information comes from a questionnaire and company brochures For the most accurate information contact each individual manufacturer.

American Air Filter, Allis-Chalmers Co Environmental Control Div Residential GWHP Dept. P.O. Box 35530 Louisville, KY 40277 Telephone· (502) 637-0325 Contact: Robert Newton Distribution U S Literature available: Yes	EnerCon Water-to-air residential units Cooling capacity range—9,500 to 62,000; heating—12,500 to 68,000
American Solar King P O. Drawer 7399 Waco, TX 76710 Telephone (817) 776-3860 Contact: Chuck Cagle	
American Sun-Sol Samlin Enterprises 701 S Dixie Dr Vandalia, OH 45377 Telephone. (513) 898-9733 Literature available: Yes	Geo-Thermal Ground Water System
Aug G Barkow Mfg Co Inc. 2230 South 43rd St. Milwaukee, WI 53219 Telephone. (414) 671-1790 Contact. Robert F Barkow Distribution: Throughout U.S. and Canada by 150 distributors Literature available. Yes	Weatherwise Water to-air units for commercial applications. 10,000 to 27,100 Btu cooling· 11,500 to 28,900 Btu heating.
Bard Mfg Co Evansport Rd. P O Box 607 Bryan, OH 43506 Telephone (419) 636-1194 Contact: James R. Bard Distribution U S , Canada, overseas Literature available Yes	Bard Water-to-air units for residential & commercial use. Cooling—31,400 to 37,400 Btu, heating—27,200 to 34,850 Btu.
Borg-Warner Corp , York Div. P.O Box 1592 York, PA 17405 Telephone (717) 864-7890 Contact George Simonson Literature available Yes	Triton Water-to-air units with cooling capacity of 19,000 to 40,000 Btu Heating capacity range of 22,500 to 45,000 Btu
California Heat Pump 2314 Michigan Ave Santa Monica, CA 90404 Telephone (213) 829-9275 Contact. Bob Lodge, Herb Rose, Steve Trelease Distribution: U.S. & Canada through 61 representatives Literature available: Yes	California Heat Pump Water-to-air units for residential & commercial use Residential cooling is 13 000 to 61 000 Btu Heating—15,000 to 67,000 Commercial heating—7,000 to 390,000; cooling—8,000 to 410,000
Cantherm Heating Ltd 8089 Trans Canada Hwy Ville St. Laurent, Quebec Canada H4S 1S4 Telephone· (514) 334-4879 Contact: Sven G Oskarsson Literature available: Yes	Aquatherm and Terratherm Water to-air and closed loop earth coupled heat pump systems
Carrier Corp Carrier Parkway Syracuse, NY 13221 Telephone: (315) 432-6779 Contact: Local distributor Distribution. U S & export Literature available. Yes	Weathermaker Water-to-air units for residential and commercial applications. Cooling range for residential is 14,000 to 80,000 Btu, heating—17,000 to 82,000 Commercial cooling—6,500 to 80,000, heating—9 000 to 82,000
Command/Aire Corp P O Box 7916 Waco, TX 76710 Telephone: (817) 753-3601 Contact: Ralph Heaterly	Command/Aire Water-to-air residential and commercial units Residential cooling—9,500 to 64,000; heating—13,500 to 94,000. Commercial cooling—88,000 to 438,000. heating—128,000 to 608,000
Dunham Bush Inc. 175 South St. West Hartford, CT 06110 Telephone. (203) 249-8671 Contact: Ronald B Winkel Distribution Throughout U.S by 100 distributors Literature available. Yes	Dunham-Bush Commercial water to-air heat pumps with cooling range of 1 08 MMBH to 4 21 MMBH heating range of 1 55 MMBH to 5 11 MMBH

Energy Control Systems Inc. 5580 White Creek Rd. Marlette, MI 48453 Telephone: (517) 635-2359 Contact: John G Van Steenis Literature available: Yes	Hydron Water-to-air units
Fedders Solar Products Co Climatrol Division Edison, NJ 08817 Telephone: (201) 549-7200 Contact: Mira Kostak Literature available: Yes	Carnot II Solar/Compression Furnace Water-to-water units
FHP Manufacturing Division Leigh Products Inc. 610 S W 12th Ave Pompano Beach, FL 33060 Telephone: (305) 781-0830 Contact: H F Waser, C.E. Smith Distribution: U S and export by 87 distributors Literature available: Yes	Florida Heat Pump Water-to-air units for commercial and residential use. Cooling—10,000 to 240,000 Btu, heating—13,000 to 290,000 Btu.
Friedrich Air Conditioning & Refrigeration Co 2007 Beechgrove Utica, NY 13501 Telephone: (315) 724-7111 Contact: Mike Linkiewicz Literature available: Yes	Geo-Thermal Heat Pumps Water-to-air units. Cooling capacity range of 15,100 to 63,800 Btu. Heating capacity range of 15,800 to 68,000 Btu.
GeoHeat Co R D 5 P O Box 71 Georgetown DE 19947 Telephone: (302) 856-2091 Contact: Bill Burns Distribution: Local through one distributor	Geoheater III Residential water to-air units with cooling capacity range to 40,000 Btu, heating capacity range to 50,000 Btu. Residential water-to-water units with heating capacity range of 40 to 1,000 Btu.
GeoSolar Energy c/o Memtel Corp P O Box 2171 Gaithersburg, MD 20760 Telephone: (301) 926-1891	
GeoSystems 3623 N Park Dr Stillwater, OK 74074 Telephone: (405) 372-6857 Contact: Jim Partin	Develops closed loop, earth-coupled heat pump systems.
Heat Controller Inc 1900 Wellworth Ave. Jackson, MI 49203 Telephone: (517) 787 2100 Contact: E.D Saylers Distribution: National Literature available: Yes	Comfort-Aire and Century Water-to-air units for commercial and residential applications. Residential cooling range—21,000 to 65,000 Btu, heating—29,500 to 78,000 Commercial cooling—100,000 to 390,000, heating—105,000 to 410,000
Heat Exchangers Inc 8100 Montucello Ave Skokie, IL 60076 Telephone: (312) 679-0300 Contact: Dennis Devlin Distribution: U S & export Literature available: Yes	Koldwave Water to-air units for commercial and residential applications. Residential cooling range—7,000 to 96,000 Btu, heating—7,800 to 112,000 Commercial cooling—6,800 to 228,000, heating—8,300 to 268,000
Lear Siegler Mammoth Div 13120-B County Rd 6 Minneapolis, MN 55441 Telephone: (612) 559-2711 Contact: R McKinley Literature available: Yes	Sol-A-Terra
Marvair Co P O Box 400 Cordele, GA 31015 Telephone: (912) 273-3636 Contact: W B Johnston Distribution: 24 southeast U S distributors Literature available: Yes	Marvair and Cnspair Water-to-air heat pumps for commercial and residential applications. Cooling capacity range—22,000 to 41,000 Btu, heating capacity range—25 000 to 54 000
National GeoThermal 1507 Buffalo Rd. P O Box 703 Lawrenceburg, TN 38464 Telephone: (615) 762-7106 Contact: James J Tiedjens Distribution: National Literature available: Yes	Hydro-Solar Water to-air units for residential and commercial applications. Cooling range—9,000 to 144,000 Btu; heating range—10,100 to 174,000 Water-to-water units for commercial use only have cooling range of 40,000 to 500,000 Btu; heating—42,000 to 555,000
Northrup Inc 302 Nichols Dr Hutchins, TX 75141 Telephone: (214) 225-7351 Contact: Harold Hammer, Chuck Harley	En-Ex System Water to-air units for residential and commercial applications Residential cooling—9,000 to 72,000 Btu, heating—11 000 to 100 000 Commercial

Distribution. 175 worldwide distributors Literature available: Yes	cooling—80,000 to 228,000; heating—94,000 to 248,000.
Phoenix Enviro-Tech 651 Vernon Way El Cajon, CA 92020 Telephone (714) 579-3883 Contact: Robert L. Watkins Distribution U.S. & export Literature available Yes	Phoenix Enviro-Temp Water-to-air units for residential and commercial applications Cooling—27,500 to 76,250, heating—33,000 to 95,000 Water-to-water units for residential and commercial applications Cooling—27,500 to 76,250, heating—33,000 to 95,000.
Prime Energy Systems Ltd. 787 Alness St. Downsview, Ontario Canada M3J 2H8 Telephone: (416) 661-3303	Dantherm
The Singer Co Climate Control Div 1300 Federal Blvd Carteret, NJ 07008 Telephone. (201) 636-3300 Contact: Robert P. Shapess	Singer Heat Pump Water to-air residential heat pump. Cooling range capacity—14,000 to 47,000 Btu. Heating range capacity—18,000 to 58,000 Btu.
SolarGen Corporation 1136 Wilmington Ave. Dayton, OH 45420 Telephone: (513) 258-0808 Contact: Carl C. Marx Literature available: Yes	Solar and geothermal reservoir heating and cooling systems.
Solar Oriented Environmental Systems Inc. 10639 Southwest 185th Terrace Miami, FL 33157 Telephone: (305) 233-0711 Contact: Scott Balmer	Power Saver Special Water-to-air units have cooling range of 11,000 to 144,400 Btu, heating range of 17,848 to 243,614 Btu. Water-to-water units.
Tempmaster Enterprises Inc. 1775 Central Florida Pkwy Orlando, FL 32809 Telephone: (305) 851-9410 Contact: Ben Benner Distribution 12 distributors in U.S. and Europe Literature available: Yes	Tempmaster Water-to-air units for residential and commercial applications Residential cooling—13,000 to 72,000, heating—15,000 to 85,000. Commercial cooling—90,000 to 360,000, heating—104,000 to 400,000 Water-to-water units for residential and commercial Residential cooling—13,000 to 72,000; heating—15,000 to 85,000 Commercial cooling—90,000 to 360,000, heating—104,000 to 400,000
Thermal Energy Transfer Corp. P.O. Box 397 Powell, OH 43065 Telephone (614) 889-6660 Contact: Hank Gregory Literature available: Yes	TETCO Geothermal Heat Extractor Water-to-air unit. Cooling range—18,900 to 79,700 Btu Heating range—43,350 to 55,250
The Trane Co. Commercial Air Conditioning Div. LaCrosse, WI 54601 Telephone (608) 787 3107 Contact: Richard Figgie	Trane EnergyFit Heat Pumps Water-to-air units with cooling capacity range of 6,800 to 39,000 Btu. Heating range of 10,000 to 42,000
Vanguard Energy Systems 9133 Chesapeake Dr. San Diego, CA 92123 Telephone: (714) 292-1433 Contact: Gordon W. Fabian Distribution: U.S., Canada, England through 18 distributors Literature available: Yes	Vanguard Heat Pump Water to-air units for residential and commercial applications. Cooling—24,000 to 112,000 Btu; heating—30,000 to 140,000 Water-to-water units for residential and commercial applications. Cooling—24,000 to 64,000, heating—30,000 to 84,000
Waterkotte Warmpumpen Gesellschaft mit beschrankter Haftung Horsthauser StraBe2 4690 Herne 1 West Germany Telephone: (49) 02323/50543 Literature available: Yes (in German)	
WeatherKing Inc. Addison Products Co. P.O. Box 20434 Orlando, FL 32814 Telephone (305) 894-2891 Contact: Jim Benjamin Literature available: Yes	WeatherKing Water-to-air units with cooling capacity range of 13,000 to 46,000 Btu, heating capacity range of 29,500 to 78,000 Btu.

Wilcox Cool Heat Solar Inc. 11203 49th St. N Clearwater, FL 33520 Telephone: (813) 577-5154 Contact: C.M. Wilcox Literature available: Yes	Wilcox Water Model Heat Pump Water-to-air unit with cooling capacity range of 14,500 to 45,300 Btu; heating capacity range of 13,100

Section 3.3

Aquaculture Disposal Wells Supporting Data

SECTION 3.3.1

TITLE OF STUDY: (or SOURCE OF INFORMATION)	Draft Report of Investigation Class V Injection Well Inspections, Oahu and Hawaii Islands, Hawaii
AUTHOR: (or INVESTIGATOR)	Engineering Enterprises, Inc.
DATE:	November, 1985
FACILITY NAME AND LOCATION:	Marine Culture Enterprises Laie, Hawaii USEPA Region IX
NATURE OF BUSINESS:	Aquaculture. The facility grows shrimp under controlled conditions.
BRIEF SUMMARY/NOTES:	The following is a copy of the results of a well inspection conducted at this facility. The wells received water used in the aquaculture process. Severe clogging problems resulted and the wells were not in use at the time of the inspection.

UIC INSPECTION REPORT

SECTION I - General Information

Name of Facility: Marine Culture Enterprises

Address: P.O. Box R
Laie, HI 96762

Telephone: (808) 293-2466

Owner Address and Telephone (if different from above):

Same

Nature of Business: Aquaculture. The facility grows shrimp under controlled conditions.

Use of Injection Well(s): The wells are not currently used. When they were in use they recieved water used in the aquaculture process.

Permit # (or Permit Application #): UO1315

Injection Well(s) Location (Island, Tax Map Key, latitude, longitude, land marks, verbal description):

Latitude: 21° 42' 00' W Tax Map Key #:5-7-02:9
Longitude: 157° 57' 45" N

Type of Injection Well(s):

Industrial_____
Domestic_____
Drainage_____
Other___X___

Injection Well Currently Operating: Yes ____ No __X__

If No, Last Date Of Operation: February, 1985

Future Plans to Operate: Yes ____ No __X__

If Yes, Date:

SECTION II - Hydrogeologic Information

Well Completion Details (complete attached diagram)

Subsurface Geology and Hydrology Data for Site:

Coral Aquifer

Injection Formation Name: Pleistocene Coral Reef

Attach the Following Information (note if unavailable):

1. Map of Facility Grounds:

2. Well Logs(s) of Injection Well: NA

3. As-built Diagram of Injection Well: NA

4. Consultant Reports for Injection Well: NA

5. Monitoring Data for Injection Well: NA

6. Location and Data for Nearby Wells: There are three wells on-site which supply salt water for the aquaculture process. These wells are approximately 1000 feet north of the injection wells.

7. Monitoring Data for Nearby Wells: NA

8. Status of Any Downgradient Water Supply Wells: NA

9. Status of Any Nearby Surface Waters (possibly affected by well operations): This plant has an NPDES discharge permit and now uses a surface discharge to the ocean instead of using injection wells.

SECTION III - Operating Data

Injection Rate, Frequency, and Volume:

The current discharge under the NPDES permit is 7000 gpm or 10 mgd. However, when the wells were operating the plant was not at full capacity and discharge was only 1.2 - 3.5 mgd.

Description of Injection Operation (including brief history):

The wells were constructed in August, 1984 and used until February, 1985. As the plant increased in capacity the wells began to clog and it became apparent that wells would not handle the discharge. A ditch to the sea was built and the plant now discharges under an NPDES permit. The wells serve as an emergency backup.

Surface Facilities/Treatment Process: None

Wastewater Sources:

Salt water effluent from aquaculture project.

Generalized Waste Category(ies)/Composition:

Salt water with added nutrients. Effluent contains nitrates, nitrites, annoxia, high BOD, and orthophosphate. The pH is approximately 7.5.

Visual Appearance of Well:

The wells are located approximately 10 feet from the canal which is used to take effluent from the growing tanks. There is a large screened intake in the center of the canal which is plumbed into the wells. The wells are 24" PVC casing set in a 30" diameter hole. The casing is flush with the ground and is covered with a 30" diameter steel plate with a vent pipe. Effluent enters the well approximately 4 feet below ground.

Method of Disposal (transport to well):

Effluent is transported to the well intake structure by a canal. The intake is connected to the well by an underground PVC pipeline. Flow is by gravity only.

Previous Problems with Well: Yes X No _____
(e.g. clogging, overflowing, excessive suction, etc.)

If yes, describe:

The wells have experienced severe clogging problems. This is probably the result of a combination of suspended solids and bacteriological growth.

Attach the following (note if unavailable):

1. All Analyses of Wastewater: NA

2. All Operating Records: NA

SECTION IV - Inspection Specifics

Name and Affiliation of Inspectors: Lorraine Council, EEI
David Shepard, EEI
William Bohrer -
EPA Region IX

Name and Affiliation of Facility Contact: Bill Salser
Vice President
Marine Culture
Enterprises

Date: 8/5/85 Time: 1:30 pm

Reason for Inspection: The inspection is part of an EPA nationwide inventory and assessment of the various types of Class V injection wells. This facility was primarily inspected to verify the permit application information submitted to the Hawaii Department of Health and to observe the condition of the injection well and any related processes.

Number of Injection Wells: 3

Number of Injection Wells Inspected: 3

Site Conditions at Inspection:
(e.g.) weather, tides, description of environs, etc.)

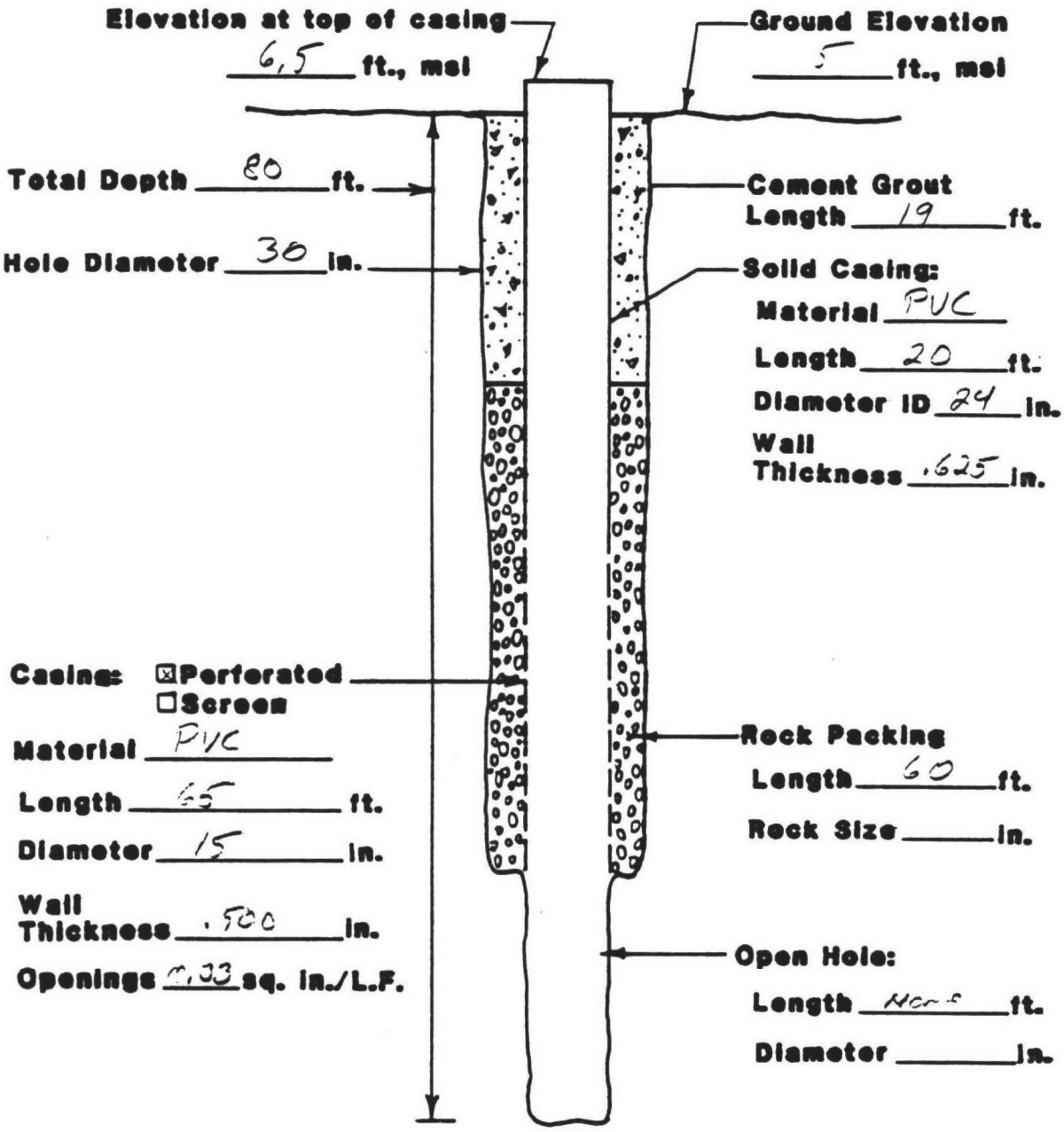
Cloudy, 85°

Inspection Comments: The three wells at this facility operated for less than seven months before clogging problems prevented their use. The facility now uses a surface discharge regulated under the NPDES program. The clogging was probably the result of high amounts of suspended solids and organic matter present in the injected fluid. There are no plans to use the wells again, however, there is a possibility that they could be used for a short period in an emergency.

The only other known wells in the area are located on the facility grounds and provide salt water for the aquaculture process. Access to the site is controlled by a security fence with a closed circuit television monitoring system.

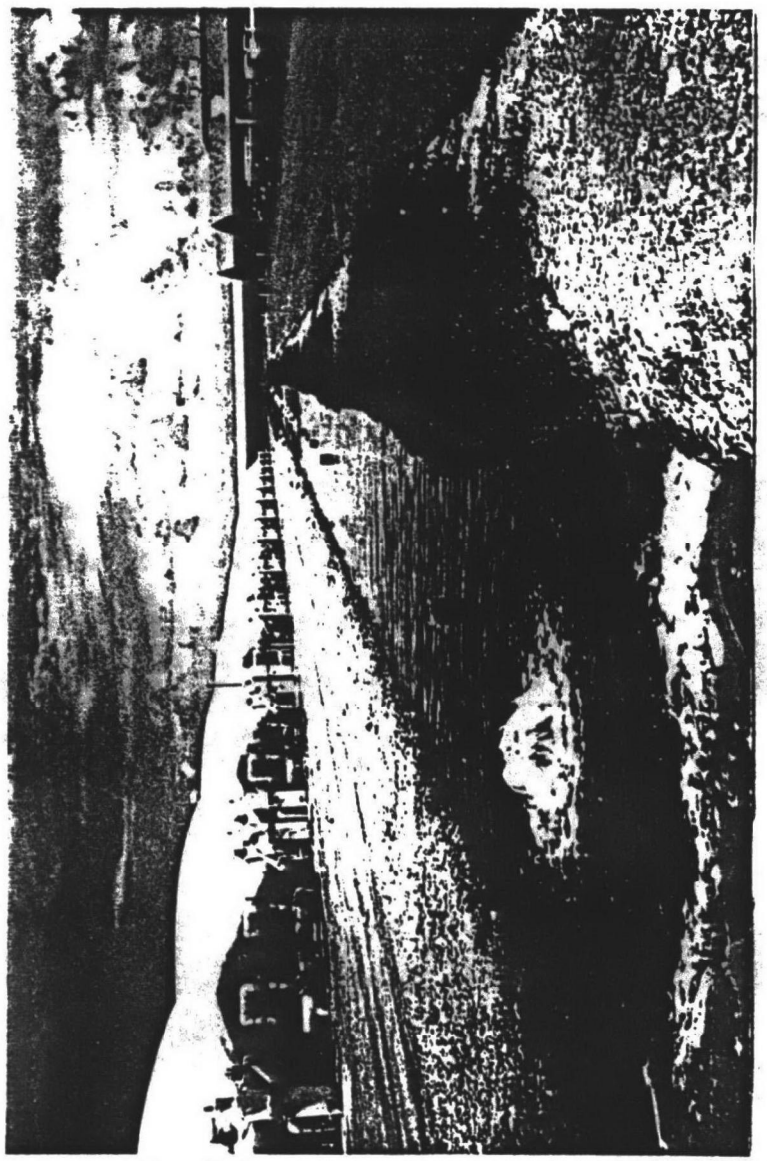
Inspection 6

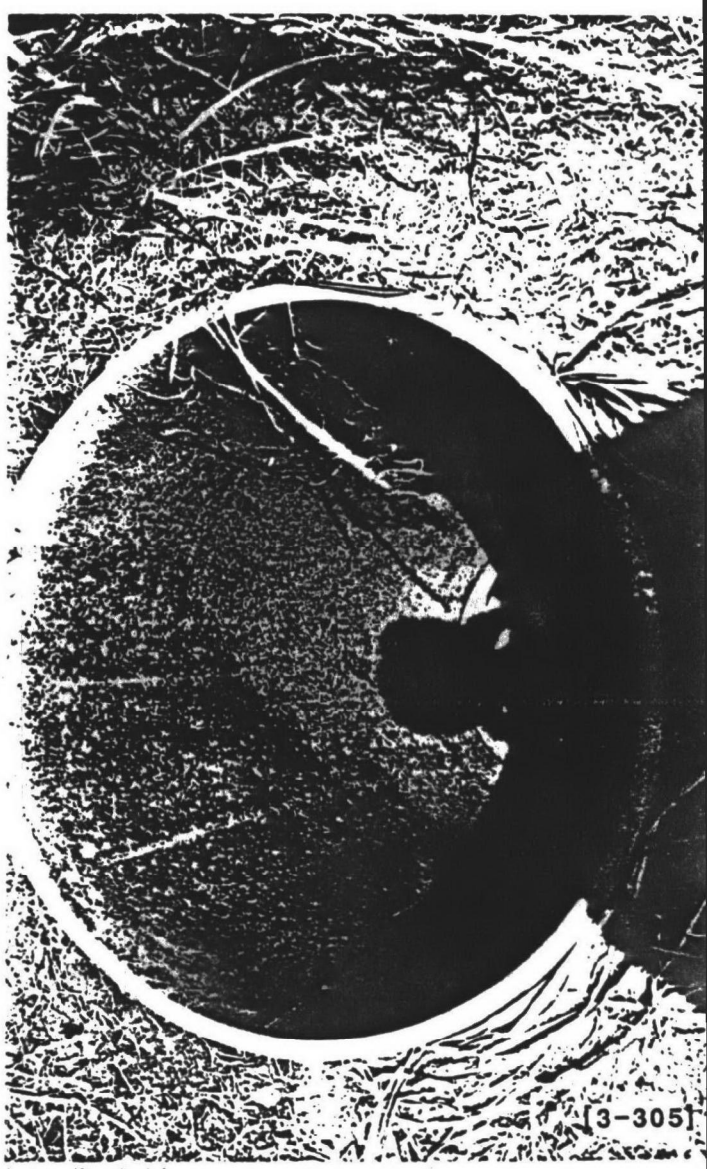
Construction Logs for all 3 injection wells



NOTES:

1. For existing wells, provide actual elevation section.
2. Include additional casing, grout seal, liner tubes, sump, etc. if applicable.
3. If design of well differs substantially, provide section showing actual construction.





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SECTION 4

Domestic Wastewater Disposal Wells

Section 4.1

Raw Sewage Waste Disposal Wells and Cesspools
Supporting Data

SECTION 4.1.1

TITLE OF STUDY: (or SOURCE OF INFORMATION)	From An Assessment of Class V Underground Injection in Illinois, Interim Report. Phase One: Assessment of Current Class V Activities in Illinois
AUTHOR: (or INVESTIGATOR)	S.L. Burch and B.R. Hensel, Illinois State Water Survey Division, Illinois State Geological Society
DATE:	July, 1986
STUDY AREA:	Illinois, USEPA Region V
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	Included for review are brief discussions of local geology associated with disposal of raw sewage into abandoned coal mines. A regional map and regional cross section are included.

Streator, Southern LaSalle County, Population 15,000.

The City of Streator is located north and east of the Vermilion River (fig. 18) on upland deposits of the Yorkville Till Member of the Wedron Formation. The till may be overlain by five to ten feet of loess. Some sand and gravel deposits are present in the till, however they are not extensive. The uppermost bedrock is shale, sandstone, and several coals of the Pennsylvanian age Carbondale Formation (fig. 19). The Herrin No. 6 Coal has been mined out beneath much of the city. A second, deeper coal, the Rock Island No. 2 Coal, was also mined in the Streator vicinity. Portions of the bedrock, including the Herrin Coal are exposed along the valley wall of the Vermilion River. The coal seams are bounded above and below by geologic materials which have a very low hydraulic conductivity. They may, however, be interconnected at random by test holes. Consequently, contamination of a locally important Pennsylvanian sandstone is possible. Together, the Pennsylvanian units are approximately 200 feet thick. They overlie other water-bearing formations of Ordovician age limestone and sandstone (St. Peter) which are of regional importance (fig. 20). Ground water from these units is utilized by local industries.

There are hundreds and perhaps more than a thousand Class V injection wells in the Streator area. Drop shafts to the roof rock of the abandoned Herrin No. 6 coal mine are commonplace. No pressure is used when injecting: the fluids simply fall to the mine (the injection zone) under the influence of gravity. Because the City draws its public water supplies from the Vermilion River upstream of where the mine opening discharge occurs, there is no immediate threat to the residents using this public water supply. However, there are water wells finished in the drift, in the sandstone just below the Herrin No. 6 Coal, or in the deeper Ordovician and Cambrian aquifers. Although there is no pressure buildup, there is still some potential for leakage from the coal mine and that may adversely affect some of these water wells.

Carrier Mills, Southwest Saline County, Population 2200.

The Town of Carrier Mills is located in the unglaciated portion of southern Illinois. The unconsolidated surfacial deposits consist of up to 15 feet of loess over a thin layer of lacustrine silt and clay of the

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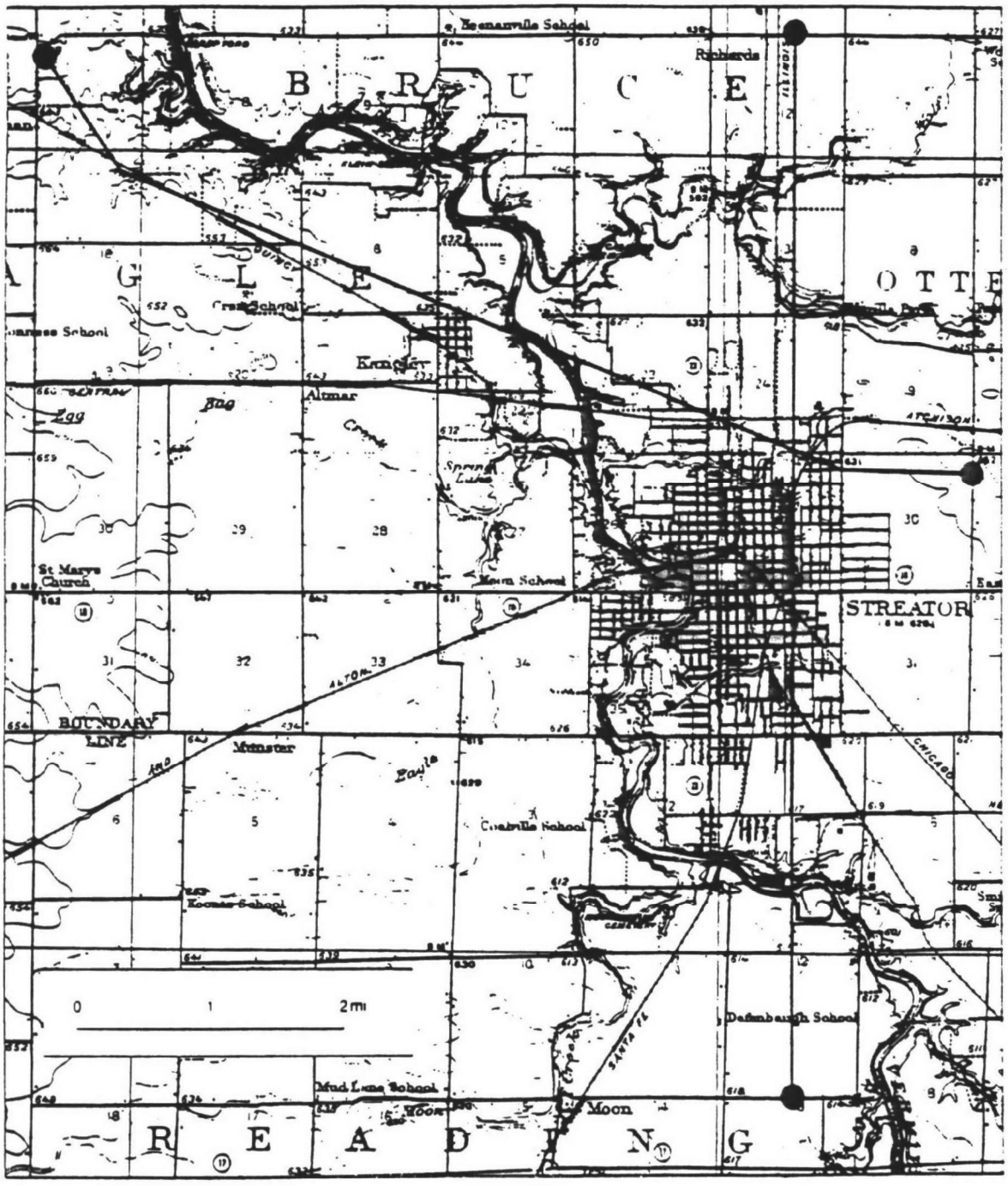

Figure 18. Location map of the Streator area, LaSalle County.

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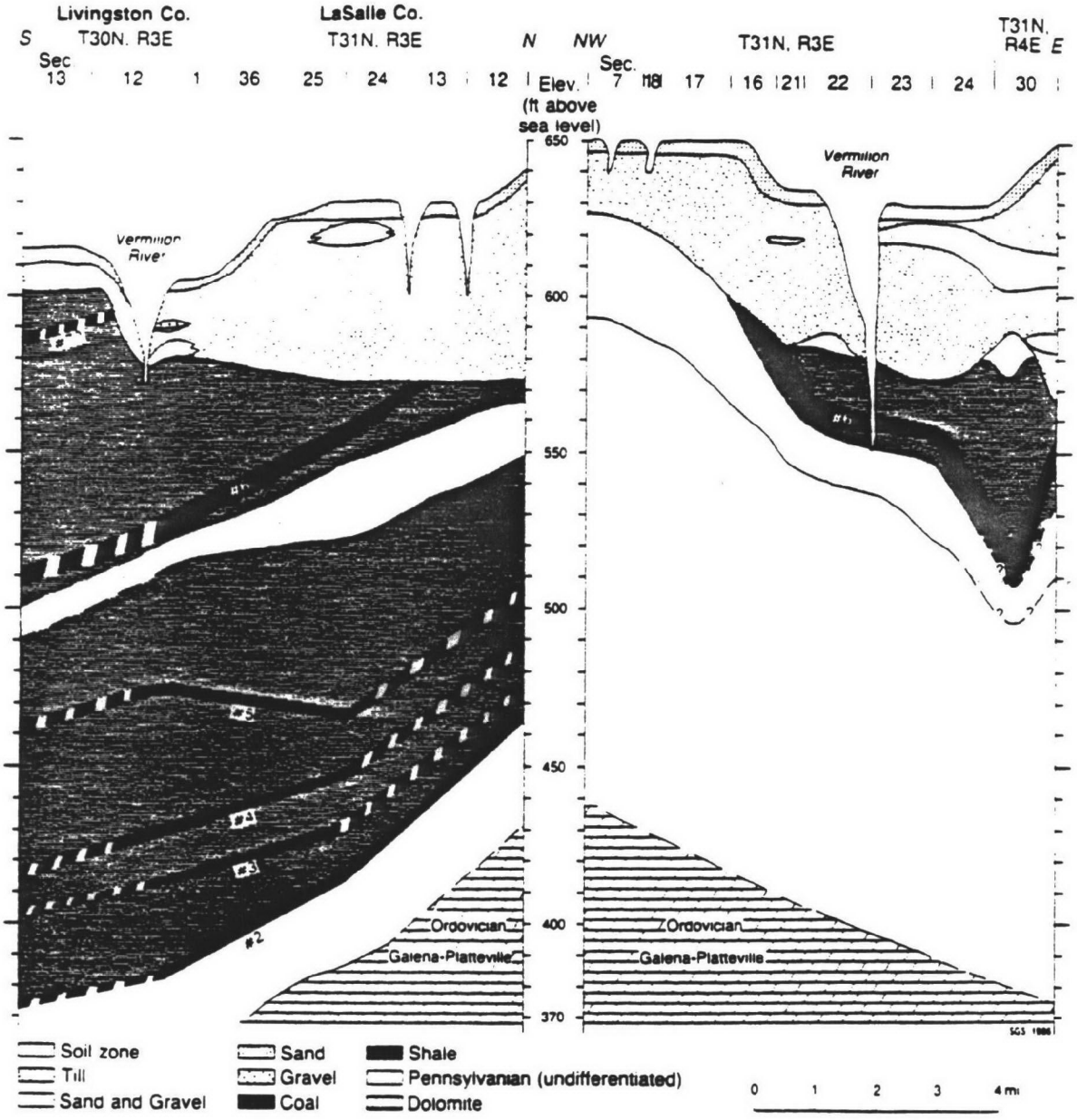

Figure 19. Cross-section through Streator area illustrating coal seams. Approximate orientations of cross-sections are indicated.

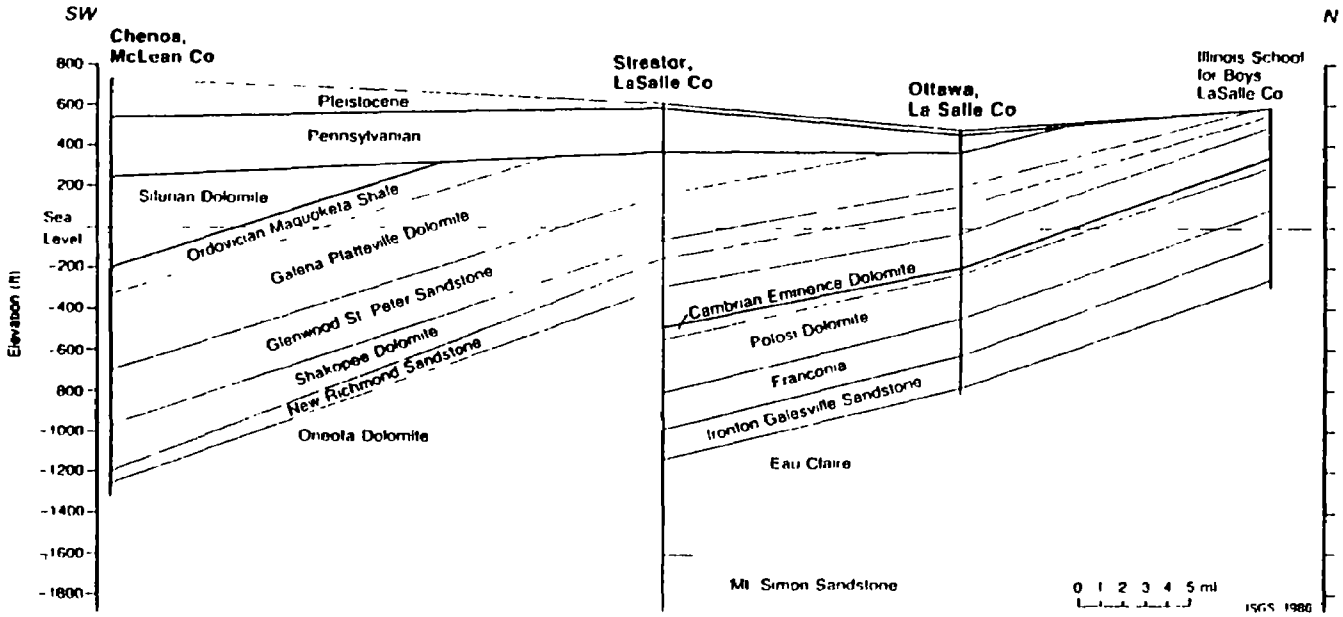

Figure 20. Regional cross-section through LaSalle County based on deep drilling logs. Illustrates stratigraphic relationships of deeper sandstones to the Pennsylvanian age strata (from Willman and Payne, 1942).

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Carmi Member of the Equality Formation. The bedrock (Pennsylvanian age Carbondale Formation) consists of heavily faulted beds of shale with lesser amounts of sandstone, limestone, siltstone, coal and clay. The Springfield No. 5 Coal has been extensively mined out beneath the city. Surface mining has also been practiced in some local areas.

There are 17 known Class V injection wells in Carrier Mills. All of these wells, according to the Class V inventory, are believed to be disposing of domestic sewage into abandoned coal mine seams approximately 75 to 100 feet deep. No records of active water wells are on file with the ISWS, however some dug wells are likely to exist in the rural areas. If any drilled wells are finished in sandstone or fractured shales (50 to 130 feet below ground surface), they may be susceptible to potential leakage from the coal mine. Leakage may occur through or along poorly sealed borings, fractures, and fault zones. Because the community relies on surface water supplies some distance away, it is unlikely that public drinking water supplies will be contaminated.

Herrin, Northwest Williamson County, Population 11,000.

The City of Herrin overlies glacial deposits of the Vandalia Till Member of the Glasford Formation. This clay rich till is 20 to 75 feet thick. Underlying the till is Pennsylvanian age bedrock of the Modesto and Carbondale Formations. The bedrock consists primarily of shale, with lesser amounts of sandstone, limestone, coal, and clay. The area is heavily faulted. Much of the city has been undermined, especially to the north and west.

There are 10 Class V injection wells at Herrin, according to the inventory, which inject domestic sewage into the abandoned Herrin No. 6 Coal mine. All of these wells are approximately 90 feet deep. No water wells are known to operate within the city which utilizes surface water supplies. The absence of any significant ground-water resource near the abandoned mine makes the contamination potential due to Class V injection at Herrin unlikely.

SECTION 4.1.2

TITLE OF STUDY: (or SOURCE OF INFORMATION)	Contamination of Underground Water in the Bellevue Area
AUTHOR: (or INVESTIGATOR)	Ground-Water Geology Section Ohio Division of Water
DATE:	June, 1961
STUDY AREA:	Bellevue, Sandusky, and Erie Counties, Ohio, USEPA Region V
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	Investigations were conducted in the Bellevue area to determine the extent of underground water contamination resulting from the use of sewage disposal wells. Field investigations, chemical analyses, bacteriological analyses, well log analyses, and all area complaints were studied. Results of the study indicated that (1) a large portion of a potential industrial aquifer had been rendered unusable; (2) contamination of the water source can be directly attributed to underground sewage disposal from Bellevue; (3) continued dumping of the contaminants would worsen the situation. Also discussed are the effects of some potential contaminants.

CONTAMINATION OF
UNDERGROUND WATER
in the
BELLEVUE AREA

A Report Prepared For The

OHIO WATER COMMISSION

by the

GROUND-WATER GEOLOGY SECTION
OHIO DIVISION OF WATER

Columbus, Ohio
June 1961
(Reprinted January 1963)

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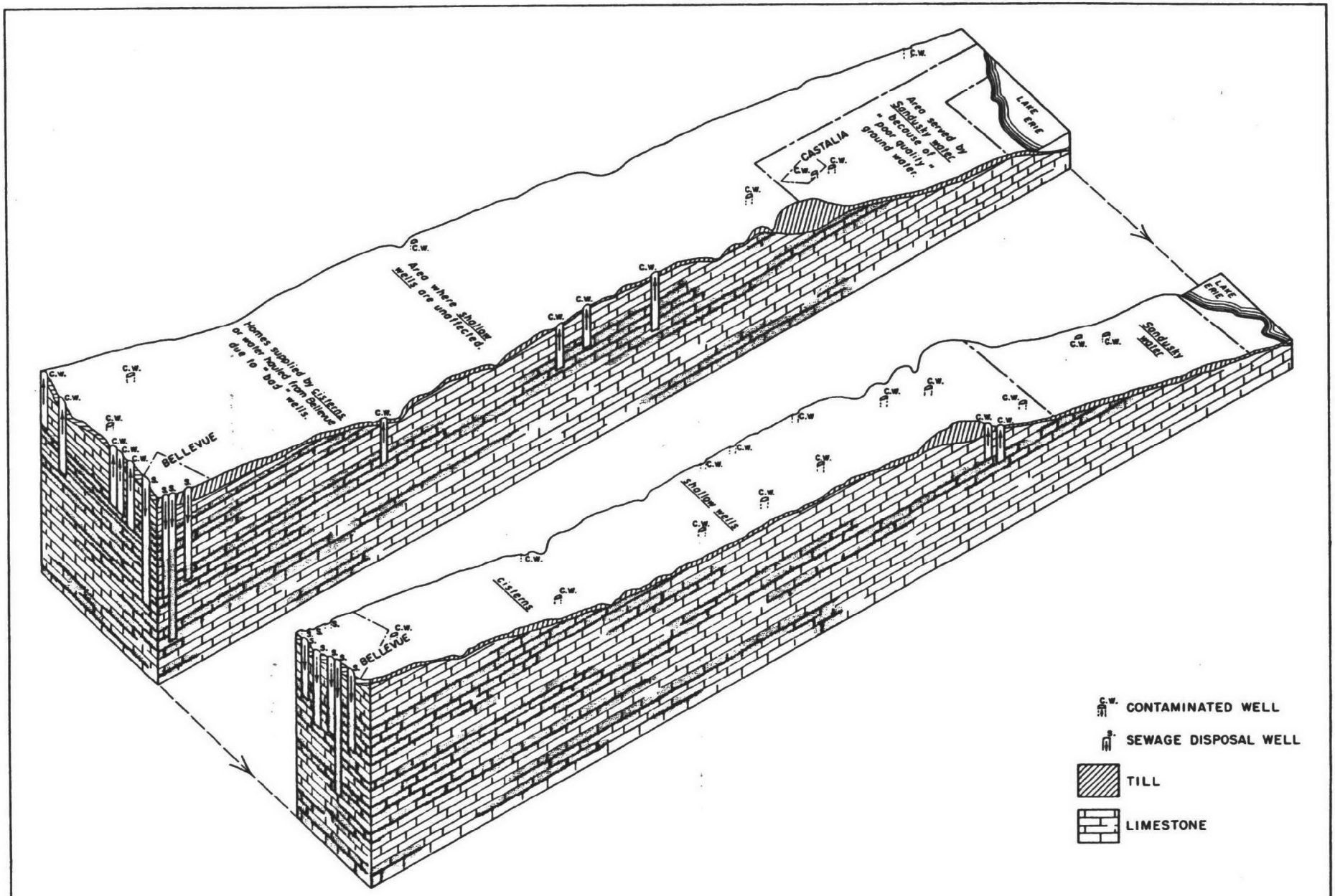


BLOCK DIAGRAM, SHOWING GROUND-WATER CONTAMINATION IN THE BELLEVUE AREA.

I. INTRODUCTION

A report, presented to the Ohio Water Commission in October 1960, pointed out that contamination is introduced in the Bellevue area through wells drilled for sewage disposal. Mention was made of 84 sewage disposal wells drilled within the city in the past seven years; contaminated water wells north of Bellevue in Sandusky and Erie Counties; and, the extremely porous nature of the limestone aquifer which permits contamination to spread over wide areas. This was based largely upon logs of disposal wells drilled for individuals and housing developments.

At that time, members of the Water Commission suggested that a more complete investigation be made of the Bellevue area for the purpose of determining the extent of underground-water contamination.

During the first four months of 1961, field investigations were made by Alfred C. Walker, James J. Schmidt, Henry L. Pree, and Russell B. Stein, geologists of the Ohio Division of Water. Donald Day, Assistant Sanitary Engineer, Ohio Department of Health, assisted in collecting water samples for analysis. Chemical analyses of water samples were made by the staff of the U.S. Geological Survey Quality of Water Laboratory, Columbus, and bacteriological analyses by the Ohio Department of Health laboratory. Additional analyses were supplied by personnel in the health offices of Erie and Sandusky Counties.

During the course of this study, all available well logs and water analyses were collected and studied; water well drillers and well owners were interviewed; old records were studied; and, all complaints were investigated. Mrs. Lydia Rickerds, R.N., Bellevue; George A. Hall, Ohio Water Pollution Control Board; Professor George Hanna, Water Resources Center, O.S.U.; Bruce McDill, Ohio Department of Health;

George Whetstone, U.S. Geological Survey, and many others, including residents of the Bellevue area, offered helpful advice.

A more complete study of this problem might take several years and involve test drilling and continuous sampling. However, we feel that the results of this four-month study show that:

(1) A large portion of a potential industrial aquifer has been rendered unuseable.

(2) Contamination of this water source can be directly attributed to underground sewage disposal from Bellevue.

(3) Continued dumping of contaminants will worsen this already deplorable situation.

Disposing of sewage and other wastes underground is much like sweeping dirt under the rug. It's out of sight, but it's still there.

There is little difference between waste disposal into a groundwater mass and waste disposal into a surface water mass. Although it may be temporarily out of sight, contamination of ground water is far more serious than similar contamination of surface waters. Underground water moves so slowly that years may pass before the contamination is detected. Once it has occurred, it may require many more years before the water is again free from contamination.

II. BACKGROUND

In the city of Bellevue (population 8286), practically every dwelling and industrial plant is provided with a well for the purpose of disposing of sewage.

Wells ranging from 35 feet to 270 feet deep discharge toilet flushings, restaurant and laundry washings, kitchen sink garbage, bath water, mortuary and hospital refuse, etc., into the limestone beneath this area.

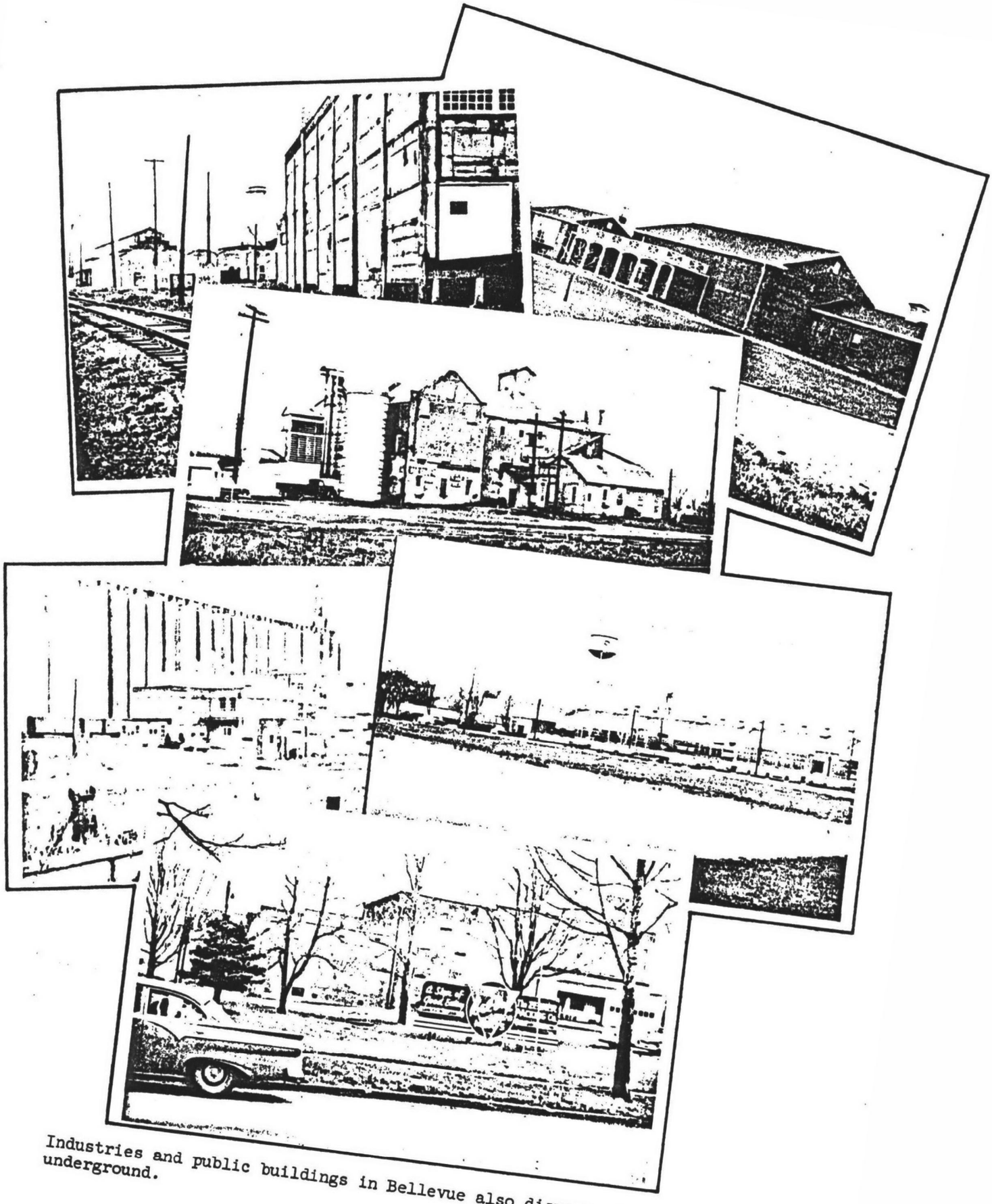
There are more than 1400 privately owned sewage disposal wells, or sinkholes, within the city and more than 200 municipally operated disposal wells, all using the porous limestone bedrock as a sewer. This system comprises what is probably the most concentrated area of underground sewage disposal in the United States.

Contaminated water wells have been reported in the Bellevue area for over 40 years. However, city wells, which were used to supplement the surface water supply, were apparently unaffected until 1944.

A brief resume of the history of Bellevue's water supply is given below.

1872 Water supply system established for the city. Surface source.

1919 A report on proposed improvements of the public water supply states, "The disposal of sewage is effected in a very unusual manner without the use of sewers; by discharging the sewage into so-called sinkholes or drilled wells penetrating the open limestone formations underlying this locality. This method of sewage disposal is quite generally practiced throughout the city and results in rendering drilled wells unsafe sources of water supply."



Industries and public buildings in Bellevue also dispose of sewage underground.

1932 Water well drilled as an auxiliary water source.

1937 Four storage reservoirs are insufficient to serve the city. Wells drilled to supplement them.

Engineer's report states that during the (1937) flood, ".... a large number of sinkholes containing sewage overflowed and the area immediately surrounding, and for miles north, was polluted with sewage. Analyses of well and cistern water in this area showed a large percentage to be contaminated."

1941 Two additional wells drilled to supplement city water supply. These wells were reported to yield a combined supply of 1050 gallons per minute from depths of around 200 feet.

Water from well (125 feet deep) at France quarry was found to be contaminated. This well was located 0.2 mile west of the city limits and produced 300 gpm.

1942 New city well drilled at water works.

Total depth: 137 feet. Yield: 500 gpm. Total hardness: 408 ppm.

1944 City water wells show contamination.

Plans for developing 500,000 gallons per day ground water supply for soybean processing plant abandoned due to contaminated water obtained at depth of 230 feet.

1945 City plans to abandon wells.

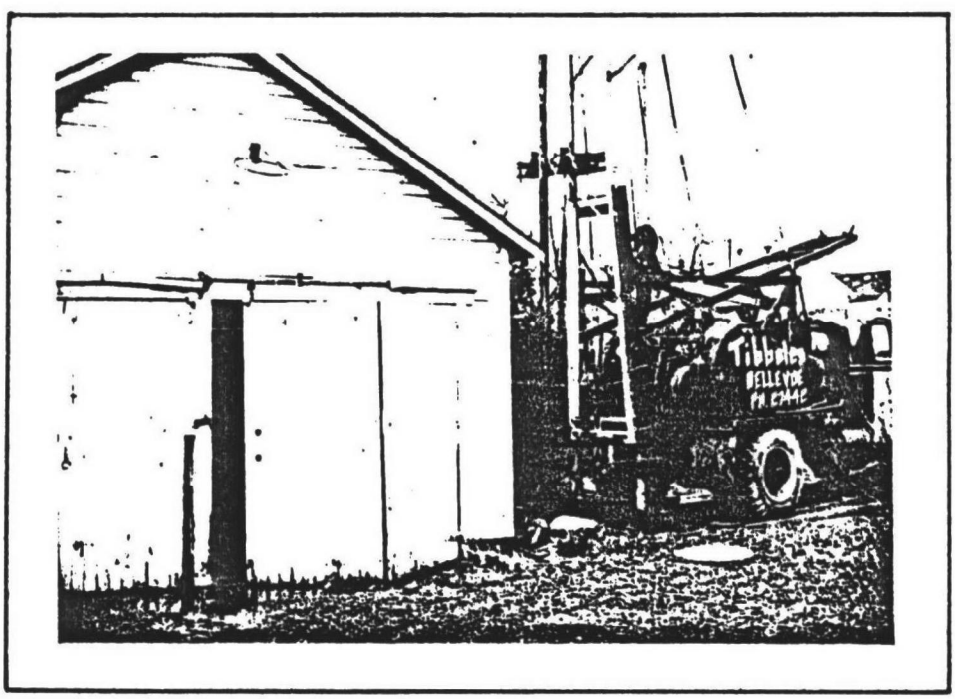
Plans being considered to install adequate sewerage and drainage facilities.

1946 Soybean plant opens using city water and 230-foot sewage disposal well. Additional upground reservoir built by city. City wells abandoned. All industrial wells in the city abandoned.

1947 Plans for sewerage abandoned due to excessive cost.

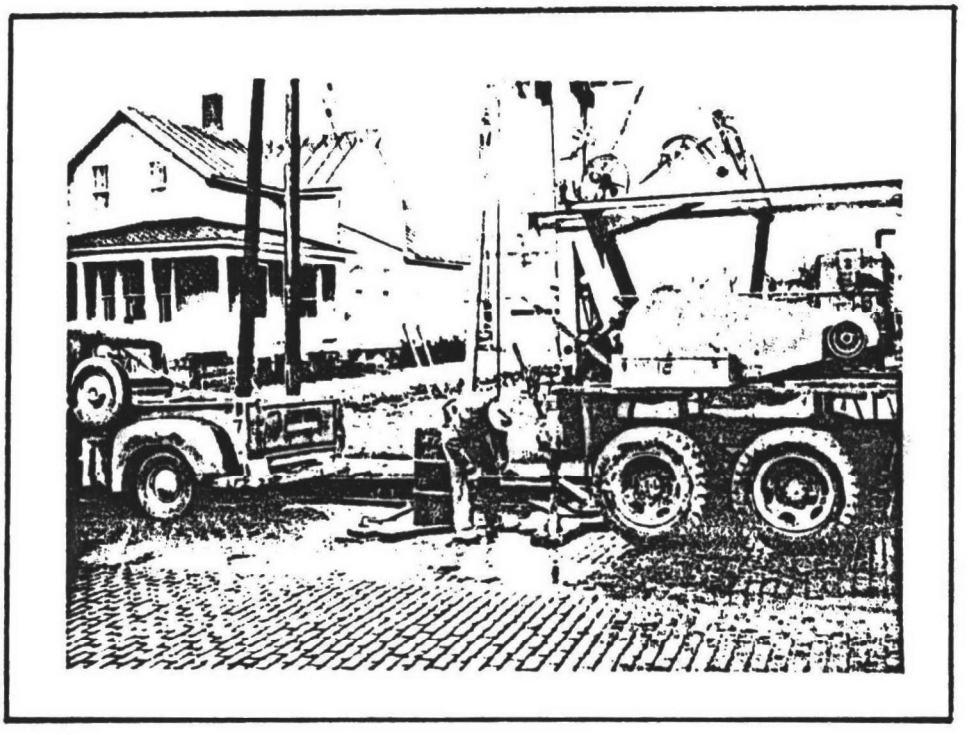
1954 Water supply capacity enlarged to 4 million gallons per day.

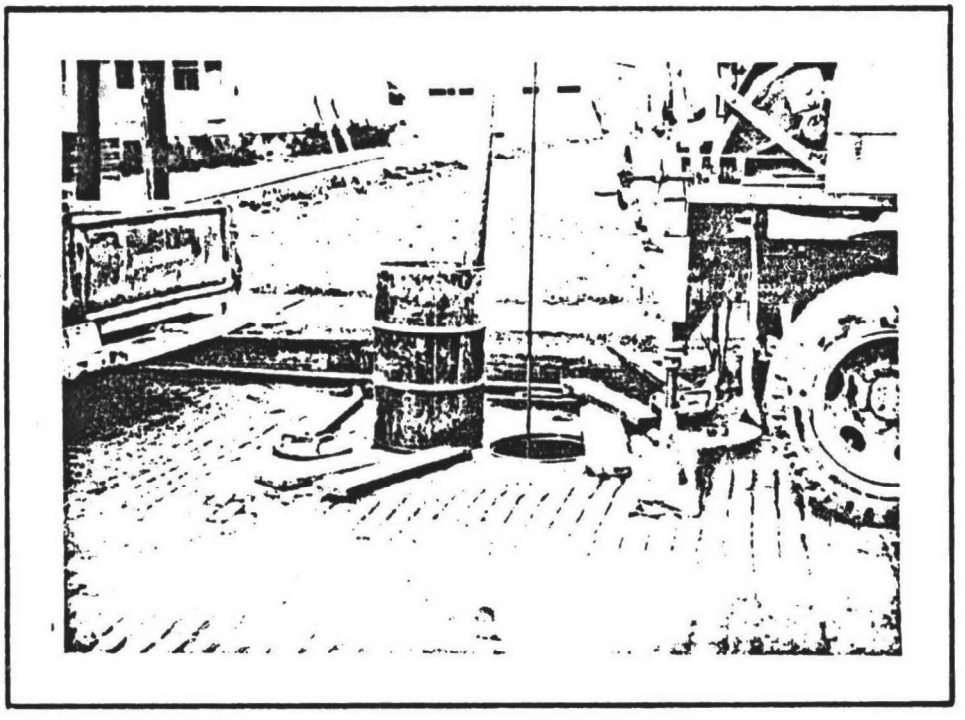
Until recent years, all waste in the city was disposed of directly into drilled wells. Local well drillers reported that, in time, those old wells became completely plugged with sewage and it was necessary to redrill them to remove the "sewage plug" so they would again permit free flow into the limestone. With the increased use of detergents for household use, plugging is reportedly no longer a major problem, although it still occurs.



Household sewage has clogged this disposal well. Re-drilling will again permit free flow into the underlying limestone formations.

The "modern" method of sewage disposal consists of a septic tank installation with the effluent from the tank flowing into a disposal well. Although a portion of the suspended matter has settled out, the remaining suspended matter and matter in solution is still present in septic tank effluent. It was not determined what means is used to dispose of the sludge from these septic tanks.





Buckeye Street, Bellevue

A city storm drainage disposal well has become clogged and is being re-drilled.

Although the Bellevue system of sewage disposal is a vestige of the 19th century, it is not unique in the United States. Nearly the entire State of Florida is underlain by limestone, which provides large supplies of ground water. Since the turn of the century, drainage wells have been drilled for waste disposal into limestone aquifers. This has resulted in continual contamination of ground-water supplies in many areas. In 1913, an act was passed by the Florida legislature to prohibit pollution of surface and ground waters. Although this law provided criminal penalties for its violation, it had no provisions for injunctive enforcement. This loophole was remedied by an amendment in 1955 which has proven helpful to the State Board of Health in its work of underground-water pollution control. (See appendix.) Last year the city of Live Oak, one of Florida's worst offenders for 56 years, completed an adequate sewage disposal system and has abandoned the use of disposal wells.

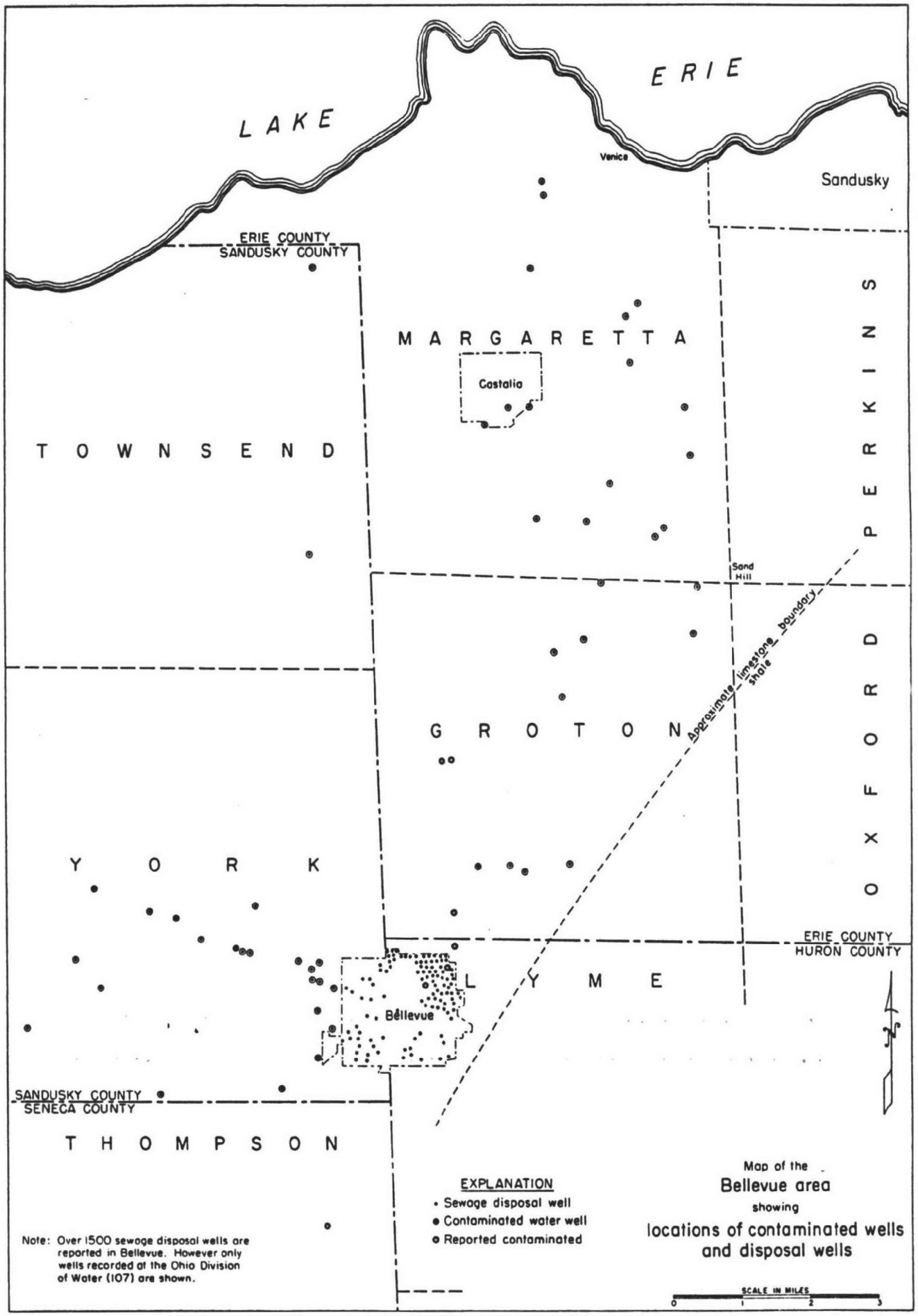
III. PRESENT STUDY

When the investigation was started, it was assumed that contamination introduced through disposal wells in Bellevue was compounded by additional disposal wells beyond the city limits. Field investigations have since shown this to be untrue. Very few disposal wells are in operation outside of the city.

A survey of 52 homes in Groton Township, Erie County, revealed that only one home uses a well, or sinkhole, for sewage disposal. Numerous disposal wells reported in Lyme Township, Huron County, were all found to be located within the city limits. None are known to exist elsewhere in this township. Wells and natural sinkholes were formerly used west of Bellevue in York Township, Sandusky County. In recent years, however, these have been replaced by septic tanks and leaching tile fields under the direction of the Sandusky County health authorities. Thus, with very few exceptions, the only direct underground contamination in the entire area is from Bellevue proper. The locations of disposal wells determined by this survey are shown on page 10.

Probably the most serious danger associated with domestic sewage is the possible presence of pathogenic micro-organisms. Recent studies of domestic sewage have shown viruses to be another danger. Professor W. L. Mallman, Michigan State University, has indicated that viruses can travel great distances in ground water and that chlorine is ineffective against them.

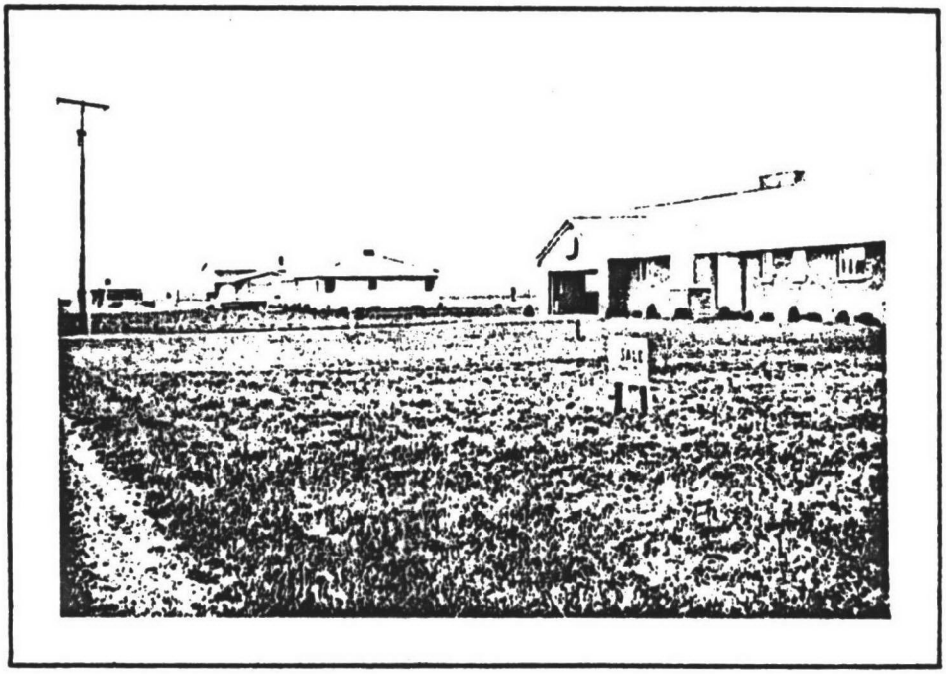
This same study shows that in granular materials, such as sandstone, bacteria will travel only a few feet from the point of entry. However, in limestone aquifers, where free movement is not restricted, the


LAKE ERIE
Venice
Sandusky
ERIE COUNTY
SANDUSKY COUNTY
MARGARETTA
Castalia
TOWNSEND
PERKINS
Sand Hill
Approximate limestone boundary
shale
GROTON
OXFORD
YORK
ERIE COUNTY
HURON COUNTY
LYME
Bellevue
SANDUSKY COUNTY
SENECA COUNTY
THOMPSON
EXPLANATION
• Sewage disposal well
● Contaminated water well
⊙ Reported contaminated
Note: Over 1500 sewage disposal wells are reported in Bellevue. However only wells recorded at the Ohio Division of Water (107) are shown.
Map of the
Bellevue area
showing
locations of contaminated wells
and disposal wells
SCALE IN MILES
0 1 2 3

[4-2

travel of bacteria is limited only by the extent of the water-bearing joints and solution channels in the rock. In most aquifers, particularly in limestone aquifers, the horizontal permeability is much greater than the vertical permeability.

A major difficulty in this study has been in obtaining samples of water from contaminated, or reportedly contaminated, wells. It is a common practice for well drillers or homeowners to abandon and plug a water well that is found, or suspected, to be unsafe. Thus, in most instances where the local health district has a record of an unsafe water well, our field investigators have been unable to collect additional samples for further analyses. Stories have been relayed to us during this investigation of wells which yielded easily recognizable raw sewage (including toilet tissue) while being drilled. Others have foamed because of high detergent content, and, still others, the contents of which are best left to the reader's imagination! Needless to say, these wells had all been immediately plugged and abandoned, so our investigators have no first-hand information.



These new homes, north of Bellevue, have no water wells because of ground-water contamination. Water is hauled in by tank truck to supplement inadequate cistern supplies.

Because of the poor quality of the ground water available north of Bellevue, many homeowners and builders have made no attempt to develop well supplies. A number of new homes built in southwestern Groton Township, Erie County, use cisterns for their household water supplies. When adequate supplies are not available from rainwater, water is hauled from Bellevue. Although twenty years ago, yields of as much as 500 gallons per minute were obtained from wells in the underlying limestones, today homes must rely upon inadequate cistern supplies. Similar quantities can still be expected, but the quality is too poor for use.

In northern Groton Township, shallow wells are apparently unaffected by contamination and they are commonly used as sources of domestic water supply. Many of the homeowners, however, chlorinate their water supplies before using, "just to be safe." Deep wells (greater than 60 feet) are reported to produce water of poor quality.

The northern part of Margaretta Township, Erie County, is served by water piped from the Sandusky water plant because of "inadequate" well supplies in this area. Records of wells on file at the Division of Water indicate this to be a quality inadequacy, rather than insufficient quantity.

A number of wells in York Township, Sandusky County, have been found unsafe and are now chlorinated before being used, although chlorination as a "cure-all" for sewage-contaminated wells is questionable.

A brief discussion of some chemical constituents, which are possible sewage indicators, follows.

Ammonia

In pure form ammonia is a colorless gas. In ground waters it generally results from the decomposition of nitrogenous organic matter. If present in ground waters in appreciable amounts (0.2 ppm), it provides strong presumptive evidence of the presence of sewage or sewage effluent, especially if there is also a rise in the chloride content. The Royal Commission on Sewage Disposal (Gt. Britain) stated in the 8th annual report that, "the most delicate chemical index of recent sewage pollution in water is the increase in the figure for ammoniacal nitrogen."

An interesting sidelight is the fact that water with traces of ammoniacal nitrogen has a high chlorine demand and requires much longer contact periods for satisfactory sterilization.

No limits have been set by the USPHS Drinking Water Standards for ammonia, but in 1938 Swiss standards for drinking water gave maximum content of free ammonia as 0.02 ppm.

Although free ammonia is often of vegetable or mineral origin and without hygienic significance, its concentration in excess of 0.10 ppm renders the water suspect of recent pollution.

Nitrites

In water, nitrites are generally formed by the action of bacteria upon ammonia and organic nitrogen. Owing to the fact that they are quickly oxidized to nitrates, they are seldom present in water in significant concentrations. In conjunction with ammonia and nitrate, nitrites in water are often indicative of pollution.

No standards have been set for nitrite in drinking water. A

generally accepted limit in domestic water supplies is 2.0 ppm.

Nitrate

Nitrates are the end product of aerobic stabilization of organic nitrogen, and as such they occur in polluted waters that have undergone self-purification. In a few instances, nitrates may be added to underground water by natural weathering processes involving nitrate salts.

Infant methemoglobinemia, a disease characterized by certain specific blood changes and cyanosis, may be caused by high nitrate concentrations in water. Reported as nitrates, concentrations of 20 ppm and 70 ppm have caused serious cyanosis in children.

No drinking water standards were set in the 1946 USPHS standards. However, the recommended standards of 1960 contain the following statement concerning nitrate:

"High nitrate content in private wells has been reported to cause methemoglobinemia in infants, but public supplies have not been involved. Although precise limits have not been established, it is generally agreed that water containing more than 10-20 ppm of nitrate as nitrogen should not be used to feed infants. The committee believes, therefore, that a recommended limit of 10 ppm nitrate nitrogen should be set. If the nitrate content of the water exceeds the recommended limit, the public and the medical profession should be informed."

The process of nitrification is also reversible. When the dissolved oxygen content of a water falls to zero, nitrates may supply the combined oxygen to bacteria and be reduced in the process.

$$NO_3 \longrightarrow NO_2 \longrightarrow NO \longrightarrow N \longrightarrow NH_2 \longrightarrow NH_3$$

This process occurs in ground water when the dissolved oxygen is depleted either by bacterial action or chemical decomposition. Anaerobic bacteria could utilize the combined oxygen in nitrate and initiate the process.

Anionic Detergent

Detergents contain surface-active agents along with wetting, dispensing, and emulsifying agents. They do not form insoluble compounds with calcium and magnesium ions in water and are generally preferred to soap which forms insoluble compounds with these ions. More than 75% of synthetic detergents in household use are the anionic type, alkyl benzene sulfonate (ABS).

Because reports of contamination of water supplies by detergents are becoming more common, standards have been proposed. The recommended limit of 0.5 ppm as ABS was set on the basis that beyond this limit water so contaminated may exhibit foaming. Actually, the presence of any ABS in ground water above 0.1 ppm is indicative of pollution.

Prior to the water quality survey of ground water in the vicinity of Bellevue, nine ground water samples had been collected in Erie, Sandusky, and Huron Counties in connection with other projects. A brief summary of these analyses is given in the following table:

Table 1

Chemical constituents in ppm

	Max.	Min.	Median
Dissolved solids	1,560	38	--
Total hardness	2,500	370	--
Nitrate (NO_3)	7.0	0.0	0.1
Chloride (Cl)	596	6.8	12

Determinations of ammonia nitrogen and nitrite nitrogen were not made in connection with these studies.

During February, March and April 1961, a series of ground water samples were collected in the vicinity of Bellevue, Ohio. Thirty-two samples were collected and the pertinent analytical results are given in table 2.

Table 2

February - April 1961 Survey

Chemical constituents, in ppm

	Max.	Min.	Median
Dissolved solids	1,000	150	430
Ammonia as NH_4	2.7	0.0	0.1
Nitrite (NO_2)	12	0.0	0.5
Nitrate (NO_3)	158	0.5	25
Chloride (Cl)	146	5.0	--
ABS	0.7	0.0	0.1

Of the 32 samples collected in the vicinity of Bellevue, 27 contained ammonia. Nine of the samples contained more than 0.3 ppm of ammonia. Approximately one-half of the samples analyzed contained detectable amounts of nitrite nitrogen.

All samples contained nitrate. The maximum amount in ground water in Bellevue, 158 ppm, was found in the Thomas well. This well contained 0.3 ABS and 0.1 ppm ammonia.

Alkyl benzene sulfonate (ABS) was detected in 22 of the 32 samples collected in the study area. The highest concentration observed was in a sample from the Lyons well, 0.7 ppm. Phosphates are present in all well waters. The highest phosphate concentrations were generally

associated with the samples with the highest ABS concentrations. This is to be expected since phosphates are generally used as "builders" in commercial synthetic detergents.

There was no correlation between chlorides and nitrates in the study area. The sample with the highest nitrate (Thomas well) contained 36 ppm of chloride. The highest observed chloride (146 ppm) was associated with a sample (Bunting well) containing one of the highest ammonia (0.6 ppm as NH_4) concentrations. However, this sample contained only 1.3 ppm of nitrate and 0.15 ppm of nitrite.

Samples collected in Bellevue during February 1961 contain nitrate concentrations which range from 0.6 ppm and 38 ppm. The samples were collected during an extended period of below freezing temperatures. During this period the ground water reservoir was at least partially cut off from surface water recharge. During March the range in nitrate was 0.5 ppm to 77 ppm. Although the weather was cold during the time the samples were collected in March, the period between sampling runs was above freezing most of the time. Three of the four low nitrate samples (Weilnau, Close, and Beechler) contained traces of hydrogen sulfide indicating that there was a reducing environment in the ground water at that time and no doubt the low nitrate content of these samples can be attributed to the reduction of the nitrate and subsequent escape of ammonia.

Six samples were collected in April at points where samples had been collected either during March or February.

Table 3 lists the results of chemical analyses of water from wells where samples had been collected on two or more occasions during the survey.

Table 3

		ppm			
		ABS	Ammonia as NH_4	NO_2	NO_3
Weiland	2-6-61	0.1	0.1	0.5	29
	4-18-61	0.1	0.2	0.05	52
Thomas	3-7-61	0.1	0.2	0.00	92
	4-18-61	0.3	0.1	.00	158
Neill	3-7-61	0.1	0.2	1.0	41
	4-18-61	0.1	0.1	.05	38
Andrews	2-6-61	0.1	0.2	1.5	26
	4-18-61	0.2	0.2	.00	36
Adams	3-5-61	0.2	0.1	0.05	77
	4-18-61	0.2	0.3	0.20	91

In every well but one, there was an increase in the nitrate content of the water after the end of the cold weather in February or March. The Neill well did not change appreciably between early March and the middle of April.

In summary, the underground water in the vicinity of Bellevue, Ohio, contains higher concentrations of nitrogen compounds than water from other underground reservoirs in Erie and adjacent counties. A significant number of samples (70%) contained alkyl benzene sulfonate and about 85% contained ammonia nitrogen. Since alkyl benzene sulfonate is not a naturally occurring compound, it is safe to say that there is a significant amount of pollution in the underground water in the Bellevue area.

Table 4

Chemical Analyses of Ground Water in the Bellevue Area

	Ammonia as NH_4	ABS	Nitrite NO_2	Nitrate NO_3	Phosphorus as PO_4
F. C. Adams (Bragg Rd.) #1	0.1	0.2	.05	77.	.20
#2	0.3	0.2	.20	91.	.50
Mr. Adams (Potter Rd.)	0.2	0.0	.00	.7	.24
Walter Andrews (Knauss Rd.) #1	0.2	0.1	1.5	26.	.10
#2	0.2	0.2	.00	36.	1.0
Mr. Beechler (McGill Rd.)	0.1	0.0	.00	5.3	.15
Wayne Bunting (Billings Rd.) #1	0.1	0.1	1.0	2.7	.10
#2	0.1	0.1	.10	15.	.70
#3	0.6	0.1	.15	1.3	.50
Dale Close (Smith Rd.)	0.0	0.0	.00	.4	.15
D. D. Crouch (Route 99)	0.0	0.0	.00	8.0	.20
L. H. Danklefsen (Billings Rd.)	0.1	0.1	.40	17.	.20
Mrs. DeCaro (Route 269)	0.2	0.0	.10	6.5	.20
H. N. Farmer (Portland Rd.)	0.2	0.0	.00	.6	.20
Wm. Gibbs (McGill Rd.)	2.7	0.6	12.	38.	1.0
M. Lyons (McGill Rd.)	0.0	0.7	.05	30.	.10
L. Markle (Potter Rd.)	0.3	0.1	.00	29.	.10

Table 4 (continued)

Chemical Analyses of Ground Water in the Bellevue Area

	Ammonia as NH_4	ABS	Nitrite NO_2	Nitrate NO_3	Phosphorus as PO_4
Earl McKinney (MaGill Rd.)	0.6	0.6	.00	28.	.20
Robert Moore (MaGill Rd.)	0.0	0.4	.90	30.	.50
Donald Moyer (Knauss Rd.)	0.7	0.1	.30	2.9	.10
Swaze Neill (Billings Rd.) #1	0.2	0.1	1.0	41.	.20
#2	0.1	0.1	.05	38.	.50
Mrs. Sanders (Maple Rd.)	0.1	0.1	.40	16.	.10
Sand Hill Comm. (Route 4)	0.6	0.0	.00	22.	.20
J. Stickradt (Route 4)	0.1	0.0	.00	3.7	.20
R. W. Thomas (Portland Rd.) #1	0.2	0.1	.00	92.	.40
#2	0.1	0.3	.00	158.	1.0
Weiland Bros. (Bragg Rd.) #1	0.1	0.1	.50	29.	.20
#2	0.2	0.1	.05	52.	.40
Kenneth Weilnau (Portland Rd.)	1.0	0.0	.45	1.9	.20
Mr. Williams (MaGill Rd.)	0.4	0.1	.00	.5	.20
L. F. Wright (MaGill Rd.)	0.0	0.1	.00	1.0	.20

IV. SUMMARY AND CONCLUSIONS

As was stated in the introduction to this report, more comprehensive studies could be made of this situation to definitely determine the direction and movement of contaminated water through the limestone. However, further investigations of this nature would be of academic interest only and of little value in eliminating the problem of groundwater contamination in this area.

We believe that the present study has shown this area to be widely contaminated. We also believe that the source of this contamination is obvious. It can be stopped by construction of a sewerage system and an adequate sewage treatment plant for Bellevue.

Is there a good reason to stop this contamination? ... and, if so, how can this be accomplished? Many reasons have been proposed for permitting this condition to remain. These will be briefly discussed.

It is said that the quality of the ground water in the Bellevue area has excessively high hardness and total solids which make it unuseable for domestic supplies. Therefore, it should not be considered as an aquifer. Examples were cited where several wells yielded water with total solids in excess of 1500 parts per million (ppm) and total hardness of over 1000 ppm.

These examples are probably true. Ground waters from limestone, not only in Bellevue, but throughout the State, are hard and high in total solids. Chemical analyses of the water from 16 wells in limestone in the Bellevue area are on file at the Division of Water. The average of the total hardness is 564 ppm and the average total solids, 782 ppm. Four of these samples show extremely high total solids and hardness; however, the

average is chemically suitable for most uses. These constituents are the most objectionable in well water from Riley and Townsend Townships, Sandusky County.

Another argument in favor of keeping the status quo is that there are very few domestic ground-water users in the area and no industrial users. Therefore, very few people are affected.

This is true, but it should be pointed out that the reason for this is contamination, or fear of contamination. Many industrial wells have been developed in and around Bellevue only to be abandoned because they became contaminated. These include individual wells yielding 500 gallons per minute (720,000 gallons per day, or over 252 million gallons per year!). Numerous domestic water users have had similar experiences with their wells. Even the city of Bellevue found it necessary to abandon its unsafe wells in 1946.

We have been advised that natural sinkholes in much of this area will continue to introduce pollution underground from surface drainage, even if Bellevue's contribution is stopped.

This also is true. However, the number of sinkholes, the amount of drainage entering them, and the concentration of pollutants in the water are only a fractional part of the total Bellevue contribution.

The last, and probably the most serious, reason offered to retain the present system of disposal is that the total cost for a municipal sanitary sewerage system and a sewage treatment plant to serve the city of Bellevue would result in a prohibitive cost per capita. Such a project would be impossible to finance in the usual ways provided by law.

This, too, is apparently true. The possibility of State aid in this project might be investigated. It is beyond the scope of this report to suggest means of financing.

We do not feel that this problem can be ignored. It is, in fact, a multiple problem since it is (1) a health problem, (2) a natural resources problem, and, (3) a moral problem.

SECTION 4.1.3

TITLE OF STUDY: *(or SOURCE OF INFORMATION)*	Report of Investigations Class V Injection Well Inspections Oahu and Hawaii Islands, Hawaii
AUTHOR: *(or INVESTIGATOR)*	Engineering Enterprises, Inc. Prepared for USEPA Region IX
DATE:	November, 1985
STUDY AREA:	Oahu and Hawaii Islands, Hawaii, USEPA Region IX
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	Included are inspection reports on three sewage disposal facilities in Hawaii: the Laie cesspool sump, the Haleiwa Shopping Plaza, and the Honakaa Hospital. Several problems with the systems are noted, including presence of pollutants of primary concern, operation of systems without permits, overflow problems, and uncontrolled access to the systems. Recommendations for follow-up procedures are also presented.

REPORT OF INVESTIGATIONS

CLASS V INJECTION WELL INSPECTIONS

OAHU AND HAWAII ISLANDS, HAWAII

FOR

U.S. ENVIRONMENTAL PROTECTION AGENCY

REGION IX

SAN FRANCISCO, CALIFORNIA

Prepared By

Engineering Enterprises, Inc.

Norman, Oklahoma

Under EPA Contract No. 68-01-7011

Work Assignment No. 9-1

November, 1985

Inspection 4

The Laie cesspool sump is a disposal facility operated by the City and County of Honolulu since 1962. The sump receives untreated sewage and cesspool wastes from authorized and unauthorized vacuum truck contractors. This injection well is actually a solution cavern in the caprock, of unknown extent.

The untreated sewage is injected on an intermittent basis with a daily average of 16,400 gallons. The injection rate is approximately 300 gpm. The well receives an average of 16 authorized vacuum truck loads per day, each load consisting of 1000 gallons. The well is easily accessible to any unauthorized vacuum truck operators and a junkyard or dump has collected around it. A vent opening into the same cavern is located approximately 15 feet from the manhole covered main access to the cavern. In 1969, the well and surrounding surface collapsed. The well was repaired by backfilling the area and pouring a cement surface pad. No other problems have occurred since.

The well is completed in a cavern system in the caprock, consisting of Pleistocene dune sandstone and limestone. The well is landward of the UIC line in a protected USDW area. Dye tests were conducted to determine if the cavern system was directly connected to the ocean. No ocean outfall was found by this study. There are no apparent tidal effects on the water level in the well. There are six known wells in the vicinity of the Laie sump. Three wells are used for irrigation, two are domestic water supply wells, and one well is sealed. However, there are

no known shallow wells in the area other than the Laie sump. No water supply wells are known to be downgradient of the sump, however, flow patterns from the cavern system are unknown. No analyses of the injected fluids or receiving waters were available. The waste categories are untreated sewage waste and wastes from restaurant sewage grease traps. The primary pollutants of concern present in untreated sewage are pathogens and nitrates.

To further assess the impact of the Laie sump on groundwater quality, a much better understanding of the hydrogeology of the area and analyses of the injected and receiving fluids are needed. Since the well is landward of the UIC line and in an underground source of drinking water (USDW) area, it is recommended that the well be closed and alternative disposal methods be provided by the City and County of Honolulu. A sewage treatment plant is close by and is currently underloaded; this plant could easily accept the Laie sump volume of wastes (Kahuku municipal sewage treatment plant is approximately 2 miles away). At a minimum, access to the sump should be restricted so that only authorized sewage pumping contractors could use the well and a more accurate accounting of injected wastes could be maintained.

For more information, refer to Appendix A, inspection report 4 and Appendix B, plate O-7. Figure 24 is a photograph of the well and manhole cover with the junkyard in the background.

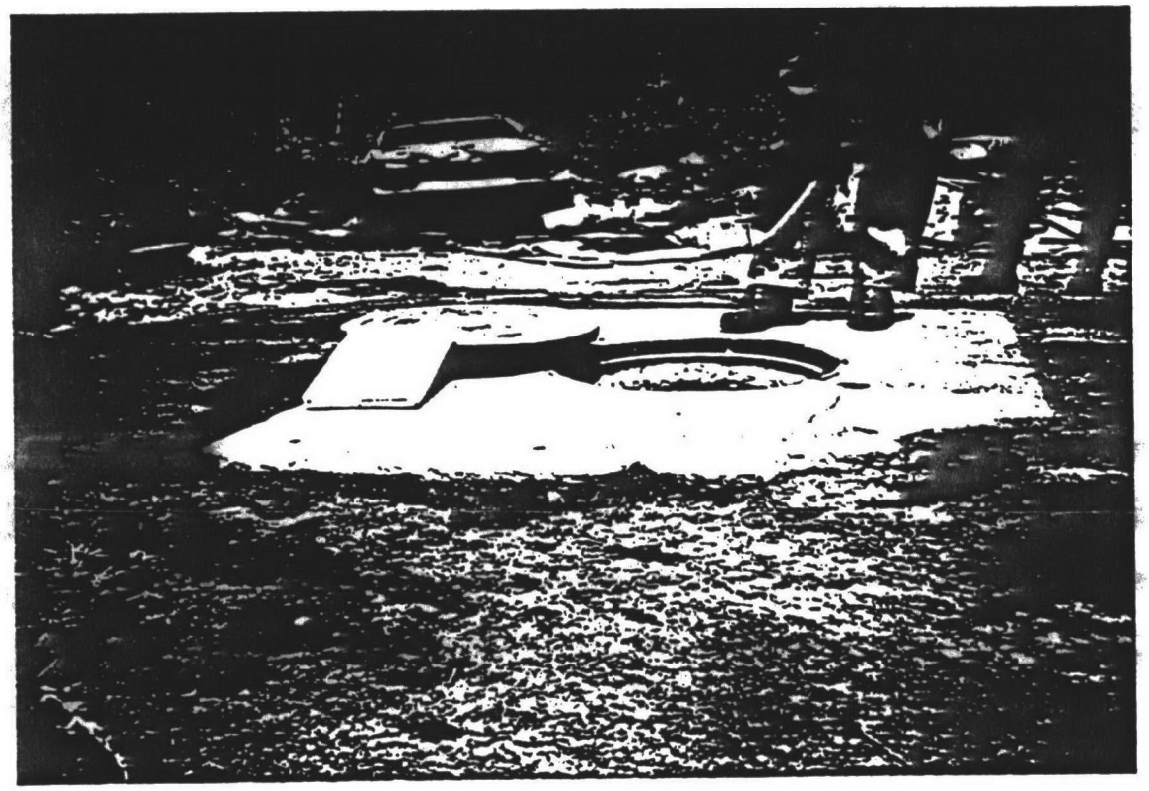


FIGURE 24. INSPECTION 4, LAIE AREA CESSPOOL SUMP WITH TRASH DUMP IN BACKGROUND.

UIC INSPECTION REPORT

SECTION I - General Information

Name of Facility: Laie Cesspool Sump

Address: 56-020 Kamehameha Highway
Oahu, HI 96743

Telephone:

Owner Address and Telephone (if different from above):

City and County of Honolulu
650 South King Street, 14th Floor
Honolulu, HI 96813
(808) 523-4347

Nature of Business: Disposal of domestic cesspool wastes

Use of Injection Well(s): This well is used to dispose of wastes pumped from domestic cesspools.

Permit # (or Permit Application #): UO1261

Injection Well(s) Location (Island, Tax Map Key, latitude, longitude, land marks, verbal description):

Latitude: 21° 39' 21" N Tax Map Key #: 5-5-5:01
Longitude: 157° 56' 15" W Island: Oahu

Type of Injection Well(s):

Industrial_____
Domestic_____X_____
Drainage_____
Other_____

Injection Well Currently Operating: Yes _X_ No _____

If No, Last Date Of Operation:

Future Plans to Operate: Yes _____ No _____

If Yes, Date:

SECTION II - Hydrogeologic Information

Well Completion Details (complete attached diagram)

Subsurface Geology and Hydrology Data for Site:

Wells in the area that are over 200 feet deep have static heads of over 13 feet above mean sea level (artesian wells).

Injection Formation Name: Pleistocene Dune Sandstone (caprock)

Attach the Following Information (note if unavailable):

1. **Map of Facility Grounds:**

2. **Well Logs(s) of Injection Well:** NA

3. **As-built Diagram of Injection Well:** NA

4. **Consultant Reports for Injection Well:** NA

5. **Monitoring Data for Injection Well:** NA

6. **Location and Data for Nearby Wells:** There are six known wells in the vicinity. Three of these wells are used for irrigation, two for domestic supply and one is sealed. There are no known shallow wells in the area.

7. **Monitoring Data for Nearby Wells:** See attached mineral analyses sheet

8. **Status of Any Downgradient Water Supply Wells:** NA

9. **Status of Any Nearby Surface Waters (possibly affected by well operations):** NA

SECTION III - Operating Data

Injection Rate, Frequency, and Volume: Injection rate is approximately 300 gpm. Waste is recieved on an intermittant basis with a daily average of 16,400 gallons.

Description of Injection Operation (including brief history):

This well is used to dispose of untreated cesspool pumping wastes. The well currently receives approximately 16 loads of waste per day. The waste arrives in 1000 gallon capacity vacuum trucks. The well is easily accessible and private sewage contractors also dump there. The well has been in use since 1962.

Surface Facilities/Treatment Process: None

Wastewater Sources: Cesspools from the surrounding areas

Generalized Waste Category(ies)/Composition: Untreated domestic sewage

Visual Appearance of Well: The well consists of a concrete shaft approximately 15 feet deep and 24 inches in diameter. This shaft opens into a solution cavity(ies) of unknown depth and extent. The well is covered by a steel manhole cover set in a 4' x 5' concrete pad.

Method of Disposal (transport to well): Cesspool wastes are transported to the well by vacuum trucks.

Previous Problems with Well: Yes _X_ No _____
(e.g. clogging, overflowing, excessive suction, etc.)

If yes, describe: The well and surrounding surface collapsed in 1969. It was repaired by backfilling and pouring of a concrete pad. No problems have occurred since.

Attach the following (note if unavailable):

1. **All Analyses of Wastewater:** NA

2. **All Operating Records:** NA

SECTION IV - Inspection Specifics

Name and Affiliation of Inspectors: Lorraine Council, EEI
David Shepard, EEI
William Bohrer -
EPA Region IX

Name and Affiliation of Facility Contact: David Nagamine
Dept. of Public Works
City & County of
Honolulu

Joe Merindino
Operator

Date: 8/5/85 **Time:** 11:45 am

Reason for Inspection: The inspection is part of an EPA nationwide inventory and assessment of the various types of Class V injection wells. This facility was primarily inspected to verify the permit application information submitted to the Hawaii Department of Health and to observe the condition of the injection well and any related processes.

Number of Injection Wells: 1

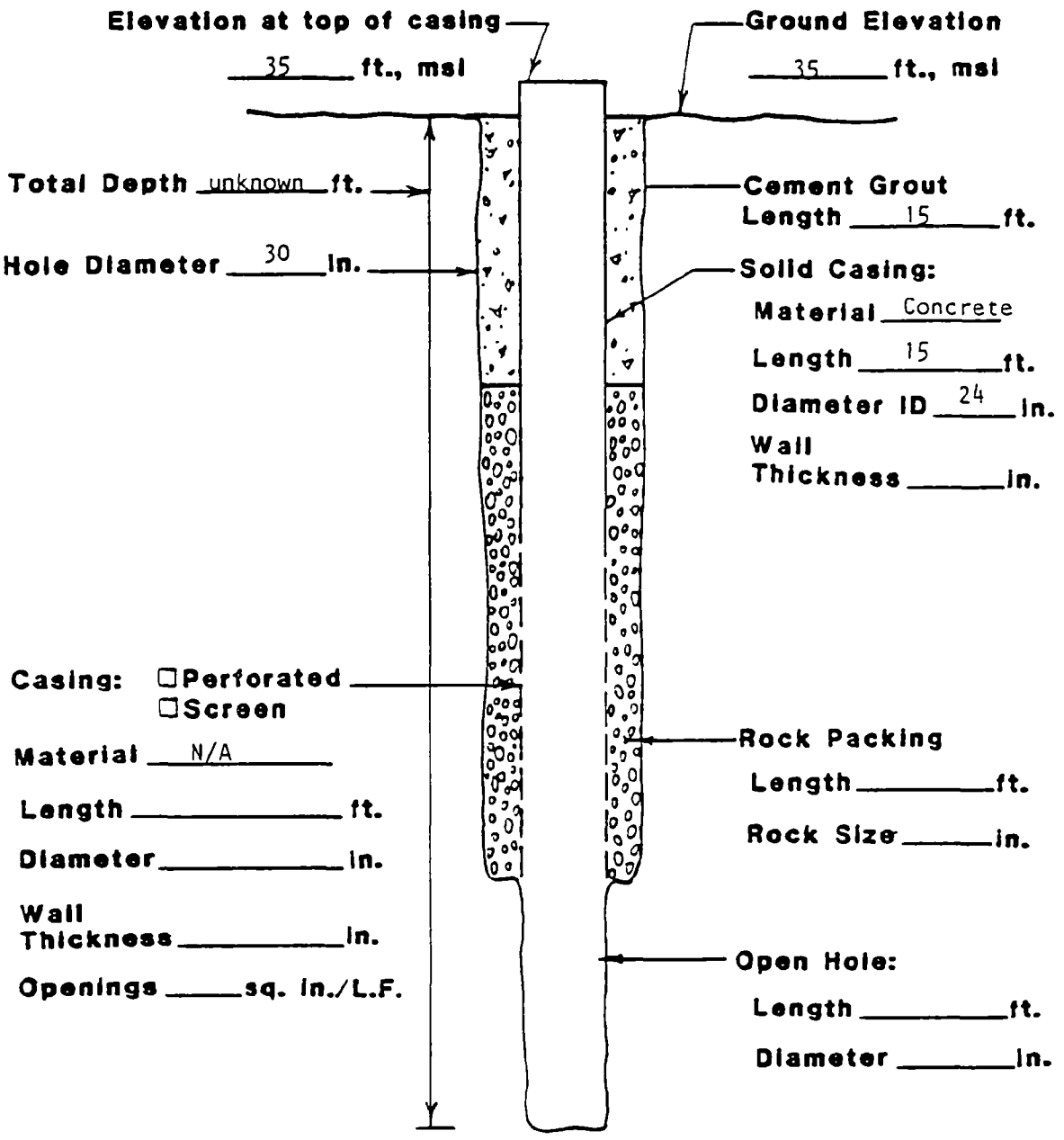
Number of Injection Wells Inspected: 1

Site Conditions at Inspection:
(e.g.) weather, tides, description of environs, etc.)

Sunny, 85° This well is located next to a small open dump. There is also an open hole (vent) to the cavern system approximately 25' from the well.

Inspection Comments: The well has been used since 1962 to dispose of untreated cesspool pumping wastes. The well opens into a solution cavern of unknown extent. The City and County of Honolulu disposes of approximately 1600 gallons per day of wastes in this well. The well is easily accessible and it is known that various private cesspool maintenance contractors use the well without authorization. The City and County of Honolulu stated that they will place a lockable cover on the well to restrict access. There is also a natural "vent" to the cavern a few feet away from the well; access to this will also need to be restricted to prevent unauthorized dumping. The area immediately surrounding the area is used as a rural "open" trash dump.

This well is above the proposed UIC line and is in an USDW area. There are several domestic water supply wells in this area. These wells may or may not be downgradient from the injection well as flow patterns from the cavern are unknown. This well should be closed and an alternate disposal method provided. There is a municipal sewage treatment plant nearby which could easily accept this volume of waste.



NOTES:

1. For existing wells, provide actual elevation section.
2. Include additional casing, grout seal, liner tubes, sump, etc. if applicable.
3. If design of well differs substantially, provide section showing actual construction.

MINERAL ANALYSES

LOCATION		Waimanalo Exploratory Well II 1982	Kahuku Well No. 1 1982
Specific conductance micromhos @ 25°C		158	243
pH value		7.95	7.35
Turbidity		3.5	0.1
Color		10.4	0.1
IN PARTS PER MILLION			
Silica		51	46
Calcium		10	8.6
Magnesium		6.8	7.5
Sodium		15	31
Potassium		0.9	0.8
Bicarbonate		65	70
Sulfate		5.6	7.0
Chloride		18	36
Fluoride		0.05	0.05
Nitrate		1.6	5.8
Phosphate		0.35	0.40
Iron	Less than	.02	.02
Manganese	Less than	.02	.02
Copper	Less than	.02	.02
Lead	Less than	.02	.02
Arsenic	Less than	.01	.01
Selenium	Less than	.01	.01
Chromium a/	Less than	.01	.01
Total dissolved solids		174	213
Alkalinity		53	57
Total hardness		51	53
IN EQUIVALENTS PER MILLION			
Calcium (Ca)		0.499	0.429
Magnesium (Mg)		.559	.617
Sodium (Na)		.646	1.349
Potassium (K)		.023	.020
Bicarbonate (HCO_3)		1.065	1.147
Sulfate (SO_4)		.116	.145
Chloride (Cl) b/		.520	1.030
Nitrate (NO_3)		.026	.093
TOTALS		3.454	4.830

a/ Hexavalent only.
b/ Includes fluoride and phosphate as PO_4.

Inspection 8

The Haleiwa Shopping Plaza is operated by Hawaiian Management Corporation and contains shops, restaurants, a bank, and a medical clinic. Sewage effluent is piped to two catch basins, one on each side of the shopping center, and then to three injection wells. One settling basin is connected to a single well. The other solids catch basin is connected to two wells in series. The medical center wastewater appears to be connected to the catch basin with two injection wells. At the time of inspection, the second well in the double well series was overflowing into the parking lot.

The shopping plaza was inspected to obtain information on its sewage treatment facilities since it was in a non-sewered area and had not applied for an operating permit or submitted any data to the Department of Health. It is unknown exactly what wastes are being disposed of but, in general, the wastes are untreated sewage, food establishment wastewater, and whatever substances are disposed down the medical center drains. The wells have experienced clogging and overflow problems in the past and there have been public complaints about odor from the system. The wells have been previously rehabilitated but will probably require regular maintenance to prevent overflow.

Completion data for the wells were not available; it is unknown which formation is receiving the wastewater. The wells are located slightly landward of the UIC line, in the protected aquifer area. There are nine wells in the area, five of the

wells are unused and the other four wells are used as irrigation wells. No analyses of the receiving water or injected fluids were available. Access to the wells is protected only by metal protective lids nearly flush with land surface. One well is in a parking lot area and the other two wells are hidden in a landscaped area of the parking lot.

Very little information exists concerning these three wells since the operator had not submitted a permit application and the necessary information. It is very difficult, if not impossible to assess the impact of the wells on groundwater quality. The operator should immediately be notified by the Hawaii Department of Health to submit a permit application and the associated information needed for continued operation. The wells and settling basins should be maintained on a regular basis to prevent further overflow problems. This operation should be inspected again once a permit application has been submitted to verify the application information and gather the necessary information to assess the impact of the operation on groundwater quality. Additionally, the medical center personnel should be interviewed to ascertain exactly what is disposed of through the sewer system.

More information is presented in Appendix A, inspection report B and Appendix B, plate O-4. Figures 32 - 34 are photographs of the two injection wells connected in series. The well shown in Figure 33 is overflowing into the parking lot.

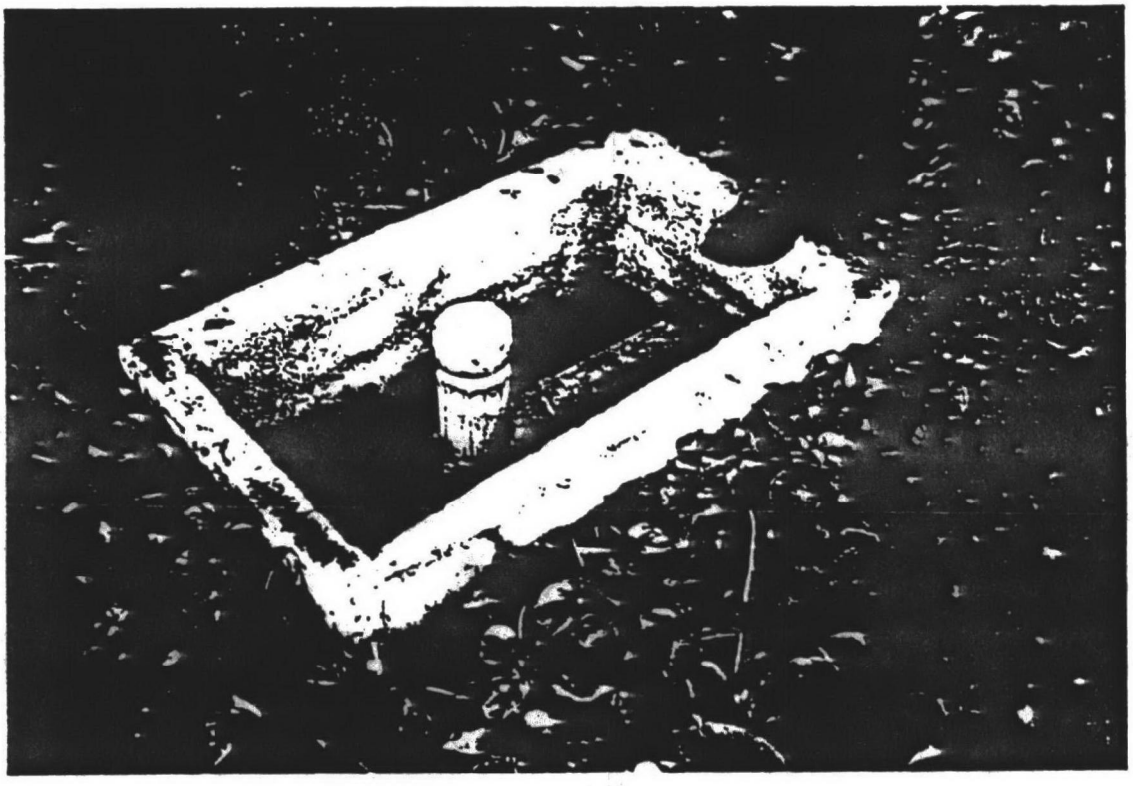


FIGURE 32. INSPECTION 8, HALEIWA SHOPPING PLAZA 1 OF 3 WELLS USED TO DISPOSE OF PRIMARY TREATED SEWAGE, FOOD, AND MEDICAL CENTER WASTEWATER.

FIGURE 33. INSPECTION 3, HALEIWA SHOPPING PLAZA OVERFLOWING INJECTION WELL USED TO DISPOSE SEWAGE, FOOD, AND MEDICAL CENTER WASTEWATER.

FIGURE 34. INSPECTION 8, HALEIWA SHOPPING PLAZA 2 OF 3 INJECTION WELLS USED TO DISPOSE OF SEWAGE, FOOD, AND MEDICAL CENTER WASTEWATER.

UIC INSPECTION REPORT

SECTION I - General Information

Name of Facility: Haleiwa Shopping Plaza

Address: Kamehameha Highway
Haleiwa, HI

Telephone: (808) 622-5179

Owner Address and Telephone (if different from above):

Hawaiian Management Corporation

Nature of Business: Shopping center and restaurants

Use of Injection Well(s): Three wells are used to dispose of domestic and food wastes from the shops in the center.

Permit # (or Permit Application #): None

Injection Well(s) Location (Island, Tax Map Key, latitude, longitude, land marks, verbal description): See Above

Latitude: 21° 35' 30" N Island: Oahu
Longitude: 158° 06' 20" W

Type of Injection Well(s):

Industrial_____
Domestic_____X_____
Drainage_____
Other_____X_____

Injection Well Currently Operating: Yes _X__ No _____

If No, Last Date Of Operation:

Future Plans to Operate: Yes _____ No _____

If Yes, Date:

SECTION II - Hydrogeologic Information

Well Completion Details (complete attached diagram)

Subsurface Geology and Hydrology Data for Site:

For area wells deeper than 150 feet the static head is between 10 and 16 feet above sea level, while for shallower wells (< 100 feet) the static head is 3 to 4 feet above sea level.

Injection Formation Name: Unknown

Attach the Following Information (note if unavailable):

1. **Map of Facility Grounds:** NA

2. **Well Logs(s) of Injection Well:** NA

3. **As-built Diagram of Injection Well:** NA

4. **Consultant Reports for Injection Well:** NA

5. **Monitoring Data for Injection Well:** NA

6. **Location and Data for Nearby Wells:** There are nine wells in the vicinity. Three of these wells are observation wells, four are irrigation wells, one is sealed and one is unused.

7. **Monitoring Data for Nearby Wells:** NA

8. **Status of Any Downgradient Water Supply Wells:** NA

9. **Status of Any Nearby Surface Waters (possibly affected by well operations):** NA

SECTION III - Operating Data

Injection Rate, Frequency, and Volume:

The injection volume and rate are unknown at this time. Most of the shops in the center are open from 8 am - 10 pm, which is when most wastes would be generated and injected.

Description of Injection Operation (including brief history):

The waste is piped to two catch basins where solids are trapped, the effluent then flows to wells. The shopping plaza is built in two sections; each section has catch basins and wells. The east half has 2 wells while the west half has only 1 well. The facility is at least 5 years old.

Surface Facilities/Treatment Process:

None

Wastewater Sources:

Domestic and restaurant wastes from shops and restaurants in the center. There is also a family medical clinic which is connected to the system.

Generalized Waste Category(ies)/Composition:

See Above

Visual Appearance of Well:

The wells are constructed of 3" PVC pipe. The wells are set below ground surface and accessed through a small steel cover. One well had backed up and filled the access area at the time if inspection. This well has been known to backup in the past at various times.

Method of Disposal (transport to well):

Well recieves effluent from solids traps through a 3" pipeline.

Previous Problems with Well: Yes _X_ No _____
(e.g. clogging, overflowing, excessive suction, etc.)

Overflowing

If yes, describe:

The wells have been redrilled. There had been overflow and odor problems in the past which prompted public complaints. The Hawaii Department of Health had been notified in the past.

Attach the following (note if unavailable):

1. **All Analyses of Wastewater:** NA

2. **All Operating Records:** NA

SECTION IV - Inspection Specifics

Name and Affiliation of Inspectors: Lorraine Council, EEI
David Shepard, EEI
William Bohrer -
EPA Region IX

Name and Affiliation of Facility Contact: Mike Sele
Maintenance Man
Hawaiian Property
Management Company

Date: 8/6/85 **Time:** 10:00 am

Reason for Inspection: The inspection is part of an EPA nationwide inventory and assessment of the various types of Class V injection wells. This facility was primarily inspected to obtain information on its sewage disposal facilities since no permit application had been filed with the Hawaii Department of Health and there is no regional sewage system in the area.

Number of Injection Wells: 3

Number of Injection Wells Inspected: 3

Site Conditions at Inspection:
(e.g.) weather, tides, description of environs, etc.)

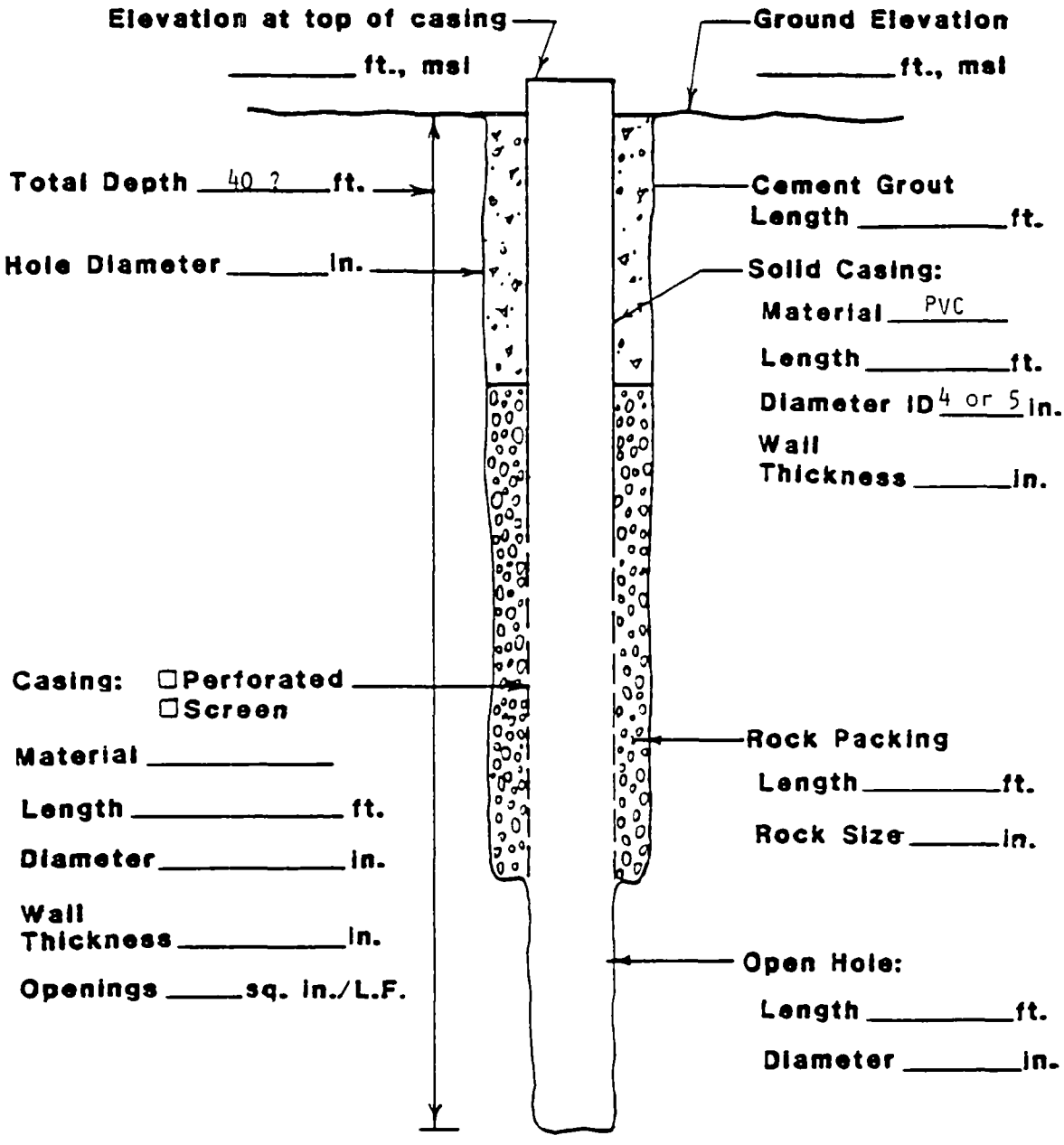
Partly Cloudy, 85°

Inspection Comments: This facility has three wells used to dispose of wastewater from a shopping center and a family medical clinic. The waste is sent to catch basins (solids traps) where solids are removed prior to injection. Very little data was available from the inspection contact, and no permit application has been filed. The operators will be notified by the Hawaiian Health Department of the need to file a permit application.

These wells have experienced clogging and overflow problems in the past. There have been public complaints about odor problems in the past. One well was overflowing at the time of inspection. The inspection contact stated that he would notify the well maintenance contractor and have the well rehabilitated. There are nine wells in the area, however only four of these are used (all four are irrigation wells).

AVAILABLE CONSTRUCTION INFORMATION APPLICABLE

TO ALL THREE INJECTION WELLS



NOTES.

1. For existing wells, provide actual elevation section.
2. Include additional casing, grout seal, liner tubes, sump, etc. if applicable.
3. If design of well differs substantially, provide section showing actual construction.

Inspection 17

The Honakaa Hospital was inspected to observe the sewage waste disposal facilities, consisting of an injection well piped into a lava tube. The "well" was originally constructed in 1949 as the County Highway Baseyard cesspool. During excavation, a lava tube (8 feet depth x 10 feet wide) was encountered and subsequently used as a sewage disposal site. The Honakaa county hospital was constructed in 1951. A sewer line was constructed to connect the hospital to the lava tube sewage disposal site, approximately 1400 feet away. Subsequently, several other establishments connected to the sewer line; it is unknown exactly which establishments are connected.

The "well" receives wastes from at least the hospital, two churches, two commercial buildings, and possibly the post office. All wastes, except the hospital wastes, are believed to be strictly sewage wastes. In addition to restroom and kitchen wastes, the hospital generates surgical, laboratory, and possibly photographic x-ray chemical wastes. The surgical and laboratory wastes contain body fluids and, if present, the photochemical wastes will consist of spent fixer and developer from an x-o-mat processor. All wastes are disposed of without treatment. The best estimate of injection rate and volume are an average rate of 4.8 gpm for a daily volume of 6900 gallons. The maximum estimated volume is 20,000 gpd. The "well" is actually a manhole leading to the lava tube. The well wafted strong odors when inspected. Additionally the manhole cover to the well was too

large and about one third of it was broken off. Access to the well is uncontrolled.

The well is completed in a lava tube of the near surface basaltic lava (name unknown). The well is definitely landward of the UIC line, in the protected aquifer area. The lava tube extent and direction, which control the fate of the wastes disposed, are unknown. A municipal water supply well was recently installed about a quarter mile almost directly "downgradient" of the injection well (assuming the lava tube issues directly toward the ocean).

No analyses of the waste stream injected or the receiving wastes are available and very little information concerning the hydrogeology of the site is known. However, the disposal well is injecting in a USDW area upgradient of a municipal water supply well. It is strongly recommended that unless proven environmentally safe, the injection well should be replaced with alternative and much improved sewage treatment facilities as soon as possible. Otherwise, the municipal water supply well should be relocated to avoid possibly intercepting the raw sewage waste stream.

Additional information is presented in Appendix A, inspection report 17 and Appendix B, plate H-44. Figures 52 and 53 are photographs of the injection well completed in the lava tube.

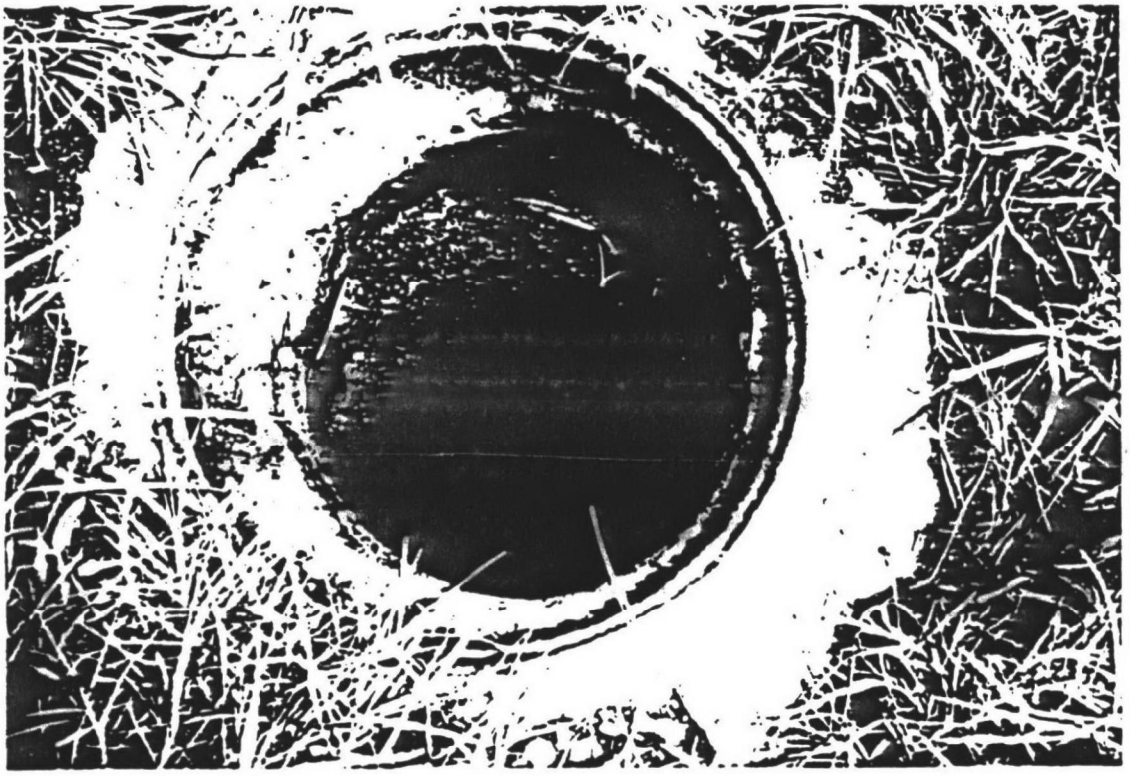


FIGURE 53. INSPECTION 17, HONAKAA HOSPITAL, INJECTION WELL COMPLETED IN LAVA TUBE, TO DISPOSE OF HOSPITAL, BUSINESS, AND RESIDENTIAL UNTREATED SEWAGE WASTEWATER.

FIGURE 52. INSPECTION 17, HONAKAA HOSPITAL, INJECTION WELL COMPLETED IN LAVA TUBE, TO DISPOSE OF HOSPITAL, BUSINESS, AND RESIDENTIAL UNTREATED SEWAGE WATERWATER.

UIC INSPECTION REPORT

SECTION I - General Information

Name of Facility: Honokaa Hospital

Address: Honokaa Hospital
Honokaa, HI

Telephone:

Owner Address and Telephone (if different from above):

Nature of Business: Hospital

Use of Injection Well(s):

The well disposes of untreated sewage from the hospital and an unknown number of businesses and residences.

Permit # (or Permit Application #): None

Injection Well(s) Location (Island, Tax Map Key, latitude, longitude, land marks, verbal description):

The well is located approximately 1,100 feet north of the hospital and approximately 450 feet north of Mamene Street.

Latitude: 20°05'00" N Island: Hawaii
Longitude: 155°28'21" W

Type of Injection Well(s):

Industrial_____
Domestic_____X____
Drainage_____
Other_____X____

Injection Well Currently Operating: Yes _X__ No _____

If No, Last Date Of Operation:

Future Plans to Operate: Yes _____ No _____

If Yes, Date:

SECTION II - Hydrogeologic Information

Well Completion Details (complete attached diagram)

Subsurface Geology and Hydrology Data for Site:

The elevation of the groundwater surface is approximately mean sea level. Flow direction is toward the coast.

Injection Formation Name: NA-basaltic lava (pahoehoe) with lava tubes

Attach the Following Information (note if unavailable):

1. **Map of Facility Grounds:** NA

2. **Well Logs(s) of Injection Well:** NA

3. **As-built Diagram of Injection Well:** NA

4. **Consultant Reports for Injection Well:** NA

5. **Monitoring Data for Injection Well:** NA

6. **Location and Data for Nearby Wells:**

   A municipal water supply well is approximately 600 yards away in a direction thought to be almost directly downgradient.

7. **Monitoring Data for Nearby Wells:** NA

8. **Status of Any Downgradient Water Supply Wells:**

   No observed effects.

9. **Status of Any Nearby Surface Waters (possibly affected by well operations):** NA

SECTION III - Operating Data

Injection Rate, Frequency, and Volume:

The best estimates of injection rate and volume are an average rate of 4.8 gpm for a daily volume of 6900 gallons. The maximum estimated volume is 20,000 gpd.

Description of Injection Operation (including brief history):

The hospital was started in 1951 and provides general medical care to the local community. The hospital averages 16 in-patients at any one time. No one is sure when the well was constructed.

Surface Facilities/Treatment Process:

None.

Wastewater Sources:

Untreated domestic wastes from the hospital and surrounding business and residences hooked into the well. The hospital laboratory also disposes of lab samples (blood, urine, spinal fluid, etc.) through the system, however these materials are sterilized in an autoclave before disposal. It is also possible that x-ray developing wastes are disposed of through the well.

Generalized Waste Category(ies)/Composition:

Untreated domestic sewage and some sterilized lab wastes. A substantial amount of storm water runoff is also believed to enter the well.

Visual Appearance of Well:

The well is an open hole with a concrete casing 18 inches in diameter leading into a large lava tube of unknown extent. Three pipes (one, 8" and two, 4") carry wastes to the well. These pipes enter the well approximately 3 feet below grade. The well is covered by a 24" diameter steel manhole cover which is cracked and broken.

Method of Disposal (transport to well):

Wastes are transported to the well by gravity flow sewer lines.

Previous Problems with Well: Yes _____ No _X_
(e.g. clogging, overflowing, excessive suction, etc.)

If yes, describe:

Attach the following (note if unavailable):

1. **All Analyses of Wastewater:** NA

2. **All Operating Records:** NA

SECTION IV - Inspection Specifics

Name and Affiliation of Inspectors: Lorraine Council, EEI
David Shepard, EEI
Dayton Fraim, Hawaii
State Department of Health

Name and Affiliation of Facility Contact: Walter Johannsen
Hospital Maintenance

Date: 8/11/85 **Time:** 10:00 am

Reason for Inspection: The inspection is part of an EPA nationwide inventory and assessment of the various types of Class V injection wells. This facility was inspected because it injects raw sewage from the Hospital and an unknown number of businesses and residences upgradient from the municipal water supply well. The injection well owner/operator had not filed a permit application with the Hawaii Department of Health.

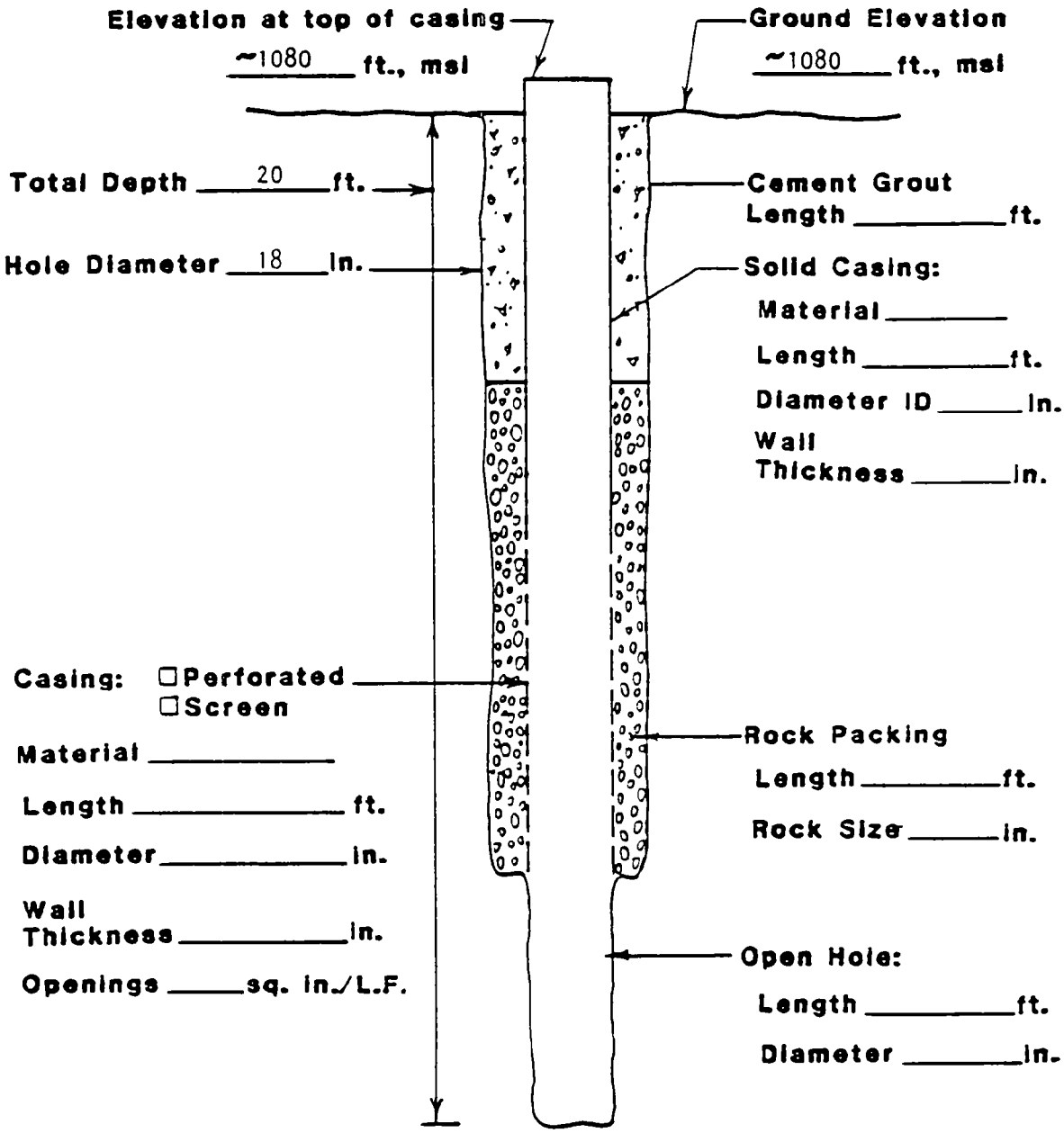
Number of Injection Wells: 1

Number of Injection Wells Inspected: 1

Site Conditions at Inspection:
(e.g.) weather, tides, description of environs, etc.)

Overcast, 78°

Inspection Comments: This well is used to dispose of untreated wastes from a small hospital and an undetermined number of businesses and private residences. The well enters a large lava tube of unknown extent. No one contacted knew the exact date of well construction, but it is known that the well was in use as early as 1951. A municipal water supply well was recently constructed a few hundred yards away in a direction thought to be almost directly downgradient. An alternate disposal method for the waste needs to be found and the injection well closed or the water supply well relocated. There is too great of a contamination potential to allow the continued operation of both wells.



NOTES:

1. For existing wells, provide actual elevation section.
2. Include additional casing, grout seal, liner tubes, sump, etc. if applicable.
3. If design of well differs substantially, provide section showing actual construction.

Section 4.2

Septic System Supporting Data

SECTION 4.2.1

TITLE OF STUDY: (or **SOURCE OF INVESTIGATION**)	Industry-Owned Septic Systems: San Fernando Valley Basin
AUTHOR: (or **INVESTIGATOR**)	Engineering Enterprises, Inc. Prepared for USEPA Region IX
DATE:	1986
STUDY AREA:	San Fernando Valley Basin, California, USEPA Region IX
NATURE OF BUSINESS:	Not applicable
BRIEF SUMMARY/NOTES:	This study consists of four parts: (1) general background, (2) hydrogeology and water use in the San Fernando Valley Basin, (3) outline of the Los Angeles Department of Water and Power's San Fernando Valley Basin Groundwater Investigation and resulting management plan, and (4) summary and assessment of City Ordinance 160388 and the implementation efforts of the L.A. Department of Public Works. The groundwater investigation revealed that TCE, PCE, and other chemicals were present at low concentrations in a number of wells in the San Fernando Valley Basin. The presence of chemicals was believed to be due to industrial and commercial disposal into septic systems. The city ordinance empowered the city to require industrial and commercial facilities to connect to available public sewer lines.

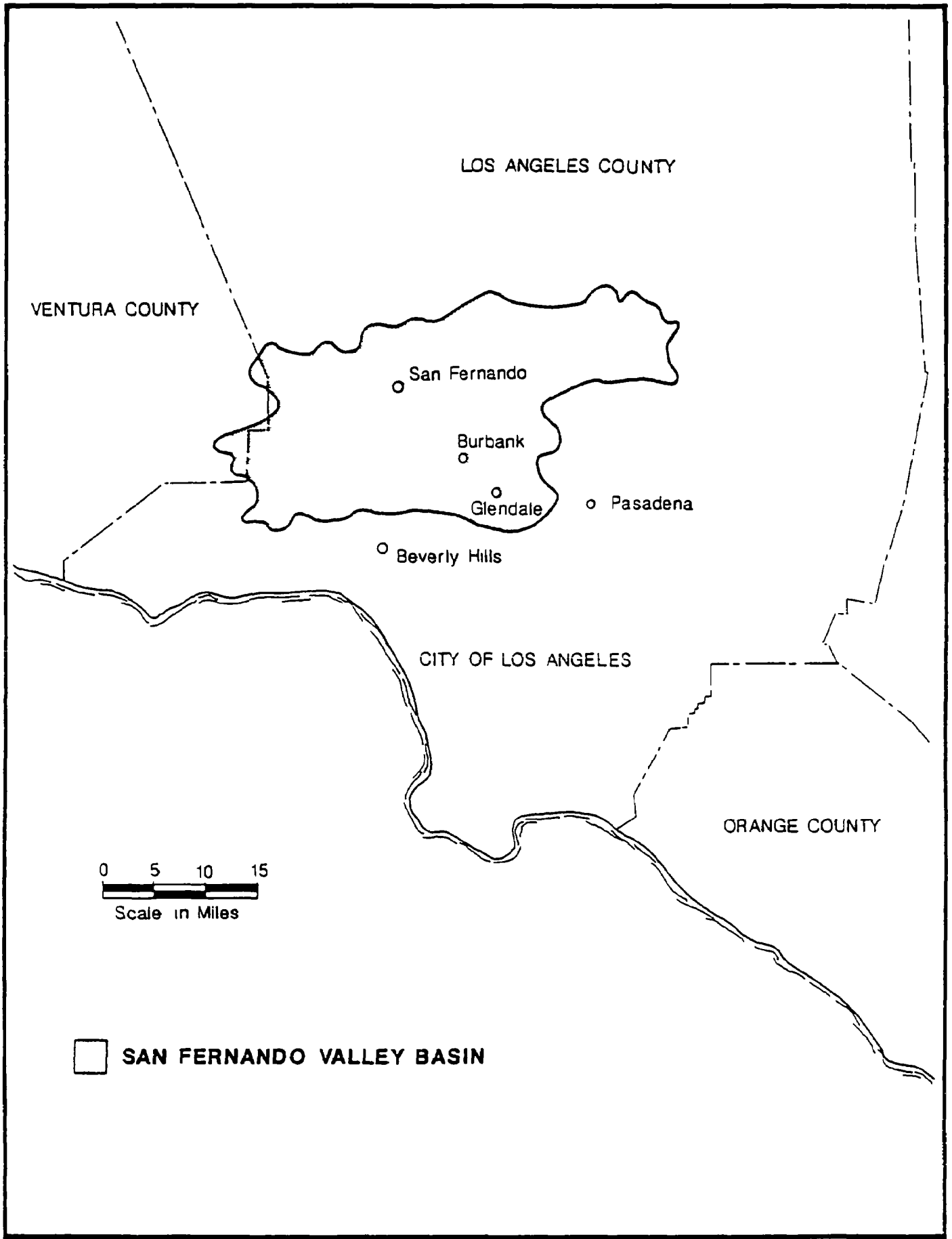
SAN FERNANDO VALLEY BASIN

I. GENERAL BACKGROUND

In late 1979, the California State Department of Health Services (DOHS) requested that all major water suppliers using groundwater conduct tests for the presence of certain industrial chemicals. These initial tests, completed in the spring of 1980, showed that trichloroethylene (TCE), perchloroethylene (PCE), and other chemicals were present at low concentrations in a number of wells in the San Fernando Valley Basin (SFVB) (Refer to Figure 1 for the SFVB study area.)

In response to these findings, the Los Angeles Department of Water and Power (LADWP), through a cooperative agreement with the Southern California Association of Governments (SCAG), applied to the California State Water Resources Control Board for EPA funding under the 208 Grant Program. Other participating cities included Burbank, Glendale, and San Fernando. Funds were received and work began in July of 1981. Activities of the study included field investigations, industrial site surveys, records and archives searches, literature reviews, and water quality analyses of more than 600 samples. (LADWP: "Groundwater Quality Management Plan; SFVB," 1983.)

Based upon the study's findings, a recommendation for the regulation of Private Sewage Disposal Systems (PSDS) in the SFVB was proposed. This recommendation called for the promulgation and implementation of a city ordinance which would require the phasing-out of PSDS on commercial and industrial properties in



VICINITY MAP
SAN FERNANDO VALLEY

(from LADWP's "Groundwater Quality Management Plan, SFVB," 1983)

EEI ENGINEERING ENTERPRISES, INC.

Figure 1

the SFVB. Proposed regulatory tasks were assigned to potentially responsible regulatory agencies.

In 1985, two years after completion of the LADWP study, the City of Los Angeles passed Ordinance 160388. This ordinance essentially empowered the city, through its agencies, to order owners of industrial and commercial PSDS to connect to available public sewer lines.

The Los Angeles Department of Public Works began implementing the ordinance upon its passage. A field survey was conducted by the Bureau of Sanitation in 1986 to identify owners of commercial and industrial PSDS in the SFVB. All identified owners were mailed letters informing them of the new City ordinance. Notices to Connect are currently being issued by the Bureau. The Bureau of Sanitation has also instituted a PSDS sampling program to identify systems which have been used to dispose of industrial (chemical) wastes. These systems will be issued Notices to Connect first, in order to reduce the continued pollution of the SFVB. As of September 1986, seven such PSDS sites have been discovered.

Section II of this case study provides background information on the SFVB. The third section outlines the LADWP SFVB groundwater investigation and management plan. Material presented within these sections has been excerpted and condensed from LADWP's, "Groundwater Quality Management Plan; San Fernando Valley Basin," 1983. The remaining sections of this study are written by EEI and summarize and assess City Ordinance 160388

and the implementation efforts of the L.A. Department of Public Works.

II. BACKGROUND

A. SFVB Hydrogeology

Groundwater in the SFVB is stored in the alluvial deposits which comprise the valley fill. The distribution of these deposits has resulted in a characteristic difference in groundwater conditions between the eastern and western portions of the basin.

The alluvial deposits in the eastern portion of the SFVB are comprised primarily of sands and gravels with some localized lenses of silts and clays interbedded. Conditions in the eastern portion of the SFVB are therefore characterized by high soil permeability and groundwater production. Groundwater in the eastern SFVB is generally unconfined with a depth to water table from 50 to 200 feet. The presence of clay lenses partially restricts the vertical movement of groundwater.

The western portion of the basin, on the other hand, consists of finer sediments and clays exhibiting low permeability and low water yields. In the western SFVB, groundwater generally is confined or partially confined; and rising water or artesian flow is common in this area. Groundwater in the western portion also contains higher total dissolved solids (TDS) concentrations than groundwater in the eastern portion.

Groundwater flow in the SFVB is southeasterly, from the

recharge areas on the alluvial fans along the edges of the valley fill, toward the basin outlet area at the Los Angeles River Narrows. Figure 2 shows groundwater flow directions and the variations in estimated groundwater flow velocities over the basin.

Because of the dense grouping of wells in certain areas and the extensive pumping of groundwater, several large cones of depression have formed in the water table. These cones of depression have caused significant changes in the natural groundwater flow patterns and generally persist throughout the year despite the highly seasonal variation in pumping activities. Three large cones of depression in the SFVB water table exist in the North Hollywood, Crystal Springs, and Pollock well fields (LADWP, 1983).

B. Water Use

The San Fernando Valley Groundwater Basin is a natural underground reservoir that represents an important source of drinking water for the Los Angeles metropolitan area. In addition to supplying annual water needs, this groundwater basin holds large quantities of stored water which can be extracted during droughts and replenished during years of surplus water supply.

Groundwater extractions from the basin are also important water supplies for the Cities of Burbank, Glendale, San Fernando and the unincorporated La Crescenta area of the county of Los Angeles (Figure 3). All the above agencies can draw upon

GROUNDWATER FLOW (1980)
SAN FERNANDO VALLEY BASIN

(from LADWP's, "Groundwater Quality Management Plan, SFVB", 1983)

ENGINEERING ENTERPRISES, INC.

Figure 2

POLITICAL BOUNDARIES
SAN FERNANDO VALLEY BASIN

(from LADWP's "Groundwater Quality Management Plan, SFVB," 1983)

ENGINEERING ENTERPRISES, INC.

Figure 3

groundwater stored in the basin for use during droughts or emergencies when sufficient water from the Metropolitan Water District of Southern California (MWD) may not be available. Groundwater extractions typically supply about 15 percent of Los Angeles' water, nearly all of San Fernando's and about half of La Crescenta's requirements (LADWP, 1983).

There are six general types of water use in the SFVB (LADWP, 1983).

1. Domestic - use for residences, including incidental irrigated gardens and orchards.

2. Industrial - use by a manufacturing or service industry that involves water being used directly in the manufacturing process or service.

3. Commercial - use by manufacturing and other commercial establishments whose primary water requirement is for the lavatory needs of employees and clients and may include incidental irrigation of ornamental plants.

4. Irrigation - use for irrigated agriculture including incidental stockwater and domestic use.

5. Recreation - use for swimming, boating, hunting, or fishing.

6. Municipal - use for domestic, industrial, commercial, irrigation, and recreation purposes; including fire protection and use for other municipal functions or services by a municipality, public utility or district.

III. THE LOS ANGELES DEPARTMENT OF WATER & POWER'S SAN FERNANDO VALLEY BASIN GROUNDWATER INVESTIGATION

A. Background

In early 1980, the industrial chemicals trichloroethylene (TCE) and perchloroethylene (PCE), were discovered in the groundwater of the San Fernando Valley Basin (SFVB). TCE, the major contaminant found, was detected in approximately one-fourth

of the groundwater wells tested in the SFVB, at concentrations in excess of the current level recommended for drinking water by the California State Department of Health Services (DOHS).

In response to these findings, the Los Angeles Department of Water and Power (LADWP), and the Southern California Association of Governments (SCAG) received EPA funds to embark upon a two-year study which began in July, 1981. The scope of the study was to determine the extent and severity of the contamination and to develop strategies to control the groundwater contamination problem. The specific objective of the study was to develop a basin-wide groundwater quality management plan which would include recommendations for the implementation of strategies to ensure the future protection and safe use of the groundwater basin (LADWP, 1983).

B. Extent of Groundwater Contamination in the SFVB

A groundwater quality testing program was conducted by the LADWP to more accurately define both the extent and severity of contamination by volatile organic compounds (VOC's) in the SFVB. Samples from 135 production and monitoring wells throughout the SFVB were analyzed for the presence of organic contaminants. Complete Gas Chromatograph-Mass Spectrometer (GC-MS) scans allowed detection of as many as 36 possible VOC's. GC-MS scans were performed on more than 60 groundwater samples taken from 45 selected wells.

Gas Chromatograph (GC) analysis was used to measure the concentrations of individual contaminants in the groundwater. GC analyses for TCE and PCE were performed on more than 600 groundwater samples. This information was used to better define the temporal and areal distribution of these hazardous chemicals in the SFVB.

The results of the groundwater testing program revealed that TCE and PCE were present in approximately 45 percent of the water supply wells located in the eastern portion of the SFVB, at concentrations exceeding the action levels recommended by the State DOHS. TCE concentrations generally ranged from 5 to 50 ppb. Maximum TCE concentrations from 200 to 500 ppb, however, were found in several sampled wells. Average PCE concentrations ranged from 4 to 50 ppb with a maximum level of 130 ppb PCE detected in one well.

Groundwater sampled in four general areas within the SFVB were shown to be contaminated. These areas were located in, and surrounding, North Hollywood, Crystal Springs, La Crescenta, and the Pollock well field. Water supply systems operated by the Cities of Los Angeles, Burbank, Glendale, and the Crescenta Valley County Water District were affected (LADWP, 1983).

C. Potential Sources of Groundwater Contamination

The extent of TCE and PCE contamination found in the groundwater quality testing program supported the theory that this contamination was attributable to a large number of sources. A field investigation was initiated to examine the sources of

groundwater contamination, and to evaluate industries' handling and disposal practices of hazardous materials within the San Fernando Valley. This investigation included the evaluation of private disposal systems, sewer exfiltration systems and permitted waste discharges at commercial and industrial establishments.

The investigation was conducted in a 1300 acre tract in North Hollywood which largely consisted of small industrial properties. The current industrial use of TCE was judged to be minimal. After 1966, when strict controls were placed on the use of TCE by the Air Pollution Control District, many industries eliminated its use in their degreasing operations. PCE and other solvents have subsequently replaced TCE in various industrial processes. The contamination potential posed by these chemicals in the North Hollywood industrial area was discovered to exist. Among smaller commercial and industrial facilities, waste disposal areas were found to be deficient. Improper disposal practices including on-site dumping as well as uncontrolled discharges to storm drains and sewer facilities were suspected to be "more prevalent than observed" (LADWP, 1983).

After scrutinizing the sampling data from the groundwater quality testing program, a correlation between groundwater contamination and land use was discovered to exist. Wells which were found to be contaminated with TCE were located within, or adjacent to, commercial and industrial zones. Higher concentrations of TCE were detected in wells within the

commercial and industrial corridors. In general, wells located in residential zones were uncontaminated (LADWP, 1983).

D. LADWP Management Plan Recommendations

Based upon their findings, the LADWP developed eight primary recommendations for the management of groundwater in the SFVB. These recommendations addressed, among other objectives:

1. The control and regulation of hazardous materials to minimize future contamination of the basin, and

2. The control and management of contaminants currently in the basin to assure a quality of groundwater supply safe for drinking (LADWP, 1983).

LADWP's Recommendation #2 specifically provided a guideline for the regulation of industrial and commercial PSDS. Portions of this recommendation which detail the proposed development and implementation of PSDS regulations in the SFVB are presented forthwith (LADWP, 1983). (Chemicals referred to as "hazardous" in the recommendation are designated as such by the City of Los Angeles.)

RECOMMENDATION NO. 2

3.2 Regulation of Private Disposal Systems

3.2.1 Introduction

3.2.1.1 Objective

The objective of this recommendation is to prevent or to control contamination of groundwater in the San Fernando Valley by hazardous chemicals discharging from private disposal systems (PDS's) operated on commercial and industrial properties.

3.2.1.2 Required Actions

A program to fully regulate private disposal systems on commercial and industrial properties where hazardous wastes are generated or handled will require the following activities:

A. Identify, Investigate and Regulate Existing Private Disposal Systems:

Field investigations and a survey of public works records should be conducted to identify all PDS's operated on commercial and industrial properties in sensitive groundwater areas of the SFVB. Inspection and monitoring of the effluent discharging from these PDS's should be conducted to thoroughly assess the impact of each PDS site on groundwater quality during the phaseout of these systems.

B. Phase Out the Use of Private Disposal Systems

A priority schedule should be developed for the phaseout and elimination of PDS's operated on commercial and industrial properties in the sensitive groundwater areas of the SFVB. This phaseout will involve the following:

1. In areas where public sewers are currently available, commercial and industrial properties that generate hazardous wastes should be required to abandon their PDS's and connect to the public sewer.

2. In areas where no sewers are available, new public sewers should be constructed to eliminate the use of PDS's on these commercially and industrially zoned properties.

DEFINITION: Private disposal systems (PDS's) are on-site wastewater disposal systems that consist of septic tanks, cesspools or other wastewater retention units, and which discharge their effluent to the ground, usually through a network of subsurface perforated pipes in an area referred to as a leach field.

3.2.2 Background

A study of PDS's was conducted in a two zip code study area in North Hollywood within the City of Los Angeles. The study revealed that 88 PDS's were operated on commercial and industrial premises which overlie well fields in this North Hollywood area. Similarly, a large number of PDS's may be operated on other commercial and industrial sites throughout the sensitive groundwater areas of the eastern SFVB.

While current regulations and permits specify that PDS's are to receive domestic type wastes only, these systems may in fact provide an unauthorized means for the disposal of hazardous liquid wastes. These hazardous wastes may then pass through the PDS and discharge with the effluent to the ground.

The reasons for the continued use of these private disposal systems are twofold:

1. Despite heavy development in the eastern SFVB, there are still many isolated areas in the City of Los Angeles which are not served by sewers. These areas rely on PDS's as the only available means of wastewater disposal. Except for some fringe areas, all areas in the Cities of Burbank, Glendale and San Fernando have been sewered.

2. Current regulations in the City of Los Angeles do not provide a systematic method for requiring both the connection to public sewers and the abandonment of PDS's as new sewer facilities become available in an area. In addition, PDS's may not have been properly abandoned when businesses were connected to the public sewer system. The Cities of Glendale and Burbank do have provisions in their municipal codes that require properties with access to available public sewers to connect to those facilities within a 5-year period and to backfill abandoned PDS's.

The disposal of hazardous materials into an operating or improperly abandoned PDS is an attractive but unlawful alternative to proper waste disposal such as pickup by a licensed chemical waste hauler or recycler. The disposal of hazardous wastes to PDS's may become increasingly attractive as more stringent enforcement is focused on the disposal of these materials into sewers and sanitary landfills for domestic refuse, and the cost of disposal becomes increasingly expensive.

At present, there are no monitoring requirements for the periodic testing or inspection of PDS's operated on commercial and industrial properties. Quantitative analyses of single grab samples from some of the PDS's in the North Hollywood area revealed that effluents from the systems contained potentially significant concentrations of volatile organic compounds (averaging 6 ppm and ranging from 0.3 ppm to 23 ppm). The effluents from each of these systems are discharged directly to the ground. These analyses indicate that the PDS is a more significant potential source of contamination than previously believed.

3.2.3 Implementation

3.2.3.1 Recommended Actions

The various city, county, and state agencies should coordinate their activities through the Interagency Advisory Committee to regulate and phase out PDS's in the San Fernando Valley. The Committee should oversee and direct the measures set forth in the following sections.

A. Identification, Investigation and Regulation of Existing Private Disposal Systems

The first phase of implementation involves the identification, investigation, and increased regulation of PDS's on commercial or industrial properties. Monitoring and testing of individual PDS's may be required to determine which sites have the greatest potential for adverse impact on groundwater quality. Where applicable, these facilites should be included in existing regulatory programs, such as the Industrial Waste Permit program or the County Hazardous Waste Control Program. Provisions should be made for regular testing of PDS effluents to ensure the proper utilization of the PDS.

B. Phaseout and Elimination of Private Disposal Systems

The second phase of implementation involves the phaseout and elimination of existing PDS's. This recommended action is in substantial conformance with the recommended management policies of the Water Quality Control Plan for the Los Angeles River Basin adopted by the Los Angeles Regional Water Quality Control Board and the State Water Resources Control Board.

Based on the information gathered from the first phase, a priority schedule for the elimination of PDS's from commercial and industrial properties should be established. This schedule should consider the following factors:

1. nature and quantity of hazardous wastes generated;

2. history of compliance with or violation of hazardous waste disposal regulations (e.g. presence of industrial wastes in PDS effluent);

3. availabilty of existing public sewer facilities; and

4. costs to construct new public sewer facilities.

Those sites that have access to existing public sewers should be required to abandon their PDS's and connect to the sewer system if hazardous wastes are generated on the premises. Currently, Burbank and Glendale have provisions in their municipal codes that require all properties within 200 feet of available sewers to connect to those facilities within a 5-year period. Similar provisions should be included in the Los Angeles and San Fernando Municipal Codes to allow for enforcement of this action for those commercial and industrial land uses where hazardous wastes may be generated.

Where no existing sewer facilities are available, new public sewers should be constructed to further eliminate the need for PDS's in those areas. The Cities of Burbank, Glendale and San Fernando have already instituted projects to sewer all areas within those cities. Except for some possible fringe areas, all

properties appear to be connected to the public sewer system. Provisions for the abandonment and backfilling of the PDS upon connection to the sewer are also included in the plumbing codes for these cities.

There are several unsewered areas in heavily developed commercial and industrial zones in the City of Los Angeles. Although there are currently no provisions to require that these areas be sewered, the County DOHS, together with the RWQCB, can order that individual sites be sewered when it is believed that the continued use of a PDS represents either a threat to public health or a significant public nuisance.

3.2.3.2 Responsible Agencies

Water Agency		Assist in locating PDS's by conducting a search of utility files and provide the appropriate agency with a listing of all locations in the east San Fernando Valley that have been exempted from the sewer service charge.
Engineering Department	1.	Review public sewer "WYE" maps, evaluate the area-wide wastewater collection network, and identify areas not served by public sewers.
	2.	Plan, schedule and construct new public sewer facilities in those commercial and industrial areas within the sensitive groundwater areas of the SFVB.
Sanitation Department	1.	Conduct field investigations and and coordinate records search to identify all PDS's operated by commercial and industrial firms in the eastern San Fernando Valley.
	2.	Conduct regular inspections and testing at commercial and industrial sites that generate industrial wastes where a private disposal system is used.
Department of Building and Safety, Cities of Los Angeles and San Fernando	1.	Review files to assist in locating existing and improperly abandoned PDS's.

	2. Recommend and pursue a revision to the Municipal Code to require mandatory connection to the public sewer system and proper abandonment of the PDS for commercial and industrial properties in areas where sewers are available.
State and County Departments of Health Services, Regional Water Quality Control Board	1. Assist in locating unauthorized PDS's during field inspections.
	2. Assist in monitoring and testing of PDS's on sites that generate hazardous wastes.
	3. Provide regulatory and legal support and guidelines for efforts to require construction of new sewers and abandonment of misused PDS's.

IV. CITY OF LOS ANGELES PSDS LEGISLATION

Approximately two years after the publication of Los Angeles Department of Water and Power's, "Groundwater Quality Management Plan; SFVB", local legislation regulating private sewage disposal systems (PSDS) was passed. In September of 1985, the City of Los Angeles passed Ordinance Number 160388. This ordinance amended the Los Angeles Municipal Code to "require the phasing-out of private sewage disposal systems employed by industrial, commercial, and multiple residential uses in the San Fernando Valley" (City of Los Angeles Municipal Code, Ordinance Number 160388).

The ordinance requires owners of industrial and commercial PSDS to abandon their systems and connect to public sanitary sewers. These requirements are in effect in areas currently

served by public sewers. All private sewage disposal systems on lots occupied by four or fewer residential units are exempt from these orders.

Owners of PSDS who are served Notices to Connect, are required to comply with the order within one year. Failure to comply may result in the discontinuance of water service, and a subsequent LADWP order to vacate the building.

Provisions under the ordinance allow persons who (1) own, use or maintain a PSDS and, (2) have been issued Notices to Connect, the right to apply for a variance from the ordinance's connection requirements. The Director may issue a variance if:

1. The ordinance requirements will result in "extreme hardships unessential to the overall purpose of such requirements", and

2. The continued operation of the subject PSDS will not have any significant adverse effect upon groundwater quality in the SFVB (LADWP, 1983).

V. IMPLEMENTATION OF PSDS PHASE-OUT PROGRAM

The City of Los Angeles' Department of Public Works began a phased implementation program in 1986. This program was instituted to ultimately eliminate the use of commercial and industrial PSDS in the SFVB. Measures were taken by the Bureau of Sanitation to prioritize its implementation. Owners of PSDS which contained hazardous wastes (as designated by the City) were issued Notices to Connect (to existing sewer systems) first. Since late 1985, the Bureau of Sanitation has completed the following tasks:

1. With 30 inspectors, completed a field survey of 3,039 San Fernando Valley site addresses provided by the Bureau of Engineering. These addresses were industrial and commercial properties that did not apply for a sewer connection permit where a city sewer was available.

2. Compiled a list of 1,502 site addresses from the original survey as possible PSDS users. The remaining addresses were identified to be properties which did not have PSDS on location (i.e. parking lots, vacant lots).

3. Mailed letters to all legal owners of the 1,502 site addresses informing them of the requirements of the recently passed Ordinance 160388.

4. Established a priority listing of sites in contaminated groundwater areas to be served Notices to Connect.

5. Identified 141 sites as suspected potential dischargers of industrial wastes. These sites were surveyed and 63 were reported to possess industrial wastes or contaminants on site grounds. PSDS on these sites were targeted for inclusion within the waste water sampling program.

6. As of September 11, 1986, 24 of the 63 PSDS were sampled and analyzed for volatile organic compounds. PSDS waste water sampling at the remaining sites is currently being conducted by the Bureau of Sanitation.

Almost all PSDS covered in the Bureau's field survey were identified as septic tanks with shallow wells. These wells were often lined, and received septic tank effluent. Because some septic tanks were not easily observable, a percentage of PSDS inspected were assumed to have these tanks. Cesspools (sewage wells without septic tanks) may have actually served some facilities.

Waste water samples were collected from on-site PSDS at one of several accessible sampling points. Samples were directly withdrawn by the Bureau of Sanitation from septic tanks when they

were accessible. Samples were also collected from the discharge pipe outlet located inside the sewage disposal well.

Table 1 presents information obtained from the industrial survey and sampling program (tasks 5 & 6 above). Results are reported for specific industrial categories. Attempts to reveal contamination trends with respect to industrial categories may aid the Bureau of Sanitation in targeting additional sites to be sampled in the SFVB area.

Of the 24 PSDS sites sampled, 7 were found to contain quantifiable amounts of volatile organic chemicals. Owners of these sites have been issued Notices of Violation to pump out their sewage disposal wells. (letter from D. Biagi, Director of the Bureau of Sanitation, to R. Ghirelli of the LARWQCB [Los Angeles Regional Water Quality Control Board], September, 1986).

Table 2 contains a summary of the VOC analyses for those 7 sites found to be contaminated. As is evident from the table, the majority of contaminants detected were aromatic hydrocarbons and chlorinated olefins.

As mentioned previously, the Bureau of Sanitation is currently sampling the remaining sites identified to have industrial wastes or contaminants on facility grounds. All remaining sites will be similarly sampled for the presence of VOC compounds.

TABLE 1
SUMMARY OF PSDS INDUSTRIAL WASTE SURVEY
AS OF SEPTEMBER 11, 1986

IC NO.	INDUSTRIAL CATEGORY	NO. OF SITES SURVEYED	DATE OF SURVEY	SITES WITH INDUSTRIAL CONTAMINANTS ON SITE GROUNDS		NO. OF SITES SAMPLED	RESULTS OF ANALYSIS		ENFORCEMENT ACTION
				WITHOUT	WITH		NO VIOLATION	VIOLATION	
002	Aircraft Mfg. Serv. & Maintenance	4	7/17/86	3	1				
006	Auto Mfg. Serv. & Maintenance	44	7/16 - 7/24/86	23	21	5	4	1	N. O. V.
028	Cleaners & Dryers	1	7/17/86	1					
039	Film Processing	3	7/24/86	1	2	2	2		
059	Jewelry-Repair & Cleaning	1	7/16/86		1				
068	Laundry-Self-Serv.	1	7/22/86	1					
069	Laundry-Linen & Genl.	1	7/23/86		1				
071	Liquid Waste & Disp.	1	7/23/86		1				
075	Metal Fabrication	22	7/16 - 7/22/86	9	13	7	4	3	N. O. V.
106	Printing-Type Setting	2	7/23/86	2					
112	Service Stations	7	7/16 - 7/24/86	2	5				
123	Tire Servicing	2	7/21/86	1	1	1		1	N. O. V.

TABLE 1,
continued

IC NO.	INDUSTRIAL CATEGORY	NO. OF SITES SURVEYED	DATE OF SURVEY	SITES WITH INDUSTRIAL CONTAMINANTS ON SITE GROUNDS		NO. OF SITES SAMPLED	RESULTS OF ANALYSIS		ENFORCEMENT ACTION
				WITHOUT	WITH		NO VIOLATION	VIOLATION	
030	Concrete Products	4	7/17/ - 7/24/86	3	1				
125	Truck Repair & Service	3	7/17 - 7/24/86		3	1	1		
020	Private Building	27	7/17 - 7/24/86	25	2	2	2		
014	Beverage Mfg.	1	7/24/86		1				
095	Paint Remover Mfg. & Service	2	7/24/86		2				
096	Paint Spray Booths	3	7/17/86		3	2	1	1	N. O. V.
097	Paper Products	1	7/22/86	1					
056	Hospital	1	7/16/86	1					
072	Lumber Treating	1	7/21/86	1					
110	Sanitarium	1	7/21/86	1					
104	Printing-Silk Screen	1	7/22/86		1	1	1		
054	Grinding & Disposal	1	7/21/86	1					
111	School	1	7/24/86	1					
011	Bar	1	7/25/86	1					

TABLE 1,
continued

IC NO.	INDUSTRIAL CATEGORY	NO. OF SITES SURVEYED	DATE OF SURVEY	SITES WITH INDUSTRIAL CONTAMINANTS ON SITE GROUNDS		NO. OF SITES SAMPLED	RESULTS OF ANALYSIS		ENFORCEMENT ACTION
				WITHOUT	WITH		NO VIOLATION	VIOLATION	
026	Chemical Packaging	1	7/17/86		1	1	1		
060	Laboratory - Analytical	1	7/17/86		1	1	1		
019	Bus Repair & Servicing	1	7/17/86		1	1		1	N. O. V.
085	Oil - Mfg. Drilling	1	7/17/86		1				
	TOTALS	141		78	63	24	17	7	

N. O. V. = Notice of Violation

TABLE 2

PSDS INDUSTRIAL WASTE SURVEY
SUMMARY OF VOLATILE ORGANIC CHEMICAL (VOC)
ANALYSES FOR CONTAMINATED INDUSTRIAL SITES

LAB NO.	OWNER/TENANT SITE ADDRESS	DATE SAMPLED	DATE ANALYSIS REPORTED	QUANTIFIED VOC	CONCENTRATION (PPM)
130	Columbia Showcase and Cabinet Company Cesspool #2 11034 Sherman Way North Hollywood, CA	8/15/86	9/8/86	Toluene P-Xylene O-Xylene	0.23 0.03 0.02
132	Columbia Showcase and Cabinet Company Cesspool #3 11034 Sherman Way North Hollywood, CA	8/15/86	9/8/86	Toluene Ethyl Benzene P-Xylene O-Xylene 1-Methyl-4-Benzene	85.1 0.07 1.32 0.01 Trace
135	Medal Tire Co. Inc. 13123 Sherman Way North Hollywood, CA	8/15/86	9/8/86	Toluene Non-priority org.	0.05 Trace
144	Chapman Studio Equip. Co. 12950 Razmer Street North Hollywood, CA	8/18/86	9/8/86	Methylene Chloride TCA PCE TCE	12.0 0.04 0.01 0.03
125	Bug Castle 12039 Branford Sun Valley, CA	8/14/86	9/8/86	Non-priority org.	Trace
133	McKinzie's Automotive 12945 Sherman Way Cesspool #2 North Hollywood, CA	8/15/86	9/8/86	Toluene P-Xylene O-Xylene Non-priority org.	0.02 0.05 0.06 Trace
134	McKinzie's Automotive Inc. 12945 Sherman Way Cesspool w/o building North Hollywood, CA	8/15/86	9/8/86	1,2-Dichloro Benzene	0.06
137	R & R Four Slide Corp. 12957 Sherman Way North Hollywood, CA	8/15/86	9/8/86	P-Xylene 1,2-DCE	0.01 Trace
155	Remo Inc. 12804 Rayner St. North Hollywood, CA	8/18/86	9/8/86	TCE Toluene 1,2-Dichloro Benzene	0.02 0.02 0.05

VI. ASSESSMENT

Sampling programs have provided evidence that industrial and commercial PSDS continue to pose a high contamination potential to SFVB groundwater. Most contaminated groundwater supply wells have been found in industrially zoned areas. A number of industrial septic systems were also found to discharge waste water effluent containing industrial chemicals. TCE contamination in the Basin has been attributed to disposal practices dating 20 to 30 years ago. PSDS, however, continue to discharge a variety of other contaminants to the subsurface.

The San Fernando Valley Basin is one of a growing number of groundwater aquifers which has been contaminated by industrial PSDS. Research conducted nationally indicates that primary sewage disposal systems (i.e. septic tank systems) are limited with respect to their treatment capacities. Field sampling programs and research have shown that:

(1) Septic systems remove little, if any, organic chemicals. The scum layer residing within the tank inhibits the volatilization of organic solvents.

(2) Subsurface soil absorption systems (i.e. wells, drain fields) do not provide adequate treatment of industrial waste streams. Past experience has shown that soils cannot adequately adsorb many of the organic compounds found in industrial waste discharges (US EPA Office of Groundwater Protection, 1986).

Concerns regarding the continued threat of industrial septic systems operating within the SFVB are, therefore, well substantiated.

The City of Los Angeles has adopted an aggressive program designed to eliminate future groundwater contamination resulting from PSDS. Rather than implementing a general permitting program consisting of effluent and groundwater monitoring, the City has committed itself to constructing sanitary sewers in the affected industrial districts. Ultimately, all industrial sewage waste waters in the Eastern San Fernando Valley (L.A. County) will be collected by sanitary sewer collection systems. The sewer construction program is projected to span a decade at an annual cost of $1,000,000 (LADWP, 1983).

Other cities considering similar PSDS phase-out programs should examine LADWP's recommendations. LADWP's Recommendation #2 represents a well organized regulatory guideline. This guideline discusses general considerations which should be addressed when developing a prioritized schedule for the elimination of commercial and industrial PSDS. Tasks performed by the City of Los Angeles' Department of Public Works should also be scrutinized. Methods used by the department to identify, survey, and sample industrial PSDS should aid other regulatory agencies who plan to implement similar prioritized programs.

Probable Class V well types operating in the San Fernando Valley are:

- Septic Systems (Well Disposal Method), 5W31
- Industrial Process Water and Waste Disposal Wells, 5W20
- Cesspools, 5W10

Industrial or commercial PSDS which were shown to contain industrial waste contaminants are essentially industrial waste disposal (type 5W-20) wells. Chemicals identified in these PSDS are listed as hazardous substances in 40 CFR Part 261 Subpart D. These wells, therefore, may be reclassified as Class IV Wells by EPA Region IX. PSDS not identified as industrial waste discharges cannot positively be classified as Class V wells based on currently available information. Field surveys conducted by the Bureau of Sanitation did not include PSDS flow rate information. These wells, therefore, may not meet minimum disposal rate requirements for Class V Wells (which must serve at least 20 persons per day.) (1500 gpd is judged here to be an indicative flow rate for systems serving 20 persons per day). Additional flow rate information must be assimilated before these wells can be included within the UIC Class V Well inventory. This deserves further attention from EPA Region IX.

Groundwater testing data obtained from the SFVB reaffirm concerns that commercial and industrial PSDS pose a high pollution threat to USDW's Aquifers across the nation. The City of Los Angeles, recognizing the threat posed by PSDS in the Valley, has expedited legislation and regulatory programs to protect the SFVB from future contamination from these sources. Other California cities with unsewered industrial districts

overlying groundwater aquifers should take heed of the SFVB groundwater quality findings. Groundwater monitoring programs should be established throughout these areas to measure the impact of industrial and commercial PSDS on regional groundwaters.

Section 4.3

Sewage Treatment Plant Disposal Wells Supporting Data

SECTION 4.3.1

TITLE OF STUDY: (or SOURCE OF INFORMATION)	Deep-Well Artificial Recharge Experiments at Bay Park, Long Island, New York, Geological Survey Professional Papers 751-A through 751-F
AUTHOR: (OR INVESTIGATOR)	United States Geological Survey, and Nassau County Department of Public Works
DATE:	1972
FACILITY NAME AND LOCATION:	Bay Park Artificial Recharge Plant, Bay Park, Long Island, NY, USEPA Region II
NATURE OF BUSINESS:	Sewage treatment plant and aquifer recharge facility.

BRIEF SUMMARY/NOTES: Title pages and abstracts of the following USGS reports are included:

751-A "Preliminary Results of Injecting Highly Treated Sewage-Plant Effluent into a Deep Sand Aquifer at Bay Park, New York" by John Vecchioli and Henry F.H. Ku

751-B "Design and Operation of the Artificial-Recharge Plant at Bay Park, New York" by Ellis Koch, Anthony A. Giaimo, and Dennis J. Sulam

751-C "Geohydrology of the Artificial-Research Site at Bay Park, Long Island, New York" by John Vecchioli, G.D. Bennett, F.J. Pearson, Jr., and L.A. Cerrillo

751-D "Geochemical Effects of Recharging the Magothy Aquifer, Bay Park, New York, with Tertiary-Treated Sewage" by Stephen E. Ragone

751-E "Microbiological Effects of Recharging the Magothy Aquifer, Bay Park, New York, with Tertiary-Treated Sewage" by Gary G. Erlich, Henry F.H. Ku, John Vecchioli, and Theodore A. Ehlke

751-F "Hydraulic Effects of Recharging the Magothy Aquifer, Bay Park, New York, with Tertiary-Treated Sewage" by John Vecchioli, Henry F.H. Ku, and Dennis J. Sulam

A10104 254732

Preliminary Results of Injecting Highly Treated Sewage-Plant Effluent Into a Deep Sand Aquifer at Bay Park, New York

By JOHN VECCHIOLI and HENRY F. H. KU

DEEP-WELL ARTIFICIAL RECHARGE EXPERIMENTS AT BAY PARK, LONG ISLAND, NEW YORK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 751-A

Prepared in cooperation with the Nassau County Department of Public Works

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[4-102

DEEP-WELL ARTIFICIAL RECHARGE EXPERIMENTS AT BAY PARK, LONG ISLAND, NEW YORK

PRELIMINARY RESULTS OF INJECTING HIGHLY TREATED SEWAGE-PLANT EFFLUENT INTO A DEEP SAND AQUIFER AT BAY PARK, NEW YORK

By JOHN VECCHIOLI and HENRY F. H. KU

ABSTRACT

Highly treated sewage-plant effluent is being injected into a sand aquifer at Bay Park, N.Y. Recharge is through a fiberglass-cased well finished with a gravel-packed 16-inch diameter stainless-steel screen set between 418 and 480 feet below land surface. The well is open to the Magothy aquifer of Late Cretaceous age. Maximum recharge rate thus far is 360 gallons per minute.

Head buildup in the injection well (but not the aquifer) in each injection test has exceeded that predicted by pumping-test data even though the water injected had a physical and chemical quality acceptable for drinking water. In one test, the specific capacity of the injection well was reduced to half the preinjection value after 10 days of injection. Excessive head buildup is strongly dependent upon the turbidity of the recharge water, even though turbidity levels are generally less than 2 milligrams per liter as SiO_2. The fine-grained nature of the aquifer probably accounts for the well's high sensitivity to small amounts of suspended matter.

Redevelopment by pumping after each injection test has resulted in restoration of most of the specific capacity prevailing prior to each test. The first slug of water recovered during redevelopment is very turbid and the concentrations of iron, phosphate, and volatile solids are many times greater than those of the injected water. Bacterial content is also many times greater and this together with other evidence suggests that some deterioration in well capacity may be a result of biologic clogging.

INTRODUCTION

PURPOSE AND SCOPE

Nassau County is a highly urbanized area on Long Island adjacent to New York City (fig. 1). Its population has grown from 672,765 in 1950 to almost 1.5 million in 1965 (Peters and Rose, 1968, p. 627). With the growth of population has come a steady increase in ground-water pumpage for public supply—to nearly 210 mgd (million gallons per day) in 1965 (Cohen and others, 1968, p. 70). Pumpage is expected to be almost 300 mgd by 2010 (Peters and Rose, 1968, p. 627). Local ground water presently is the only source of public-supply water, with most of the water being obtained from the Magothy aquifer of Late Cretaceous age. Intensive net withdrawals from that aquifer have

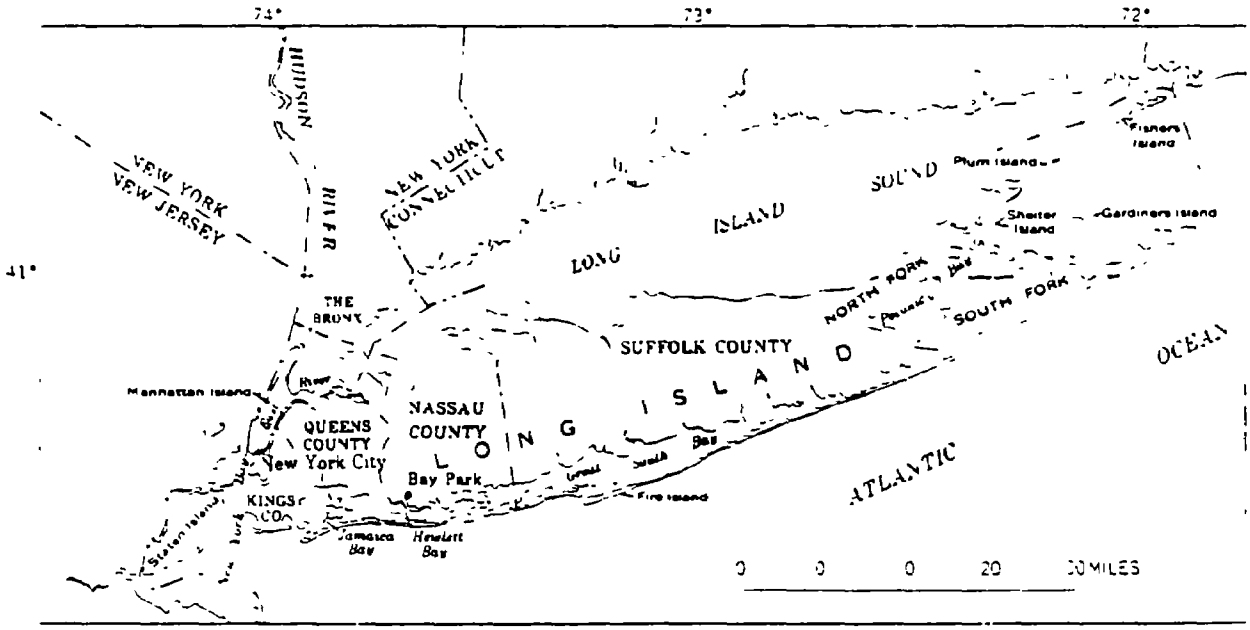

FIGURE 1.—Location of Bay Park injection site.

A10104 254724

Design and Operation of the Artificial-Recharge Plant at Bay Park, New York

By ELLIS KOCH, ANTHONY A. GIAIMO, *and* DENNIS J. SULAM

DEEP-WELL ARTIFICIAL-RECHARGE EXPERIMENTS AT BAY PARK, LONG ISLAND, NEW YORK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 751-B

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[4-10

DEEP-WELL ARTIFICIAL-RECHARGE EXPERIMENTS
AT BAY PARK, LONG ISLAND, NEW YORK

DESIGN AND OPERATION OF THE ARTIFICIAL-RECHARGE PLANT AT BAY PARK, NEW YORK

By Ellis Koch, Anthony A. Giammo, and Dennis J. Sulam

ABSTRACT

The Bay Park artificial-recharge plant, in southwestern Nassau County, is an extensively instrumented facility adjacent to a 60-million gallon-per-day sewage-treatment plant. The facility was constructed to inject reclaimed water (sewage-plant effluent that has been given tertiary treatment) into a deep well in the Magothy aquifer and to monitor hydraulic and geochemical effects of that water on the aquifer, the major source of water for Nassau County. An array of observation wells permits monitoring those effects at distances up to 200 feet from the injection well. Major components of the facility include (a) a 50,000-gallon storage tank, (b) a vacuum degasifier, (c) pumping and controlling equipment for maintaining injection either at a constant rate or under a constant head, (d) flow-rate and water-quality monitoring and recording equipment, (e) a 490-foot-deep injection well, (f) an array of observation wells, and (g) pumping equipment for testing and redeveloping the injection well.

Effluent can be injected at rates as much as 400 gallons per minute and the injection well can be redeveloped at rates as much as 1,000 gallons per minute.

Casings of the injection well and of most of the observation wells are made of fiber-glass-reinforced epoxy pipe. One of the well screens is made of slotted fiber-glass-reinforced epoxy pipe; the others are made of stainless steel. Associated piping and tanks are made either of polyvinyl chloride or of steel coated with chemically stable materials, such as epoxy or coal-tar enamel. These materials were selected to minimize corrosion of tanks, pipes, and screens exposed to reclaimed water or to chemical solutions used in redevelopment of the injection well.

The chemical character of the water to be injected can be changed by the addition of chemicals at the storage tank's inlet or outlet and by the degasification process. Automatic sensors continuously monitor injection water, repumped water, or water from observation wells for temperature, turbidity, specific conductance, pH, Eh, and dissolved-oxygen and residual-chlorine contents. In addition, periodic calibration of the automatic sensors as well as some chemical and bacteriological analyses can be made in a small laboratory at the site.

INTRODUCTION

PURPOSE AND SCOPE

The Bay Park artificial-recharge study was begun in 1964 as part of a cooperative program of water-resources investigations by the U.S. Geological Survey and the Nassau County Department of Public Works. The study involves experimental injection of reclaimed water (sewage-plant effluent that has been given tertiary treatment) into a 490-foot-deep well in the Magothy aquifer. The recharge facility is in southwestern Nassau County (fig. 1), in the Village of East Rockaway, on the property of the Bay Park sewage-treatment plant.

The Bay Park sewage-treatment plant is the activated-sludge type. It has a design capacity of 60 mgd (million gallons per day). About 0.6 mgd of the effluent from this plant is diverted to a pilot plant, where it receives tertiary treatment. There the effluent is clarified, filtered, first through sand-anthrafilt beds and then through beds of activated carbon; and chlorinated. About 425,000 gallons of the treated effluent from the pilot plant (reclaimed water) is then piped to the recharge facility (fig. 2).

This report, one of a series on the experimental results at Bay Park, describes the design and the operation of the recharge plant.

PREVIOUS WORK

Several reports on the Bay Park facility and its operation have been published. Cohen and Durfor (1966) described the injection well in detail. In a subsequent report, Cohen and Durfor (1967) listed the objectives of the recharge study and described

A10104 254708

Geohydrology of the Artificial-Recharge Site at Bay Park, Long Island, New York

By JOHN VECCHIOLI, G. D. BENNETT, F. J. PEARSON, JR., *and* L. A. CERRILLO

DEEP-WELL ARTIFICIAL-RECHARGE EXPERIMENTS AT BAY PARK, LONG ISLAND, NEW YORK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 751-C

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[4-106

GEOHYDROLOGY OF THE ARTIFICIAL-RECHARGE SITE AT BAY PARK, LONG ISLAND, NEW YORK

By John Vecchioli, Gordon D Bennett, Frederick J Pearson, Jr., and Lawrence A. Cerrillo

ABSTRACT

Reclaimed water (highly treated sewage-plant effluent) is being injected into a 480-foot-deep well at Bay Park, Long Island, N.Y., as part of a cooperative experimental study by the U S. Geological Survey and the Nassau County Department of Public Works Before the recharge experiments were started, the local geology, well and aquifer hydraulics, and chemistry of the native water were studied to define the background against which to measure the effects of injecting the reclaimed water Results of these studies are presented in this report.

The recharge well is screened in the lower part of the Magothy aquifer of Late Cretaceous age. Because the Magothy, the principal source of ground water in most of Long Island, is hydraulically interconnected with bodies of salty surface water, salt-water encroachment is a great concern. A search for methods with which to manage this problem prompted the cooperative study of recharging the aquifer with reclaimed water At Bay Park, the Magothy aquifer is confined below by the clay member of the Raritan Formation, also of Late Cretaceous age The aquifer is largely unconfined above, owing to the generally coarse-grained texture of the overlying Pleistocene deposits The injection zone is a 60-foot interval of slightly silty fine to medium sand beds that lie between Magothy beds of lower hydraulic conductivity Average lateral hydraulic conductivity of the stratified 60-foot injection zone is estimated to be 940 gallons per day per square foot (126 feet per day), but flowmeter surveys indicate considerable variation in lateral hydraulic conductivity within this interval. Vertical hydraulic conductivity of the material between the water table and the top of the injection zone ranges from 2 to 20 gallons per day per square foot (0.27 to 2.7 feet per day) The hydraulic characteristics of the hydrologic system were determined by standard aquifer-test methods and were later verified by electric-analog studies

Water from the Magothy aquifer has an unusually low dissolved-solids content because of the lack of readily soluble minerals in the aquifer deposits At Bay Park, the dissolved-solids content is about 25 milligrams per liter Most of the specific chemical components are those present in precipitation, the source of natural recharge. Dissolved silica, the single most abundant dissolved constituent in water from the Magothy aquifer, results from the solution of quartz, the dominant mineral in the sand that constitutes most of the aquifer.

INTRODUCTION

PURPOSE AND SCOPE

The U.S Geological Survey in cooperation with the Nassau County Department of Public Works is continuing a study of hydrologic and geochemical problems connected with injection of reclaimed water into a deep well at Bay Park, Long Island, N.Y. Although this work is part of a larger study to evaluate the feasibility of the use of barrier recharge wells to prevent salt-water encroachment, the work is not concerned with the effect of recharge on the salt-water front. Rather, it is restricted to a study of the mechanics of the recharge process Pilot-plant experimentation is underway at the Nassau County sewage-treatment plant in Bay Park, Long Island, N.Y. Bay Park, on the northern shore of Hewlett Bay in southwestern Nassau County (fig. 1), is about 3 miles north of the southern shore of Long Island.

Early work in the project included construction of the experimental recharge well and a series of observation wells, installation of injection equipment, and instrumentation of observation wells and injection equipment. Lithologic core samples collected during drilling of the wells and geophysical logs of the wells were studied to define the hydrogeologic framework at the recharge site. Aquifer tests were made to determine the hydraulics of the wells and the aquifer These tests were later supplemented with electric-analog studies Hydrochemical studies were made to define the geochemical environment of the aquifer. This report presents the results of geologic, hydrologic, and hydrochemical studies that

A10104 254693

Geochemical Effects of Recharging the Magothy Aquifer, Bay Park, New York, With Tertiary-Treated Sewage

By STEPHEN E. RAGONE

DEEP-WELL ARTIFICIAL-RECHARGE EXPERIMENTS AT BAY PARK, LONG ISLAND, NEW YORK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 751-D

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON 1977

GEOCHEMICAL EFFECTS OF RECHARGING THE MAGOTHY AQUIFER, BAY PARK, NEW YORK, WITH TERTIARY-TREATED SEWAGE

By Stephen E. Ragone

ABSTRACT

A ground-water deficit of 93.5 to 123 million gallons per day (4.10 to 5.39 cubic meters per second) has been predicted for Nassau County, N.Y., by the year 2000 in a State report. Because of the predicted deficit, the U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, began an experimental deep-well recharge program in 1968. Thirteen recharge tests using tertiary-treated sewage (reclaimed water) and six tests using water from the domestic supply (city water) were completed between 1968 and 1973. Recharge was through an 18-inch (46-centimeter) diameter recharge well screened in the Magothy aquifer between depths of 418 and 480 feet (127 and 146 meters) below land surface. Recharge rates ranged from about 200 to 400 gallons per minute (13 to 25 liters per second). In the longest test, reclaimed water was injected during 84.5 days of a 199-day period.

Although the iron concentration of native water in the recharge zone and of reclaimed water is less than 0.5 milligrams per liter, the iron concentration of samples collected from observation wells 20, 100, and 200 feet (6.1, 30, and 61 meters) from the recharge well, and screened in the zone of recharge, approached 3 milligrams per liter at times. Iron mass-balance calculations indicate that dissolution of pyrite and marcasite (FeS_2) in the aquifer are the only known sources of iron that could explain the observed increase. Within a 20-foot (6.1-meter) radius of the recharge well, dissolved oxygen in the reclaimed water oxidizes pyrite and releases Fe^{+2} (ferrous iron) to solution. However, the amount of iron in water continues to increase with distance from the recharge well even though dissolved oxygen is no longer present in water reaching the 20-foot (6.1-meter) radius; the mechanism by which iron continues to be dissolved is not quantitatively understood.

Some cation exchange also occurs during recharge. Loss of ammonium and potassium cations in the water was balanced by an increase in H^+, which at times caused pH to decrease by more than 1 pH unit.

Tertiary treatment removes 90 to 98 percent of the phosphate, MBAS (methylene blue active substances), and COD (chemical oxygen demand), leaving an average of 0.17, 0.07, and 9 milligrams per liter, respectively. During recharge, phosphate concentrations remain at native-water levels at the 20-, 100-, and 200-foot (6.1-, 30-, and 61-meter) observation wells, which indicates phosphate retention by the aquifer. Some MBAS and COD are retained at the 100- and 200-foot (30- and 61-meter) wells, presumably by adsorption reactions.

INTRODUCTION

Population of Nassau County, Long Island, N.Y. (fig. 1) increased from 0.41 million in 1940 to 1.43 million in 1970 and is expected to increse to between 1.63 and 1.85 million by the year 2000 (Temporary State Commission on the Water-Supply Needs of Southeastern New York, 1972). As a result of population increase, gross pumpage from the ground-water system, the only source of public water supply to date (1977), has increased from 75 Mgal/d (3.29 m^3/s) in 1940 to 215 Mgal/d (9.42 m^3/s) in 1970. Gross pumpage is expected to range from 258 to 313 Mgal/d (11.3 to 13.7 m^3/s) by the year 2000 (Temporary State Commission on the Water-Supply Needs of Southeastern New York, 1972). The increased demand for water—together with decreased recharge resulting from the replacement of cesspools and septic tanks, which return effluents to the ground, with sewer systems, which discharge effluents offshore—is predicted to cause a water deficit in Nassau County of 93.5 to 123 Mgal/d (4.10 to 5.39 m^3/s) by the year 2000 (Temporary State Commission on the Water-Supply Needs of Southeastern New York, 1972).

PURPOSE AND SCOPE

This report summarizes the geochemical effects of injecting reclaimed water (tertiary-treated sewage) into a sand aquifer. Because of the very good chemical quality of the native water, as reflected by a dissolved-solids concentration of 22 to 25 mg/l (milligrams per liter), it was necessary to determine the type and extent of any chemical reaction caused by artificial recharge that could lead to a degradation of water quality. The study began in 1964 and was completed in 1973 as part of a cooperative water-resources program between the U.S. Geological Survey and the Nassau County Department of Public Works. Thirteen

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Microbiological Effects of Recharging the Magothy Aquifer, Bay Park, New York, With Tertiary-Treated Sewage

By GARRY G. EHRLICH, HENRY F. H. KU, JOHN VECCHIOLI, *and* THEODORE A. EHLKE

DEEP-WELL ARTIFICIAL RECHARGE EXPERIMENTS AT BAY PARK, LONG ISLAND, NEW YORK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 751-E

Prepared in cooperation with the Nassau County Department of Public Works

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON 1979

[4-110

MICROBIOLOGICAL EFFECTS OF RECHARGING THE MAGOTHY AQUIFER, BAY PARK, NEW YORK, WITH TERTIARY-TREATED SEWAGE

By Garry G Ehrlich, Henry F H. Ku, John Vecchioli, and Theodore A. Ehlke

ABSTRACT

Injection of highly treated sewage (reclaimed water) into a sand aquifer on Long Island, N.Y., stimulated microbial growth near the well screen. Chlorination of the injectant to 2.5 milligrams per liter suppressed microbial growth to the extent that it did not contribute significantly to head buildup during injection. In the absence of chlorine, microbial growth caused extensive well clogging in a zone immediately adjacent to the well screen.

During a resting period of several days between injection and well redevelopment, the inhibitory effect of chlorine dissipated and microbial growth ensued. The clogging mat at the well-aquifer interface was loosened during this period, probably as a result of microbial activity.

Little microbial activity was noted in the aquifer beyond 20 feet from the well screen, this activity probably resulted from small amounts of biotransformable substances not completely filtered out of the injectant by the aquifer materials.

Movement of bacteria from the injection well into the aquifer was not extensive. In one test, in which injected water had substantial total-coliform, fecal-coliform, and fecal-streptococcal densities, no fecal-coliform or fecal-streptococcal bacteria, and only nominal total-coliform bacteria, were found in water from an observation well 20 feet from the point of injection.

INTRODUCTION

Continuing population growth in Nassau County, a suburb of New York City, has been accompanied by increased withdrawals of ground water, the only source of public-supply water for the area.

Net withdrawals from the ground-water system have resulted in declining ground-water levels and decreased streamflow (Franke, 1968) and in local landward movement of salty ground water (Luszczynski and Swarzenski, 1966; Cohen and Kimmel, 1970). Net withdrawals are expected to increase with the rising population, per-capita water use, and percentage of population served by sewers. These growth factors indicate a water-supply deficit of between 71.1 and 91.1 Mgal/d by 1990 (Temporary State Commission on Water Supply Needs of Southeastern New York, 1972, p. 142–144).

PURPOSE AND SCOPE

Artificial recharge of the ground-water reservoir with water reclaimed from sewage is one of several alternatives under examination by Nassau County to meet the anticipated water-supply deficit (Peters and Rose, 1968). From 1968 to 1973, the Nassau County Department of Public Works operated a pilot advanced waste-treatment plant at Bay Park, N.Y., near the south shore of Nassau County (fig. 1). Reclaimed water from this plant was used in a series of 13 deep-well artificial-recharge experiments made by the U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, to provide some of the scientific and engineering data needed to evaluate (1) the degree and causes of well clogging that resulted from injection of reclaimed water, and remedies for the clogging, and (2) the geochemical compatibility of the reclaimed water with the aquifer.

This report, the fifth chapter in Professional Paper 751, "Deep-Well Artificial-Recharge Experiments at Bay Park, Long Island, New York," summarizes the results of microbiological investigations carried out during those tests. The geochemical aspects of injection of reclaimed water are described in the previous chapter (Ragone, 1977).

Microbial activity associated with artificial recharge may have three principal effects: (1) bacteria may grow near the well screen and cause a gradual reduction of aquifer hydraulic conductivity in the immediate vicinity of the well; (2) microbial activity may produce substances that adversely affect the taste and odor of injected water later recovered from the aquifer; and (3) pathogenic organisms in the injected water may travel through the aquifer and cause illness when the water is later recovered for domestic use.

WATER-RECLAMATION AND ARTIFICIAL-RECHARGE FACILITIES

Reclaimed water for injection was obtained by tertiary-stage treatment of 0.6 Mgal/d of effluent from an activated-sludge-type, 60-Mgal/d sewage-treatment plant (Peters and Rose, 1968; Peters, 1968; Vecchioli, Oliva, Ragone, and Ku, 1975). This treatment consisted of (1) coagulation and sedimentation, (2) primary filtration

Hydraulic Effects of Recharging the Magothy Aquifer, Bay Park, New York, With Tertiary-Treated Sewage

GEOLOGICAL SURVEY PROFESSIONAL PAPER 751-F

Prepared in cooperation with Nassau County Department of Public Works

HYDRAULIC EFFECTS OF RECHARGING THE MAGOTHY AQUIFER, BAY PARK, NEW YORK, WITH TERTIARY-TREATED SEWAGE

By JOHN VECCHIOLI, HENRY F. H. KU, and DENNIS J. SULAM

ABSTRACT

From 1968 to 1973, water from public supply and water reclaimed from sewage were used in a series of 19 artificial-recharge experiments at Bay Park, N.Y. Recharge to the Magothy aquifer was through a fiberglass-cased well with a 16-inch-diameter stainless-steel screen set from 418 to 480 feet below land surface. Tests ranged from 2 to 33 days, except for the final test, in which water was injected intermittently over a 6-month period. During the 6-month test, a total of 42 million gallons of water was injected. In some tests, selected treatments were applied to the injectant to evaluate their effects on well clogging and to determine whether they caused geochemical reactions within the aquifer. After each test the injected water was pumped out of the aquifer.

The recharge well and contiguous parts of the aquifer developed varying degrees of clogging, which resulted in excessive head buildup in the recharge well. Maximum reduction in specific capacity from 23.5 to 2.5 gallons per minute per foot occurred during injection of 14 million gallons of reclaimed water.

Clogging of the recharge well was caused primarily by suspended-solids content (turbidity) of the injected water. Concentrations above 1 milligram per liter as silica caused disproportionately higher rates of clogging than those below 1 milligram per liter. Microbial growth was an insignificant factor in clogging as long as a total residual chlorine level of about 2 milligrams per liter was maintained.

Specific capacity of the recharge well diminished gradually during injection but was partly restored by pumping and surging the well. Pumping rate was commonly 400 to 500 gallons per minute. Dosing the well with hydrochloric acid aided in removal of clogging material that could not be dislodged by pumping alone. Dosing with solutions of sodium hypochlorite and a bactericidal ammonium compound resulted in some improvement in specific capacity. Biodegradation of the clogging materials occurred when the well was idle after injection; redevelopment by pumping and surging was more successful after idle periods of several weeks.

INTRODUCTION

Growth in the population of Nassau County, a suburb of New York City, has been accompanied by increased withdrawals of ground water, which, in 1974, was the only source of public-supply water. Net withdrawals from the ground-water system have resulted in declining ground-water levels and decreased streamflow (Franke, 1968; Garber and Sulam, 1976) and in local landward movement of salty ground water (Lusczynski and Swarzenski, 1966; Cohen and Kimmel, 1970). A continued increase in net withdrawals is expected as population, per capita water use, and percentage of population served by sewers increase. These growth factors indicate a water-supply deficit of between 71.1 and 91.1 Mgal/d by 1990 (Temporary State Commission on Water Supply Needs of Southeastern New York, 1972, p. 142–144).

One of several alternatives under consideration by Nassau County to meet the anticipated water-supply deficit is reclamation of water from sewage and injection of the reclaimed water into the ground-water reservoir (Peters and Rose, 1968). From 1968 to 1973, the Nassau County Department of Public Works operated a pilot advanced waste-treatment plant at Bay Park, N.Y., near the south shore of Nassau County (fig. 1). Reclaimed water from this plant was used in a series of deep-well artificial-recharge experiments by the U.S. Geological Survey in cooperation with the Nassau County Department of Public Works. These tests were intended to provide some of the scientific and engineering data needed to evaluate the degree, causes, and remedies for well clogging that results from injection of reclaimed water and the geochemical compatibility of the reclaimed water with the aquifer.

PURPOSE AND SCOPE

This report is the sixth and last chapter in U.S. Geological Survey Professional Paper 751, "Deep-Well Artificial-Recharge Experiments at Bay Park,

SECTION 4.3.2

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	Notification of Threat to Underground Source of Drinking Water
AUTHOR: **(or INVESTIGATOR)**	W.J. Whitsell, Sr. Groundwater Engineer, Engineering Enterprises, Inc.
DATE:	July, 1986
FACILITY NAME AND LOCATION:	Florida Sewage Treatment Plant Barceloneta, Puerto Rico USEPA, Region II
NATURE OF BUSINESS:	Sewage treatment plant
BRIEF SUMMARY/NOTES:	The Florida Sewage Treatment Plant is designed for tertiary treatment of 167,000 gallons per day (gpd) of domestic sewage and is currently handling more than twice the design flow. It appears that sufficient chlorination is not provided prior to discharge to an improved sinkhole. The plant may be in violation of Federal law that prohibits the injection of wastes which endanger human health into or above an USDW.

ENGINEERING
ENTERPRISES, INC.

WATER RESOURCES SPECIALISTS

1225 West Main, Suite 215 Norman, Oklahoma 73069 Phone (405) 329-8300 Telex 333668 (ENG ENT INC)

July 3, 1986

Mr. William Pedicino
Groundwater Protection Program Manager
U.S. EPA - Region 2
26 Federal Plaza
New York, N.Y. 10278

Dear Mr. Pedicino:

Enclosed please find the first "Notification of Threat to Underground Source of Drinking Water (USDW)."

This is sent to you in compliance with terms of contract 68-01-7011, Work Assignment No. 2-4, Assessment of Class V Wells in Puerto Rico, which states, "The Contractor will notify EPA immediately when a well which poses a potential threat to public health is identified." It is our considered opinion that the Florida Sewage Treatment Plant operation constitutes a significant threat to public health.

Sincerely yours,

W.J. Whitsell
Senior Groundwater Engineer

WJW:skm

Enclosures

cc: Ing. Pedro Gelabert
Roger Anzzolin

NOTIFICATION OF THREAT TO UNDERGROUND SOURCE
OF DRINKING WATER (USDW)

AQUIFER THREATENED (name) Aguado/Cibao

LOCATION:

STATE Puerto Rico DISTRICT ~~COUNTY~~ Arecibo

MUNICIPALITY Barceloneta TOWN Florida

NATURE OF THREAT:

KIND OF WELL Improved Sinkhole (Class V injection well)

NATURE OF INJECTATE Incompletely treated sewage

EXACT SITE: LATITUDE/LONGITUDE $18^{o}22'15"/66^{o}34'15"$

TOWNSHIP/RANGE/SECTION --

STREET ADDRESS Hwy. P.R. 642, Florida

IDENTITY (name) Florida Sewage Treatment Plant

OWNER/OPERATOR Puerto Rican Aqueduct and Sewer Authority (PRASA)

POPULATION(S) THREATENED: Town of Florida - pop. 3,640 (1980 census).
Other "Barrios" downgradient: Bajonales; La Alianza; Allende; La Romana;
Cruce Magueyes; Cortes - populations unknown

OPERATIONAL HISTORY

See next page

The Florida Sewage Treatment Plant, operated by the Puerto Rican Aqueduct and Sewer Authority (PRASA) is located about 1/4 mile west of the center of the town bearing the same name.

The plant, designed for tertiary treatment of 167,000 gallons per day (gpd) of domestic sewage, is currently handling more than twice the design flow. Only secondary treatment is being applied as the tertiary section (sand filtration beds) was removed from service some 3 years ago.

At the time of the inspection--performed by Ms. Racqueline Shelton, U.S. EPA Environmental Scientist with the Caribbean Field Office in San Juan and by the undersigned--, discharge from the plant was about 360,000 gpd. It was turbid, and light brown in color; an earlier examination by H. Silva, Engineer with this firm, revealed the presence of 1 inch-long worms in the effluent.

PRASA's records of plant operation confirm the low plant efficiency and the discharge of incompletely treated sewage. (The PRASA directors and plant operators have been most courteous and cooperative throughout this investigation and repeatedly assured us that any data at their disposal would be provided to us.)

Before discharge from the plant, the effluent is chlorinated. The operator told us a concentration of 2 ppm of chlorine residual is sought. This is probably inadequate to disinfect the effluent with so much organic matter and suspended solids present.

The effluent is discharged directly to a sinkhole that has been "improved" by the installation of a vertical pipe and the construction of a low, concrete wall around the entire sinkhole area. The sinkhole directs the wastewater into or above the water table aquifer.

During the summer of 1985, leakage through the bottom of the trickling filter became so great, that the filter had to be by-passed for repair. Just prior to the repair, the town of Florida experienced an outbreak of gastroenteritis. The relationship between this outbreak and the sewage treatment plant operation has not been established.

The Puerto Rican Office of National Resources identifies the aquifer serving wells in the area as either the Aquado or the Cibao--in either case a water table aquifer and therefore not protected by any confining layer.

Although reliable data on groundwater levels and direction of flow are either difficult to get or unavailable, the flow generally has to be northward (northwest through northeast), toward the coast. Any of these directions would carry groundwater from the sewage treatment plant area past one or more of the water wells in the area.

POSSIBLE SOLUTIONS

The most obvious corrective step is to stop discharging plant effluent into the Karst formations (through the improved sinkhole). Possible alternatives for sewage disposal might be:

1. Shut down the existing plant at Florida and divert all sewage to a new sewer line that would carry it to the sewage treatment plant at Barceloneta;

2. Increase the capacity and efficiency of the plant so that its effluent would meet NPDS requirements for discharge to surface streams or to the ocean; or

3. Dispose of the plant effluent through properly constructed, monitored and maintained disposal wells in suitable formations deeper than the deepest known USDW's.

Economic considerations will weigh heavily in the necessary feasibility studies. Any solution will be expensive. PRASA is the agency best qualified to evaluate solutions such as the first two listed above.

The third (deep disposal well) may not even be possible. The existence of a suitable injection zone would first have to be established; a very expensive exploratory drilling operation would be necessary. Even if such an injection zone were found, the completion of a properly constructed disposal well through Karst formations would be another very expensive construction project. Finally, unless the injection zone were another cavernous, channeled formation, the injectate would have to be highly treated to avoid plugging problems during operations. The third alternative should be considered only as a last resort.

RECOMMENDATION

The Puerto Rican Aqueduct and Sewer Authority should be advised that the Florida Sewage Treatment Plant operation is in violation of Federal law that prohibits the injection of wastes which endanger human health (40 CFR 144.12(a)) into or above a USDW. PRASA should be directed to prepare its proposal for eliminating discharges to the underground formations and develop a schedule for the work, to be approved by EPA.

W.J. Whitsell
Senior Groundwater Engineer

SECTION 4.3.3

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	"Assessment of Recharge Wells," Assessment of Class V Wells in the State of Virginia
AUTHOR: **(or INVESTIGATOR)**	CH_2M Hill
DATE:	April, 1983
FACILITY NAME AND LOCATION:	Moore's Bridges Filter Plant Norfolk, Virginia USEPA Region II
NATURE OF BUSINESS:	Water Treatment Plant
BRIEF SUMMARY/NOTES:	The report describes the assessment of an injection well used to recharge an aquifer with treated wastewater. It provides general information on the well and a brief summary of the project, hydrogeology of the area, and discussion of the contamination potential. (Note: pages 37 and 38 were combined.)

3.0--ASSESSMENT OF RECHARGE WELLS

Two wells were selected by EPA Region III under this category.

3.1 FACILITY NO. VAS 710 5R 0001

3.1.1 GENERAL INFORMATION AND DESCRIPTION

Well Number	-	VAS 710 5R 0001
Owner/Location	-	City of Norfolk, VA Moore's Bridges Filter Plant
Source of Information	-	Mr. Craig Ziescmer & Mr. Creech - Plant Personnel
Nature of Business or Facility	-	Water Treatment Plant
Number of Wells	-	1
Construction Features:		
Depth	-	990 feet
Casing (diameter-depth)	-	32-inch - 100 feet 18-inch - 125 feet 8-inch - 125' to 896' to 976'
Construction Method	-	Rotary
Grout	-	896' to land surface
Special Features	-	Gravel Packed - 896' to 990'
Use of Well	-	Test Recharge/Recovery
Source of Injected Fluid	-	Treated water from plant
Volume of Injected Fluid	-	115 - 400 gpm
Operation Status	-	Inactive
Operation Period	-	Less than 6 months
Driller	-	Unknown
Consultant	-	U. S. Geological Survey
Data Available	-	Geological Survey Professional Paper 939
Date Visited	-	May 20, 1981

This recharge well is part of a test well field installed at the Moore's Bridges Filter Plant, Norfolk, Virginia. The location of this well is shown on Figure 3-1. The following has ben extracted from "Artificial Recharge to a Freshwater-Sensitive Brackish-Water Sand Aquifer, Norfolk, Virginia" by Donald L. Brown and William D. Silvey; U. S. Geological Survey Professional Paper 939 for this paragraph and adapted in Paragraph 3.1.2 Hydrogeology.

> The water supply for the City of Norfolk, Virginia, comes from surface impoundments to the independent cities of Nansemond, Norfolk, and Virginia Beach. During the winter months, when water demand is low and reservoirs are full, water must be diverted from the reservoirs and allowed to escape to the ocean with the potential use of water unfulfilled. It has been estimated (Schweitzer, oral commun., 1968) that as much as 2.5 Bgal (billion gallons) water per winter quarter could be available for use if sufficient storage areas were available.
>
> The U.S. Geological Survey and the city of Norfolk entered into a cooperative program to determine if it would be possible to utilize the water presently flowing to waste by processing it in the treatment plants and storing it underground in aquifers containing saline water. The freshwater would then be retrieved during the summer months when peak water demands and low water levels in reservoirs place strains on the present water system.
>
> During late 1971 and early 1972, three injection and withdrawal tests were made at the Norfolk, Virginia injection site. In test 1, freshwater was injected at the rate of 400 gpm. The specific capacity of the well decreased from 15.4 to 9.3 gpm/ft of drawdown (injection pressure increase) at the end of 260 minutes (4.3 hours) of injection. In test 2, the initial injection rate of 400 gpm decreased to 215 gpm after 7,900 minutes (5.5 days) of injection. The specific capacity dropped from 14.2 to 3.7 gpm/ft during the test. At the start of test 3, the aquifer accepted water at a maximum rate of 290 gpm, but the injection rate decreased to 100 gpm within 150 minutes (2.5 hours) and continued to decrease to a low of 70 gpm after approximately 1,300 minutes (0.9 days). The specific capacity decreased from 3.7 to 0.93 gpm/ft. Attempts at redevelopment of the injection well failed to improve the specific capacity.
>
> Treatment of the injection well with a clay stabilizer prior to the injection of any freshwater will minimize clogging and increase recovery of freshwater. If plugging of the screen can be prevented so that

injection and withdrawal flow patterns remain similar, the storage of freshwater in a brackish-water sand aquifer is feasible.

3.1.2. HYDROGEOLOGY

This well is located in the Atlantic coastal plain province in southeast Virginia. The injection zone is in the lower artesian aquifer system as described in the referenced report described in Paragraph 3.1.1.

> "The lower artesian aquifer is the principal source of water in southeastern Virginia. It consists essentially of a single geologic unit that underlies the entire southeast area. The aquifer, which is overlain by the upper artesian aquifer system and is underlain by crystalline bedrock, is wedge-shaped and thickens eastward from a few tens of feet or less at the fall zone to about 2,400 feet at the shoreline in the city of Virginia Beach. The average thickness of the fresh- water zone is about 330 feet. The aquifer materials are variable in character and consist of lenses and beds of fine to coarse sand, gravel, silt and clay, and mixtures of these sediments."

The injection zone selected for this well lies below the fresh-water zones in the lower artesian aquifer, at depths between 900 and 1,000 feet.

The chosen aquifer for injection is a moderately sorted, angular to sub-angular fine to medium-grained, poorly cemented quartz sand.

The formation water in the injection zone is brackish having a dissolved-solids concentration of 3,010 mg/l and is not used as a source of water supply at present.

3.1.3 CONTAMINATION POTENTIAL

Due to the good quality of treated freshwater that was injected during these tests, there is no contamination potential to this aquifer. These wells have not been used since the experimental work performed in the early 1970's and reportedly due to the relatively poor results caused by clogging of the screens by the native clays in the formation it is doubted that further development of this recharge/ recovery well field is likely.

3.1.4 CORRECTIVE MEASURES

None recommended.

3.1.5 REMEDIAL ACTIONS

None recommended.

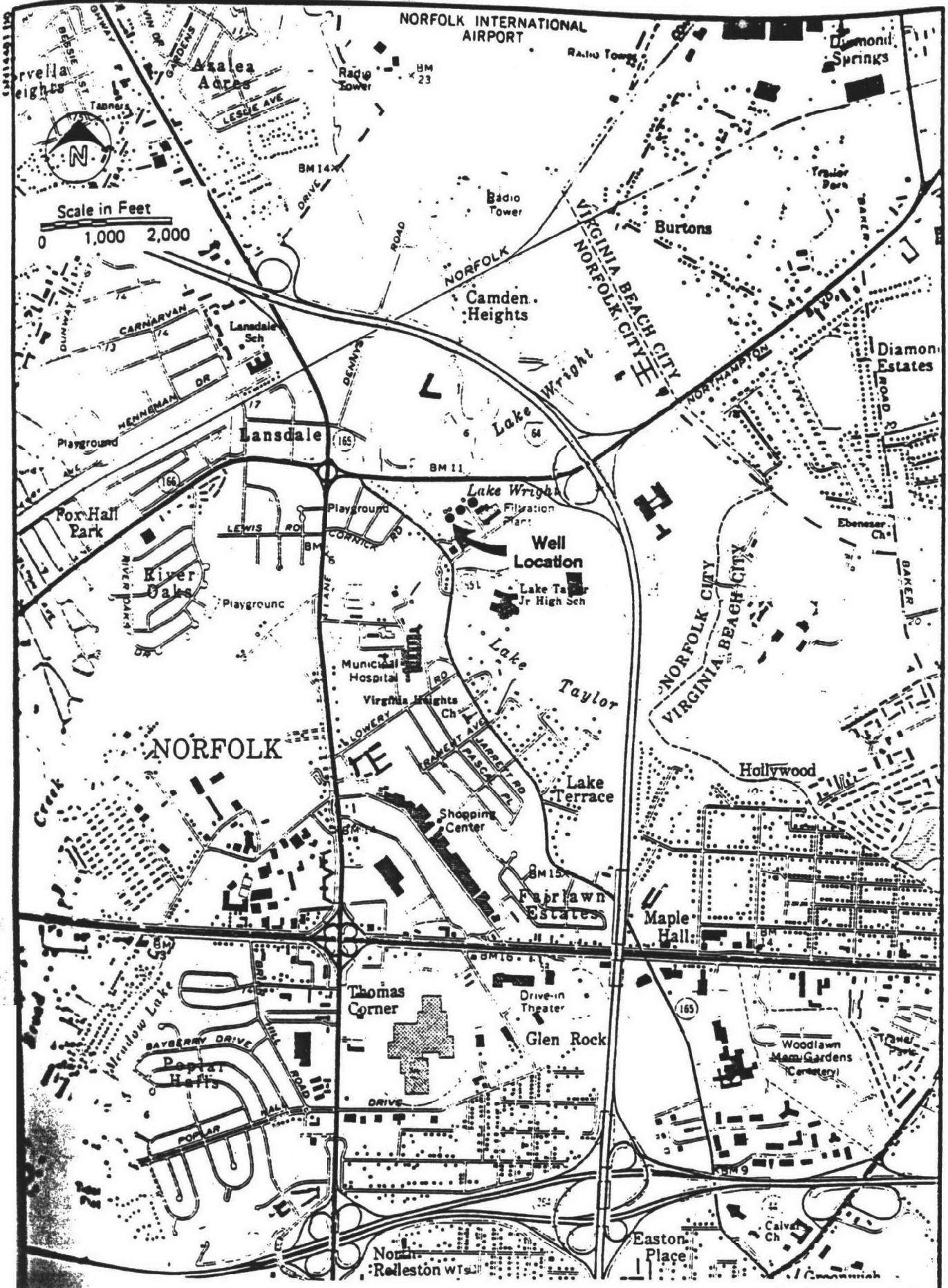


FIGURE 3-1.
Location of Facility No. VAS 710 5R 0001
City of Norfolk.

CH2M HILL

[4-125]

SECTION 4.3.4

TITLE OF STUDY: (or **SOURCE OF INFORMATION**)	"Artificial Recharge Wells," Underground Injection Operations in Texas: A Classification and Assessment of Underground Injection Activities, Report 291
AUTHOR: (or **INVESTIGATOR**)	Texas Department of Water Resources
DATE:	December, 1984
FACILITY NAME AND LOCATION:	Hueco Bolson Recharge Project, El Paso, Texas USEPA Region VI
NATURE OF BUSINESS:	Sewage treatment facility and recharge project
BRIEF SUMMARY/NOTES:	One type of well used for recharge of aquifers in Texas includes treated effluent injection wells. Two pilot injection wells and ten proposed wells will be used to inject wastewater (treated to drinking water standards). The Recharge Project is authorized by a wastewater permit issued by the Department of Water Resources. (Note: Figures and Tables have been omitted.)

ARTIFICIAL RECHARGE WELLS

Introduction

Texas has many valuable aquifers which provide water for irrigation and municipal and domestic needs. However, because of increasing demand for ground water, excessive pumping of some aquifers is depleting underground supplies of water Replenishment of ground water usually occurs through natural recharge where surface water enters pores and fractures on the outcrop of an aquifer, or percolates through overlying sediments to enter the aquifer Where water has been produced from an aquifer faster than the rate of natural recharge to the aquifer, methods have been sought for replacing the depleted water supply These methods have usually involved operation of wells which inject surplus volumes of surface water into the underground aquifer

In the last 20 to 30 years, farmers throughout the High Plains of Texas have been using the injection well method of artificial recharge with "dual-purpose" wells which can alternately produce ground water for irrigation and inject surface runoff water back into the underground aquifer With advances in technology, the basic artificial recharge well has been applied to other ground-water problems including secondary recovery of capillary ground water, flood control and storm water drainage, and control of subsidence and salt water intrusion Artificial recharge wells, in their various applications, are Class V wells under the regulatory jurisdiction of the Texas Department of Water Resources, local water districts, and city and county governments

Following are descriptions of various types of wells used for artificial recharge of aquifers in Texas Assessments are presented by geographic area and well type Figure 8-1 shows the locations of artificial recharge wells investigated by the Department.

Trans-Pecos Region

El Paso Area

Geohydrology

The principal ground-water supply of the City of El Paso is the Hueco Bolson, which together with other bolson deposits of the Trans-Pecos region constitutes a major aquifer (Table 2-2). Hueco Bolson lies east of the City of El Paso and the Franklin Mountains (Figure 8-2). In Hueco Bolson, ground water occurs under water table conditions As ground water moves into the city artesian area, it passes beneath relatively impermeable sediments and becomes confined under pressure exerted by the higher elevation of the water surface underlying the mesa. Ground-water movement in the Hueco Bolson deposits in and adjacent to the city artesian area is predominantly

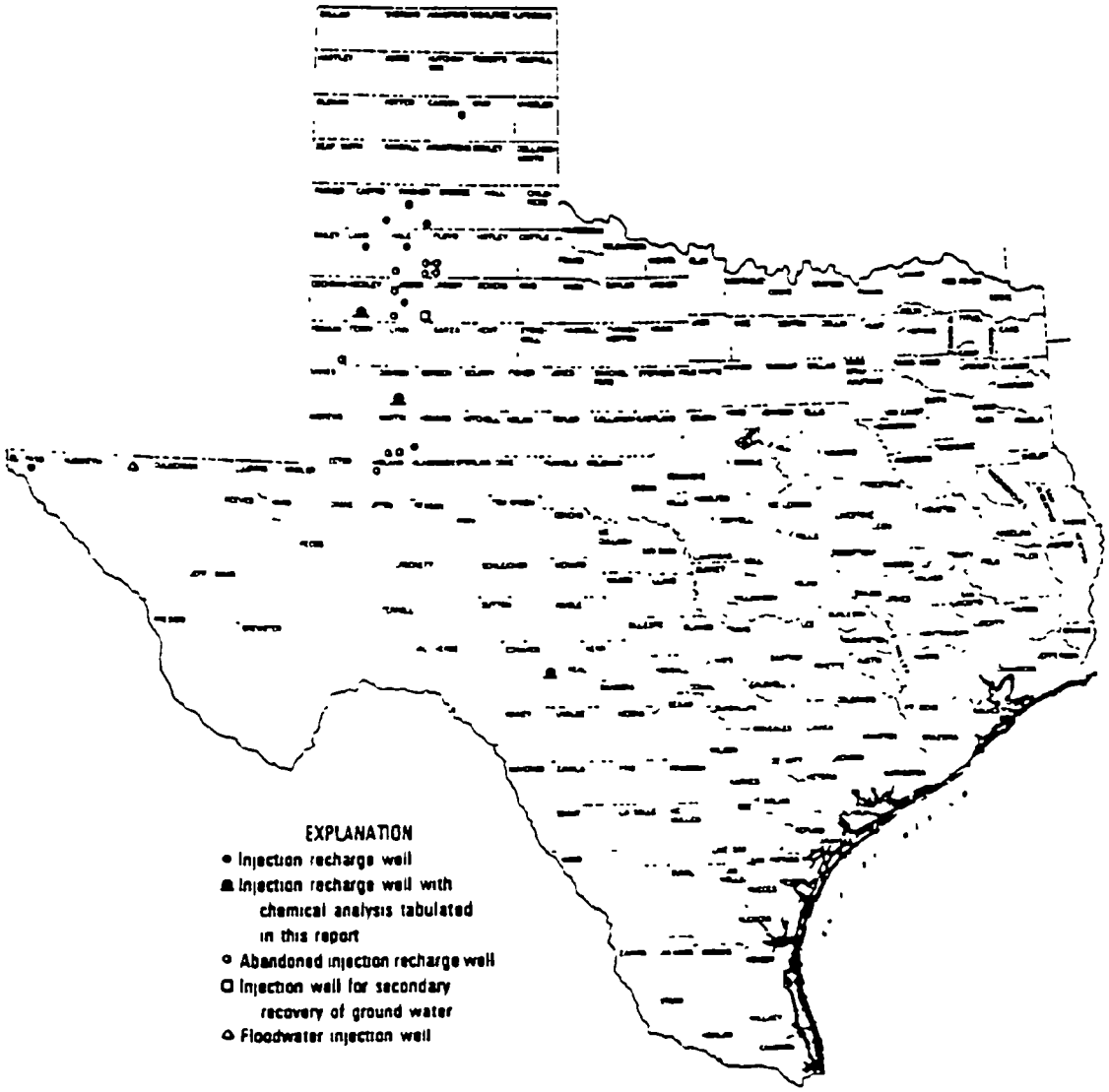


Figure 8-1.—Locations of Artificial Recharge Wells in Texas, 1982

toward centers of water-well development and pumpage. Earlier studies suggested the same condition of ground-water movement toward producing well fields, and showed that the direction of regional ground-water movement in 1936 in Texas and Mexico was generally to the south and southeast toward the Rio Grande and other areas of natural discharge.

Assessment of Treated Effluent Injection Wells

The City of El Paso Water Utilities began construction of a 10 million gallons per day sewage treatment facility in 1983. The facility, located just northeast of the city, should be operating by 1985, with treated wastewater to be injected into Hueco Bolson. Presently, two pilot injection wells are in operation, with ten injection wells proposed for the treatment facility Figure 8-3 shows the wellhead of one of the operating injection wells. Figure 8-4 shows a diagram of Hueco Bolson recharge well design The Hueco Bolson project will treat wastewater to drinking water standards before injection into the local aquifer. Treated effluent will be injected into wells for

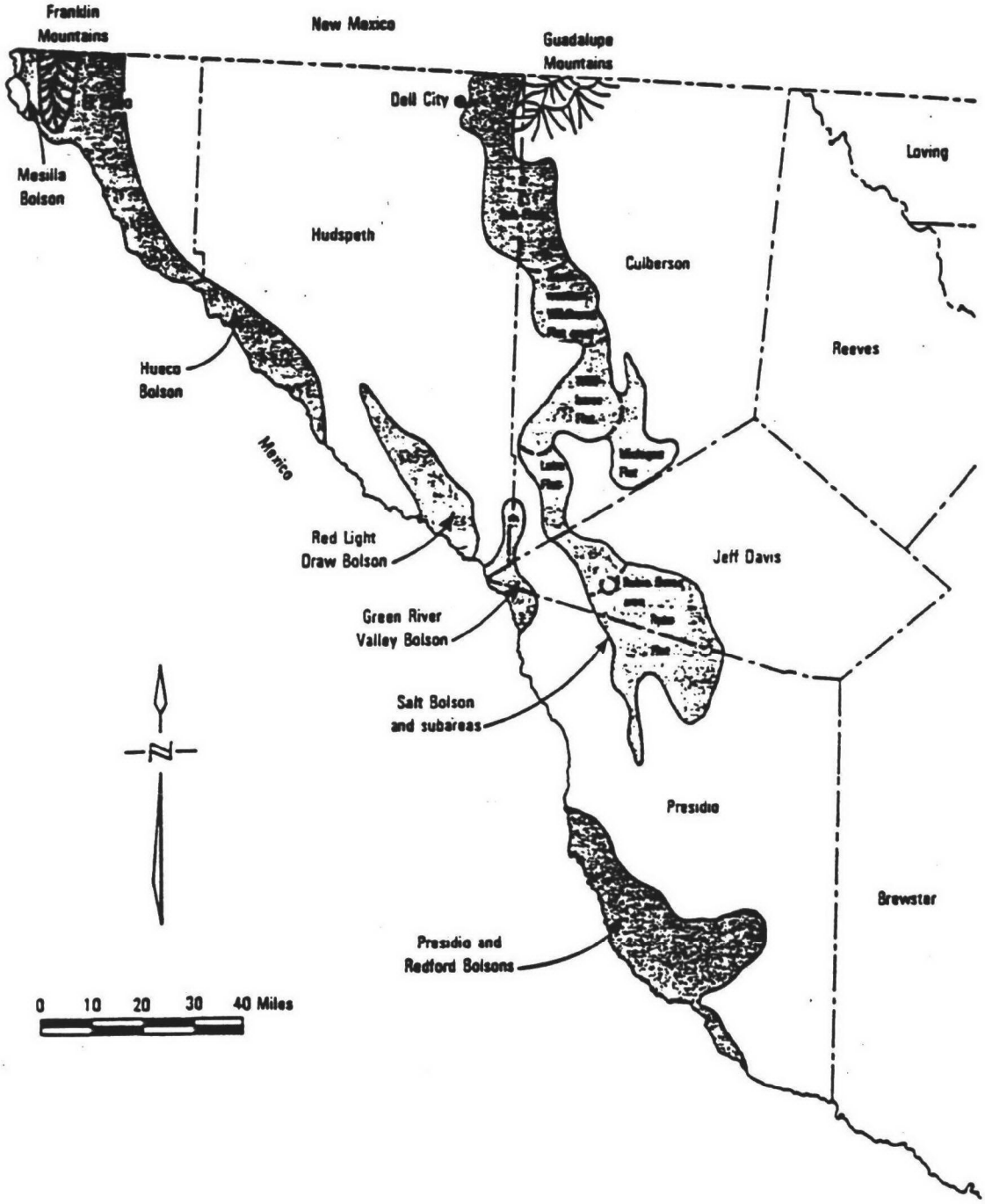


Figure 8-2.—Alluvium and Bolson Aquifers of the Trans-Pecos Texas Region

recharge of Hueco Bolson or directed to a nearby power station for industrial use. Table 8-1 compares the water quality standards of the El Paso injected effluent with the water quality of the Hueco Bolson aquifer in the vicinity of the injection well project. From these data (Table 8-1) it is concluded that the El Paso recharge wells should have very low potential for contaminating the local ground-water supply, and that the ground water will be maintained at drinking-water quality.

The Hueco Bolson Recharge Project in El Paso is authorized by a wastewater permit issued by the Department. The permit consolidates regulation of the treatment facilities and injection wells, under the authority of Chapter 26 of the Texas Water Code.

SECTION 4.3.5

TITLE OF STUDY: **(or SOURCE OF INFORMATION)**	From Assessment of Class V Injection Wells in the State of Wyoming
AUTHOR: **(or INVESTIGATOR)**	Western Water Companies
DATE:	September, 1986
FACILITY NAME AND LOCATION:	Teton Village Wastewater Treatment and Disposal Plant, Teton Village, Wyoming, USEPA Region VIII
NATURE OF BUSINESS:	Wastewater treatment and disposal plant
BRIEF SUMMARY/NOTES:	The Teton Village Wastewater Treatment and Disposal Plant was selected for assessment by the Wyoming Department of Environmental Quality Division in conjunction with Western Water Consultants, Inc. The facility discharges an average of 0.1 million gallons per day of tertiary-treated sewage effluent into a shallow aquifer through three recharge wells. Water levels and water quality have been monitored at the recharge wells since 1981 and at 9 monitoring wells since 1978. The study discusses regional hydrogeology, site hydrogeology, facility-specific details (construction, etc.), background water quality, effluent characteristics, the effects of injection on groundwater, and the necessity for computer modeling.

CHAPTER 6

RECHARGE WELLS - TETON VILLAGE

Introduction

"Recharge wells" are wells which are generally used to replenish the water supply in an aquifer. The injection by recharge wells is usually into or above sensitive aquifers.

Three facilities, with a total of at least seven recharge wells, have been inventoried in the State of Wyoming. Of these, two facilities are related to mining or hydrocarbon recovery operations and the third (the Teton Village Wastewater Treatment and Disposal Facility, discussed in this section) disposes treated sewage effluent. Injected water quality varies among wells of this type. Ground water reinjected as part of mining or hydrocarbon recovery operations may have elevated concentrations of sodium, sulfate and total dissolved solids with respect to the receiver. Injected sewage effluent may contain nitrates or ammonia, viral and bacterial organisms, and chlorides and chlorinated amines.

The Teton Village Wastewater Treatment and Disposal Plant, Teton Village, Wyoming, has been selected for assessment by Wyoming Department of Environmental Quality/Water Quality Division (WDEQ/WQD), in conjunction with Western Water Consultants, Inc. (WWC), as a representative facility which uses recharge wells in the State of Wyoming. The facility discharges an average of 0.1 million gallons per day of tertiary-treated sewage effluent into a shallow aquifer through three recharge wells. Water levels and water quality have been

monitored at the recharge wells since 1981 and at 9 monitoring wells since 1978.

Study Area

Teton Village is located at the base of Rendezvous Mountain, a peak in the southern part of the Teton Range, Teton County, Wyoming, (Figure 6-1) approximately 7 1/2 miles northwest of Jackson, Wyoming . The resort village contains 165.77 acres of private land located in the southern half of Section 24, T.42N., R.117W. The resort is bounded on the north and west by Teton National Forest lands; private lands make up the remaining boundaries. Teton Village has been in operation since the 1965-1966 ski season.

The wastewater treatment and disposal facility at Teton Village (Teton Village Wastewater Treatment and Disposal Facility) is currently under the ownership and management of the Teton Village Water and Sewer District. The facility, as shown on Figure 6-1, is located in the SE 1/4 SW 1/4 Section 24, T.42 N., R.117 W., Teton County, Wyoming, immediately south of Teton Village. The Teton Village Water and Sewer District is authorized by permit GPC 84-190 (dated 11/29/84) to operate the recharge and monitor well systems associated with the wastewater treatment and disposal system.

Regional Hydrogeology

Geologic Setting

Three major structural features in the study area are shown on Figure 6-2 (Blackstone, 1971): the Teton Range, Jackson Hole and the

Teton Fault. The Teton Fault is a major east-dipping, normal, Precambrian-cored fault which trends northeast along the eastern flank of the Teton Range. The fault exhibits up to 20,000 feet of displacement and severs basin sediments to the east from the uplifted Precambrian tilt block to the west. The uplifted Precambrian block is capped by west-dipping Paleozoic strata that, in all but the southern terminus of the Teton Range, are hydrologically separated from the basin sediments. Near Teton Village, the Paleozoic strata are about 3,000 feet above the valley floor.

Jackson Hole is a broad, folded and faulted downwarp east of the Teton Fault (Cox, 1976). The basin is young in geologic terms and reflects active crustal movement continuing from mid-Pliocene time (approximately 8 million years ago) to the present. Approximately 10,000 feet of poorly consolidated to unconsolidated lacustrine, glacial and alluvial sediments ranging in size from clay to coarse gravels have filled the basin since Pliocene time.

Ground-Water Occurrence and Flow

In the vicinity of the study area, ground water is present in 1) the Paleozoic strata high in the Teton Range; 2) the thin weathered zone that in places mantles the Precambrian metamorphic rocks of the Teton Range; 3) fractures and joints in the Precambrian rocks; and 4) the thick sequence of valley-fill alluvium underlying Jackson Hole. Only the valley-fill aquifer is important to this investigation.

Ground-water is present in a shallow, unconfined aquifer up to 300 feet thick that comprises alluvium and glacial outwash overlying lacustrine deposits in Jackson Hole (Cox, 1976). The lacustrine

deposits and deeper sediments are not considered in this report because they will not be affected by the Teton Village recharge wells.

The main components of ground-water recharge to the Jackson Hole alluvial aquifer are 1) infiltration of precipitation; and 2) infiltration of seepage from numerous small streams and lakes fed by snowmelt runoff originating in the mountains. Minor recharge to the alluvium occurs through the weathered mantle on, and secondary fractures in, the metamorphic rock of the Teton Range and through minor aquifers in the Gros Ventre Range. Natural recharge of the alluvium and glacial outwash by these mechanisms occurs primarily at the foot of the mountain ranges which form the east and west boundaries of the alluvial valley. A minor source of recharge in the immediate study area is the injection well system at the Teton Village Wastewater Treatment and Disposal Facility.

Figure 6-3 shows the approximate ground-water table for the Jackson Hole Area. Regionally, ground water flows south southwest, down the Snake River valley. The water table near the margins of the basin closely reflects the land surface. On the west side of the basin, near the study area, flow is directed east, off the eastern flank of the Teton Range.

Cox (1976) summarized the water-yielding properties of the valley-fill aquifer in the Jackson Hole area. The aquifer yields from a few to 2,000 gallons per minute (gpm) to wells in Jackson Hole and as much as several cubic feet per second to individual springs in the area.

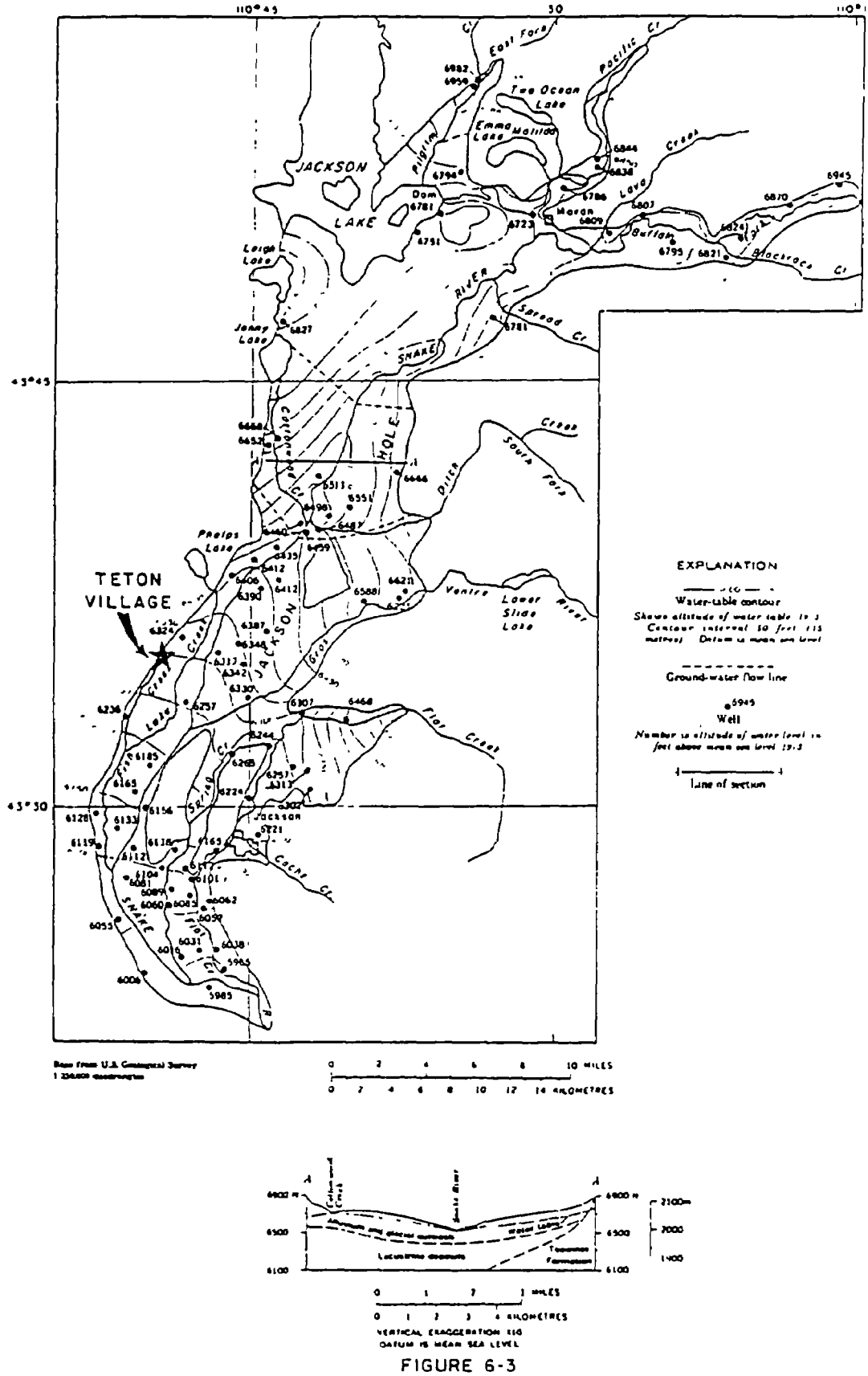


FIGURE 6-3

WATER TABLE IN JACKSON HOLE
AND NEARBY STREAM VALLEYS
(Cox, 1976)

Site Hydrogeology

The majority of the Teton Village wastewater treatment and disposal facility is located on alluvium and glacial outwash which were deposited on the eastern flanks of the Teton range and thicken basinward (Figure 6-4). Ground water in the vicinity is present under unconfined conditions in the alluvial and glacial outwash deposits. The Spring Creek aquifer, as it is known locally, ranges from a thin veneer overlying the Precambrian rocks on the eastern flank of Rendezvous Mountain to approximately 200 to 300 feet in the main Snake River Valley. The aquifer locally comprises Quaternary alluvium and glacial-outwash deposits, predominantly poorly sorted silt, sand, gravel and cobbles and is 50 to 100 feet in the vicinity of Fish Creek and Teton Village.

In the study area, the slope of the water table generally approximates that of the land surface, as shown on Figure 6-5. The steep, southeast-tending gradient at Teton Village indicates that the shallow aquifer receives a significant amount of recharge through the weathered mantle on the flank of Rendezvous Mountain. As the ground water flows southeast through the thickening wedge of alluvium and approaches the Teton fault, it is gradually diverted to the south and joins the regional flow system in the thicker valley-fill aquifer. Based on the elevations of the water table (6,267 ft) and Fish Creek, a tributary of the Snake River, (6,275 to 6,280 ft) southeast of Teton Village, it is likely that Fish Creek loses water to the shallow aquifer. The creek could not be a ground-water discharge point unless its elevation was at or below the water-table elevation. The creek has shallow banks and is not deeply incised into the alluvium. Because no

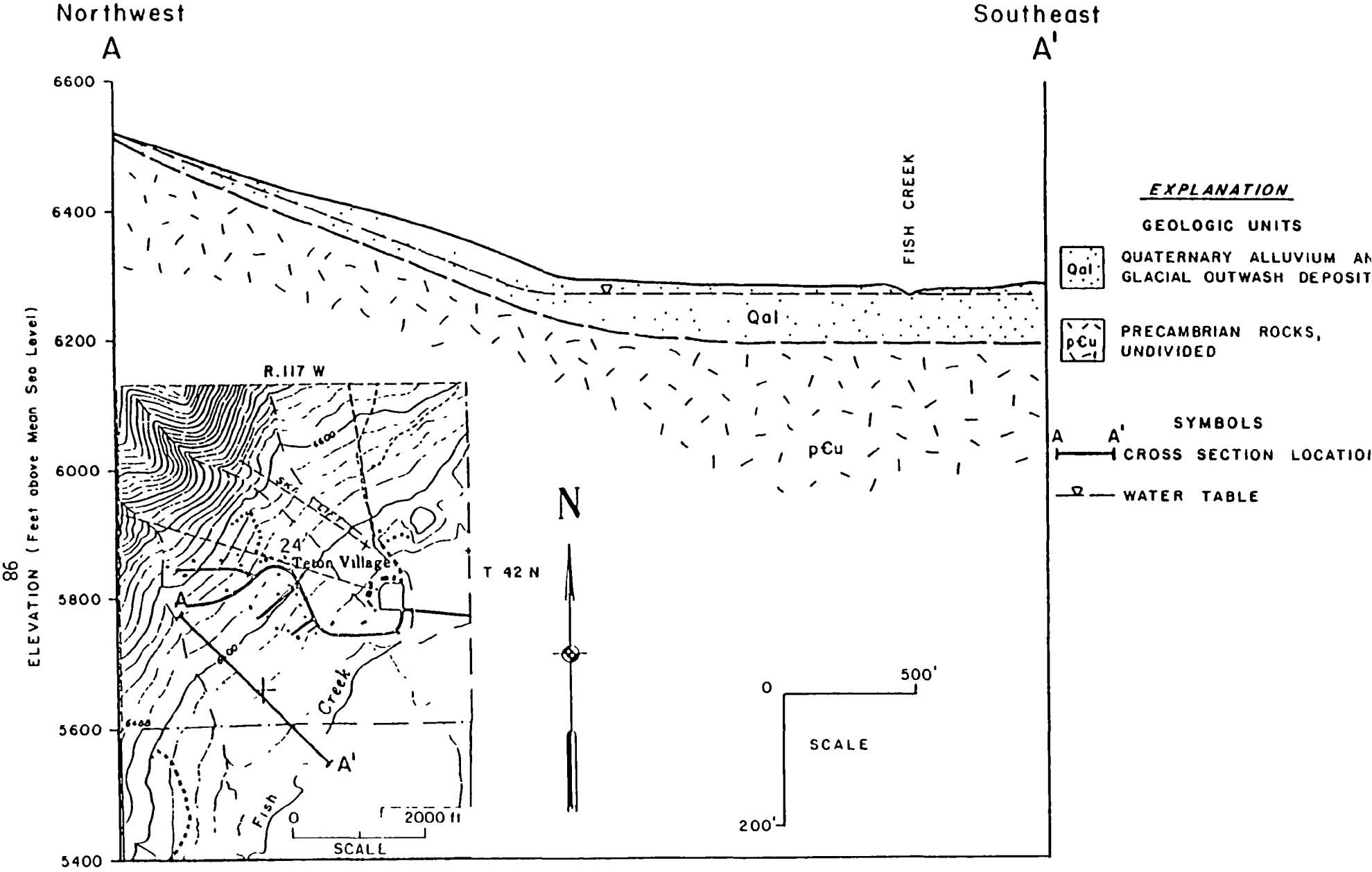


FIGURE 6-4 · SCHEMATIC GEOLOGIC CROSS-SECTION PARALLEL TO GROUND WATER FLOW, TETON VILLAGE WASTEWATER TREATMENT AND DISPOSAL FACILITY STUDY AREA, TETON VILLAGE, WYOMING, 1986

streamflow gaging data are available above or below this reach of Fish Creek, a relationship cannot be quantified.

The ground-water monitoring program associated with the facility began prior to the installation of the recharge wells and provides a good indication of the seasonal fluctuations of the water table. During the winter months, the ground-water table is at its yearly low. It begins to rise in late March and peaks in mid-summer when it rises to within approximately 4 feet of the land surface near the recharge wells.

A "pump-in/open end" test conducted in the gravel layer in monitor well OH-11 showed the aquifer to have a hydraulic conductivity of 5,000 feet per day (ft/da) (Nelson Engineering and Culp Wesner Culp, 1979). Published values for hydraulic conductivity for gravels in the area range from 13 to 13,000 ft/da (Nelson Engineering and Culp Wesner Culp, 1979). Drawdown tests, which were run in a gravel, silt and cobble aquifer with the Town of Jackson's Well No. 1, indicated a hydraulic conductivity of 1,100 ft/da. A drawdown test conducted in July 1980 by Nelson Engineering, using existing monitor wells OH-11A, OH-11, OH-13 and OH-14 indicated a hydraulic conductivity of 3,000 ft/da and a transmissivity of 120,000 ft^2/da.

In July 1979, attempts were made to determine the velocity of the ground-water by placing dye in monitor well OH-3 and testing for it in the polishing pond and monitor well OH-10. No trace of the dye was detected at these locations, indicating either a substantial dilution effect by the ground water or a flow path different from what was expected. The approximate ground-water flow rate calculated by WWC based on an assumed porosity of 35 percent, the hydraulic conductivity values presented above, and existing hydraulic gradients, is 230 ft/da.

Ground-Water Classification

The ground water receiving the treated effluent from the Teton Village wastewater facility has been designated a Class I ground water of the State of Wyoming. Class I designation signifies that the ground water is suitable for domestic use, and must be sufficiently protected that it remains suitable for that use.

Ground Water Use

Ground-water rights and wells permitted by the Wyoming State Engineer are listed in Table 6-1. There are no permitted ground-water users immediately downgradient of the Teton Village Wastewater Treatment and Disposal Facility, and ground water affected by the Teton Village subsurface discharge is not known to be withdrawn for domestic or other use. Other ground-water users in the vicinity include private homes, businesses, and condominium complexes. Future developments will likely increase the use of ground water.

Description of Facility

The basic components of the existing wastewater treatment facility were constructed in 1971 as a 200,000 gallons per day (gpd) contact-stabilization activated-sludge plant. The plant was put into operation for the 1971-1972 ski season. An effluent polishing lagoon was constructed in 1973. Additional modifications were made in both 1978 and 1979 to improve facility performance and reliability.

Prior to May 1979, the treatment plant discharged effluent to Fish Creek, a tributary of the Snake River. Discharge to the Class I water

Table 6-1. Ground-Water Rights and Wells Permitted by the Wyoming State Engineer, Teton Village Area, Teton County, Wyoming.

Location (T R Sec ¼-¼ Sec)	Permit Number	Facility Name	Well Depth (ft)	Depth to Static Water Level (ft)	Well Yield (gpm)	Well[a] Use	Year Drilled
42N 116W 19 SW/NW	P21280 P	Grey #1	100	-	25	DOM,STO	1920
SE/SE	P37480 P	Waincko #1	50	3	12	DOM	1977
20 NW/NW	P6796 W	Hoffman #2	60	34	10	DOM,STO	1971
NE/SW	P9343 W	Brooks #1	47	6	20	DOM	1971
SW/SW	P68319 W	Mathieu #1	60	4	22	DOM	1984
NW/SE	P70646 W	Daub #1	60	7	22	DOM	1985
NW/SE	P55965 W	Eaton #1	60	8	15	DOM	1981
29 SW/NW	P49587 W	Owl Ranch #1	50	7	12	DOM	1979
SE/NW	P22423 P	Donman #1	21	6	5	DOM	1968
SW/SW	P21283 P	Snake River Ranch #3	60	10	25	DOM	1931
Lot 3	P40059 W	Knori #1	48	10	5	DOM	1978

Table 6-1. Ground-Water Rights and Wells Permitted by the Wyoming State Engineer, Teton Village Area, Teton County, Wyoming (cont'd).

Location (T R Sec ¼-¼ Sec)	Permit Number	Facility Name	Well Depth (ft)	Depth to Static Water Level (ft)	Well Yield (gpm)	Well Use[a]	Year Drilled
30 SW/NE	P35096 W	Hughes #1	62	18	15	DOM	1976
32 NW/NW	P21282 P	Snake River Ranch #2	40	5	25	DOM,STO	1921
SW/NW	P11396 W	Resor #3	60	8	25	DOM	1972
SW/NW	P21281 P	Snake River Ranch #1	60	10	25	DOM,STO	1925
42N 117W 24 NE/NW	P5890 W	Crystal Spring Well #1	15	2	75	MIS,COM	1965
SE/SW	P52720 W	OH-11A	60	25	-	MON	1980
SW/SE	P52719 W	OH-15	50	20	-	MON	1980
NE/SE	P32547 W	Jackson Hole Ski Corp. #1	158	106	200	DOM,IRR,MIS	1976
25 NE/NW	P52721 W	OH-13	60	22	-	MON	1980
NE/NW	P52722 W	OH-14	50	24	-	MON	1980

[a] Ground-Water Rights and Wells Permitted by the Wyoming State Engineer, Teton Vellage Area, Teton County, Wyoming.

of Fish Creek was discontinued then, and was switched to the polishing pond, a sand filter basin through which effluent is discharged to the Spring Creek aquifer. In 1981 the Village Sewer Company replaced the existing treatment plant with a new facility which would discharge into the Spring Creek aquifer via three recharge wells, instead of discharging water through a sand filter basin. The new facility consisted of secondary and tertiary treatment devices capable of producing an effluent of very good quality. Tertiary treatment consists of chlorination and sand filtration. Traditional measures of sewage effluent such as Total Suspended Solids and Biochemical Oxygen Demand are very low for the effluent from this plant, on the order of 10 mg/L or less. The plant is capable of routinely reducing total nitrogen content in the effluent to less than 10 mg/L as well.

The recharge wells are 40 to 50 feet deep and consist of approximately 15 feet of 14-inch diameter steel casing set above 30 or 33 feet of 12 1/2-inch diameter stainless steel well screen. All three wells are completed in the Spring Creek aquifer. Construction details for the recharge wells are listed in Table 6-2; a generalized typical completion is depicted on Figure 6-6. A site plan of the present Teton Village Wastewater Treatment and Disposal Facility is shown on Figure 6-7.

With the new system in operation, the effluent from the wastewater treatment facility is discharged into the alluvial Spring Creek aquifer at depths between 16 and 42 feet below the land surface. Normally, the recharge wells operate on gravity discharge. A pressure pump system was installed, but to date pumped discharge has not been needed.

Table 6-2. Construction Details for Recharge Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming.

Item	Recharge Wells		
1. Name and Number	RC-1	RC-2	RC-3
2. Location	SE¼ SW¼, Section 24 T42N, R117W Teton County, WY	SE¼ SW¼, Section 24 T42N, R117W, Teton County, WY	SE¼ SW¼, Section 24 T42N, R117W Teton County, WY
3. Construction Start Date Construction Stop Date	9/17/81 11/4/81	9/5/81 11/6/81	9/11/81 11/9/81
4. Type of Well Construction	Air Rotary	Air Rotary	Air Rotary
5. First Use Date	12/25/81	12/25/81	5/21/82
6. Hole Depth	49'	42'	46'
7. Hole Diameter	14"	14"	14"
8. Surface Elevation at Well	6291.00	6292.60	6288.80
9. Static Depth (After Screen Installation)	10/27/81 19'	11/9/81 22'	11/4/81 17'
10. Casing Elevation	6293.12	6294.09	6291.01
11. Well Development	Air Jet Water Surge	Air Jet Water Surge	Air Jet Water Surge
12. Casing Description	New Steel 14" ϕ O.D. 0.375 th.	New Steel 14" ϕ O.D. 0.375" th.	New Steel 14" ϕ O.D. 0.375" th.
13. Grout Depth	7' Concrete	7' Concrete	5' Concrete
14. Well Completion	Screened	Screened	Screened
15. Screen Type	304 Stainless Steel Cont Slot	304 Stainless Steel Cont Slot	304 Stainless Steel Cont. Slot
16. Slot Size	120	120	120
17 Perforation Interval	N/A	N/A	N/A

Table 6-2. Construction Details for Recharge Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming (cont'd).

Item	Recharge Wells		
18. Screen Diameter x Length	12¼" x 33'	12¼" x 30'	12¼" x 30'
19. Effective Area	1.27 ft^2/LF	1.27 ft^2/LF	1.27 ft^2/LF
20. Developed Yield (pumpout)	750 gpm	595 gpm	670 gpm
21. Packer Installation	Stainless Steel w/ Neoprene O-Ring	Stainless Steel w/ Neoprene O-Ring	Stainless Steel w/ Neoprene O-Ring
22. Screen Installation	Pull Back	Pull Back	Pull Back
23. Well Driller	Andrew Well Drilling 1268 E 17th Idaho Falls, ID 83401	Andrew Well Drilling 1268 E 17th Idaho Falls, ID 83401	Andrew Well Drilling 1268 E 17th Idaho Falls, ID 83401
24. Land Ownership	Village Sewer Company P.O. Box 586 Teton Village, WY 83025	Village Sewer Company P.O. Box 586 Teton Village, WY 83025	Village Sewer Company P.O. Box 586 Teton Village, WY 83025

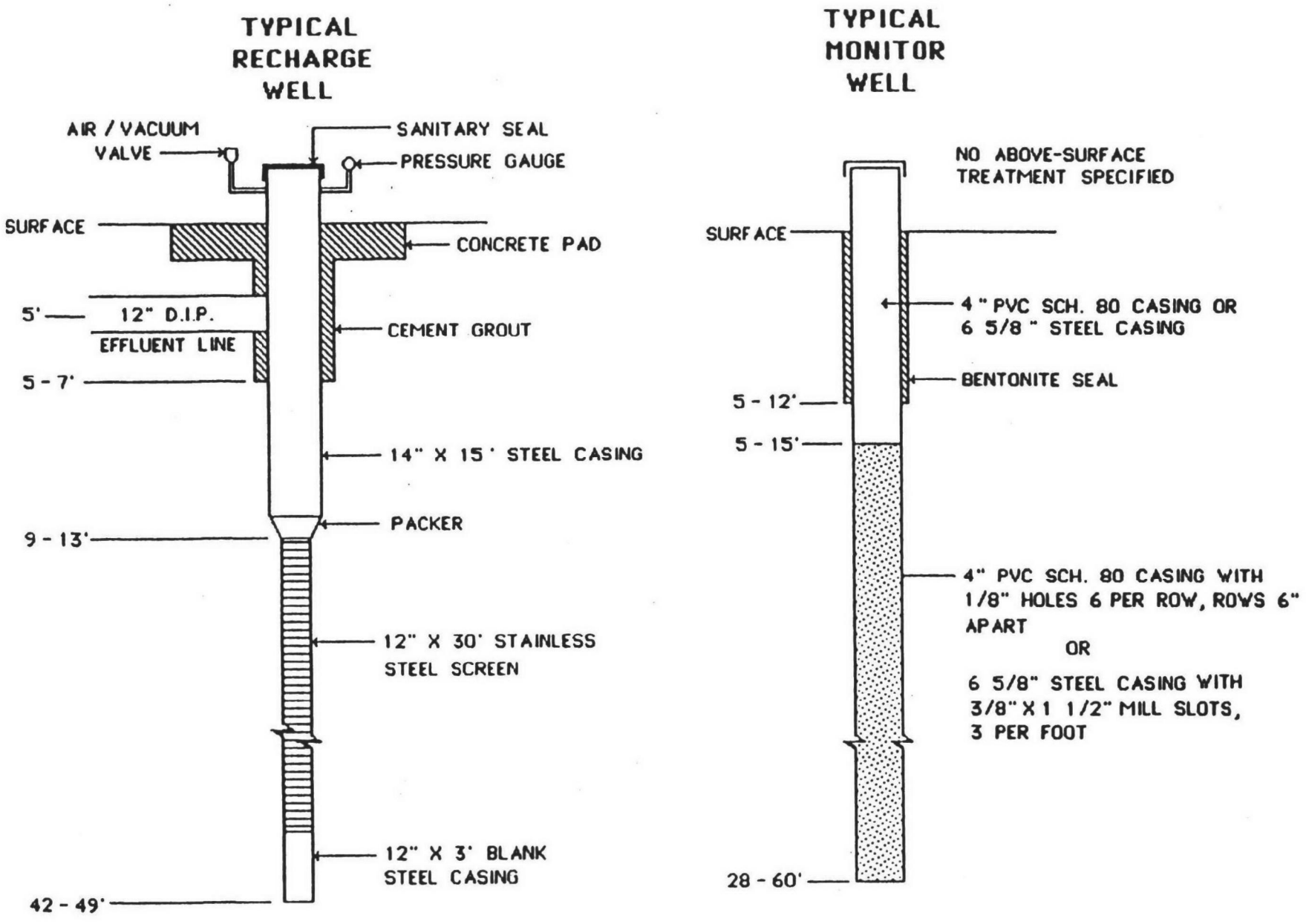


FIGURE 6-6 TYPICAL COMPLETION DIAGRAM OF RECHARGE AND MONITOR WELLS

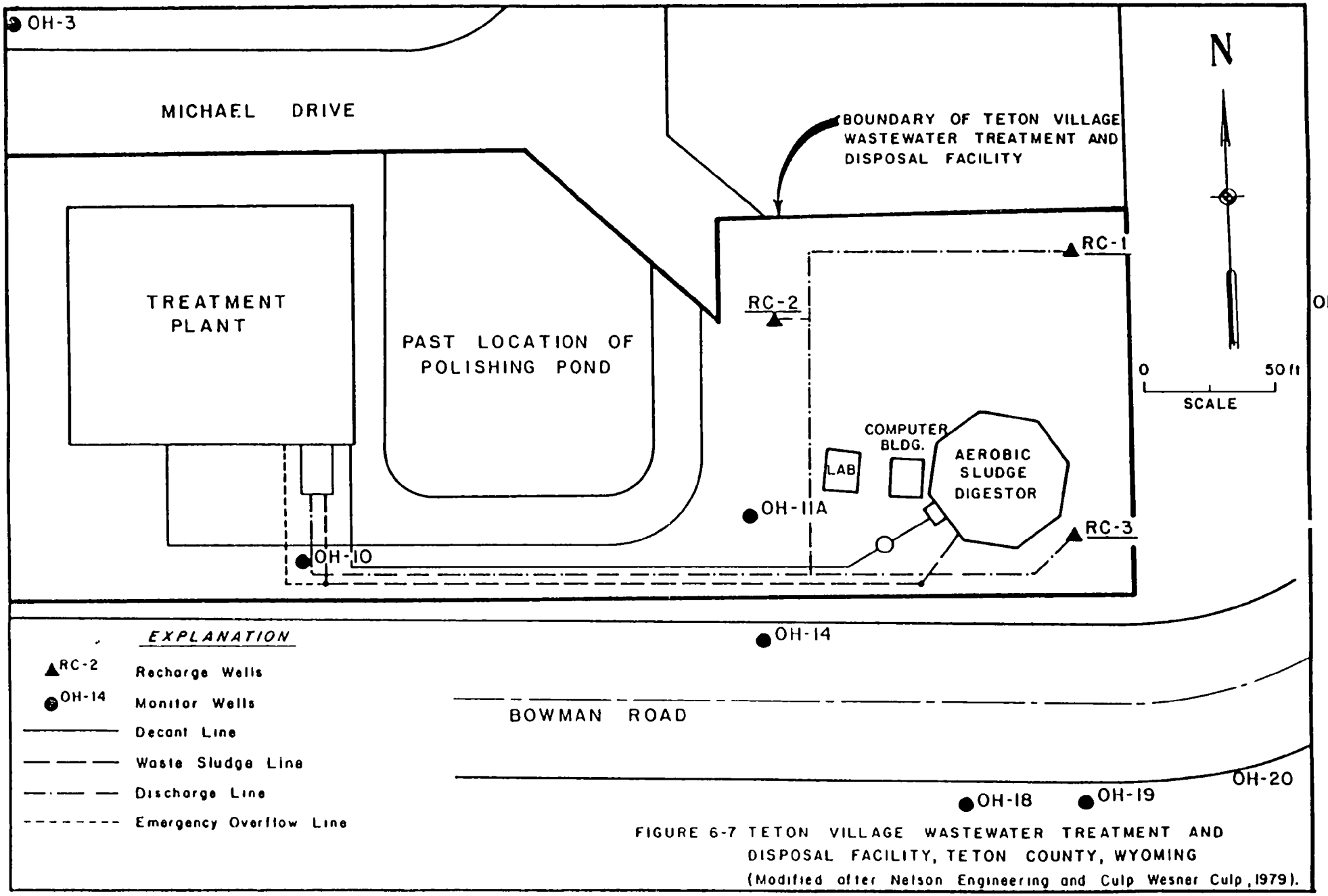


FIGURE 6-7 TETON VILLAGE WASTEWATER TREATMENT AND DISPOSAL FACILITY, TETON COUNTY, WYOMING
(Modified after Nelson Engineering and Culp Wesner Culp, 1979).

The recharge well system is authorized as a miscellaneous discharge to ground-waters of the State of Wyoming by a permit (GPC 84-190) issued by the Department of Environmental Quality. The three recharge wells authorized are wells RC-1, RC-2 and RC-3 in the SE 1/4 SW 1/4, Section 24, T.42N., R.117W., Teton County, Wyoming (Figure 6-7).

Ground Water Monitoring Prior to Recharge Well Installation

Monitoring of the ground-water at the Teton Village Wastewater Treatment and Disposal Facility began in November 1978 with the installation of 8 monitoring wells. Ground water levels and quality have subsequently been monitored by the operator, since January 1979. Monitor wells constructed in 1978 are not permitted with the State Engineer's office and well construction data are limited. Very little information on these well completions is available and existing completion data are inconsistent. For this study, WWC has not included pre-1981 past monitoring data in the analysis of the recharge site.

Background Water Quality

The background quality of the ground water into which the Teton Village wastewater is injected is very good. A typical analysis of water-quality parameters from background well OH-3 is shown in Table 6-3. The water is useable for domestic, municipal, industrial, irrigation or stock purposes, and meets the requirements for a Class I ground water in the State of Wyoming (Chapter VIII, Wyoming Water Quality Rules and Regulations). The water is low in dissolved solids, soft, shows little or no evidence of contamination by human or animal

Table 6-3. Water Quality Data from Well OH-3, October 22, 1981.

Parameter	Well OH-3 (mg/L)
Aluminum	<0.001
Ammonia	<0.01
Arsenic	<0.001
Barium	0.065
Cadmium	<0.001
Chloride	6.0
Chromium	<0.001
Cyanide	<0.001
Iron	0.180
Lead	<0.001
MPN Fecal Coliform MPN/100 mL	<2.0
MPN Total Coliform MPN/100 mL	79.0
Manganese	0.110
Nitrate	0.35
Nitrite	0.01
Oil and Grease	1.00
Phenol	<0.001
Selenium	<0.001
Silver	<0.001
Sodium	8.10
Sulfate	<3.0
Total Dissolved Solids	245.0
Turbidity NTU	2.70
Zinc	0.230
pH Units	7.40

activity, and is not known to contain chemical contaminants resulting from industrial activity.

Recharge Well Operation

The tops of the recharge wells are provided with a pressure gauge and an air/vacuum valve. The treated wastewater can flow either by gravity or under pressure to the recharge wells. Gate valves are used to control the recharge well or combination of recharge wells to which the effluent flows. Under normal operating conditions, treated wastewater will gravity-flow to the recharge wells.

During the months of May through August, the high ground-water table combined with a ground-water mound created by the recharge wells could make gravity flow from the clear well to the recharge wells impossible. Water levels in the recharge wells are monitored daily to document ground-water mounding so that corrective action can be taken if necessary to prevent treated effluent and/or ground water from rising to the surface in one or more recharge wells. A high water level alarm is installed in the facility to alert the operator to inadequate gravity flow. The treatment facility is designed to allow the treated wastewater to be pumped to the recharge wells.

Injection of Effluent

All the wastewater produced by the Teton Village Wastewater and Disposal Facility is discharged to one recharge well at a time, permitting the other recharge wells to recover. No more than one recharge well is used at any given time without prior written approval from WDEQ/WQD.

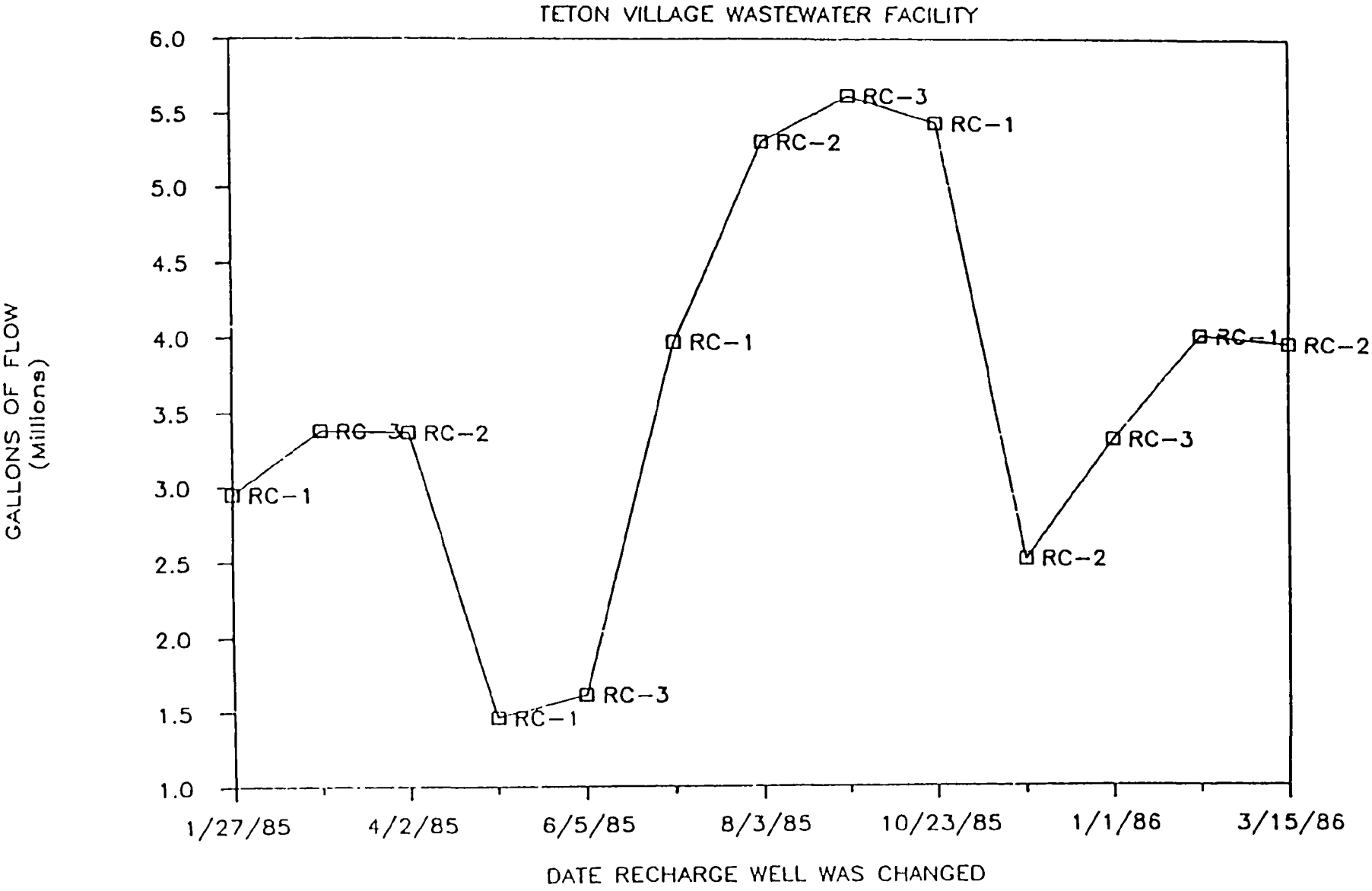
Effluent flow is changed monthly to a different recharge well. The recharge well system was designed to accept effluent at a rate not to exceed 0.83 million gallons per day (mgd). Effluent recharge generally ranges from .05 mgd during the off-season (May & June) to about 0.2 mgd during late summer, and averages 0.1 mgd. Total effluent flow to each recharge well is shown on Figure 6-8 for the period January 1985 to March 1986.

Quality of Effluent

Effluent quality is monitored and analyzed on the same schedule as the ground-water monitor wells. Samples are collected from the effluent just before it enters the recharge well system and are analyzed for parameters included in the Environmental Protection Agency (EPA) Interim Primary Drinking Water Standards. Table 6-4 summarizes the chemical quality of the effluent when sampled at various intervals from November 1981 to February 1986. Comparison of concentrations present in the effluent to maximum levels set by EPA Interim Primary Drinking Water Standards indicates the effluent meets all EPA standards except for turbidity and coliform bacteria.

The Teton Village wastewater treatment system generally produces an excellent quality effluent for injection, as demonstrated by the data in Table 6-4. At one time, the facility discharged effluent with a significant concentration of phenols. Correspondence in the WDEQ/WQD files indicates that this problem was traced to the use of various cleaning chemicals which were subsequently dumped into the system. The problem was alleviated by strongly discouraging the use of the chemicals

FIGURE 6-8 TOTAL EFFLUENT FLOW



[4-151]

Table 6-4. Comparison of Effluent Quality Parameters with Interim Primary Drinking Water Standards.

Parameter	U.S. EPA Interim Primary Drinking Water Standard (mg/L)	Date Effluent Sampled		
		11/18/81	12/17/84	12/19/85
Arsenic	0.05	0.006	<0.001	<0.001
Barium	1.0	0.010	0.01	0.02
Cadmium	0.01	<0.001	<0.001	<0.001
Chromium	0.05	<0.001	<0.001	<0.001
Lead	0.05	<0.001	<0.005	<0.001
Mercury	0.002	--	<0.002	--
Nitrate (as N)	10	3.92	9.80	0.23
Selenium	0.01	<0.001	<0.001	--
Silver	0.05	<0.001	<0.001	<0.001
Radium	5 pCi/L	--	<1.0	<1.6
Gross Alpha	15 pCi/L	--	<2.0	<2.0
Gross Beta	4 millirem/yr	--	<3.0	<3.0
Turbidity	1/TU	1.20	5.50	5.10
Coliform Bacteria	1/100 mL	5.0	--	--

-- Not analyzed.

in question. There was also a period of time when the concentration of cyanide in the effluent was sufficiently high to cause a violation of the Permit. This problem was caused by the use of cyanuric acid at a swimming pool which discharged to the sewage treatment facility, and was eliminated by ceasing use of that chemical.

Figures 6-9 through 6-12 present effluent water quality data for ammonia, nitrate, oil and grease, and phenols. Ammonia and nitrate concentrations are given as nitrogen (NH_3-N and NO_3-N) on figures 6-9 and 6-10. The figures show measured parameter concentrations for the period between October 1981 and February 1986. Although there is considerable variability in the data for each parameter, the overall effluent quality can be seen to be good, with occasional increases or "spikes" being exhibited by all of the parameters. The data exhibit some seasonal variation also. Some parameters, particularly ammonia, tend to reach highest concentrations in the winter months. Ammonia is likely affected by decreased nitrification rates that result from lower operating temperatures during winter.

Total dissolved solids (TDS) in the effluent is significantly higher than background concentrations in the receiving aquifer. Domestic use of water ordinarily results in an increase in TDS concentrations in sewage effluent (when compared with the water supply) due to addition of various soluble salts to the water during use. The concentration in the effluent, however, would not render the receiving water unfit for any of the uses for which it is currently suitable. In fact, the TDS concentration in the effluent is much lower than that in the raw water supplies of many Wyoming communities. Additionally, this

FIGURE 6-9

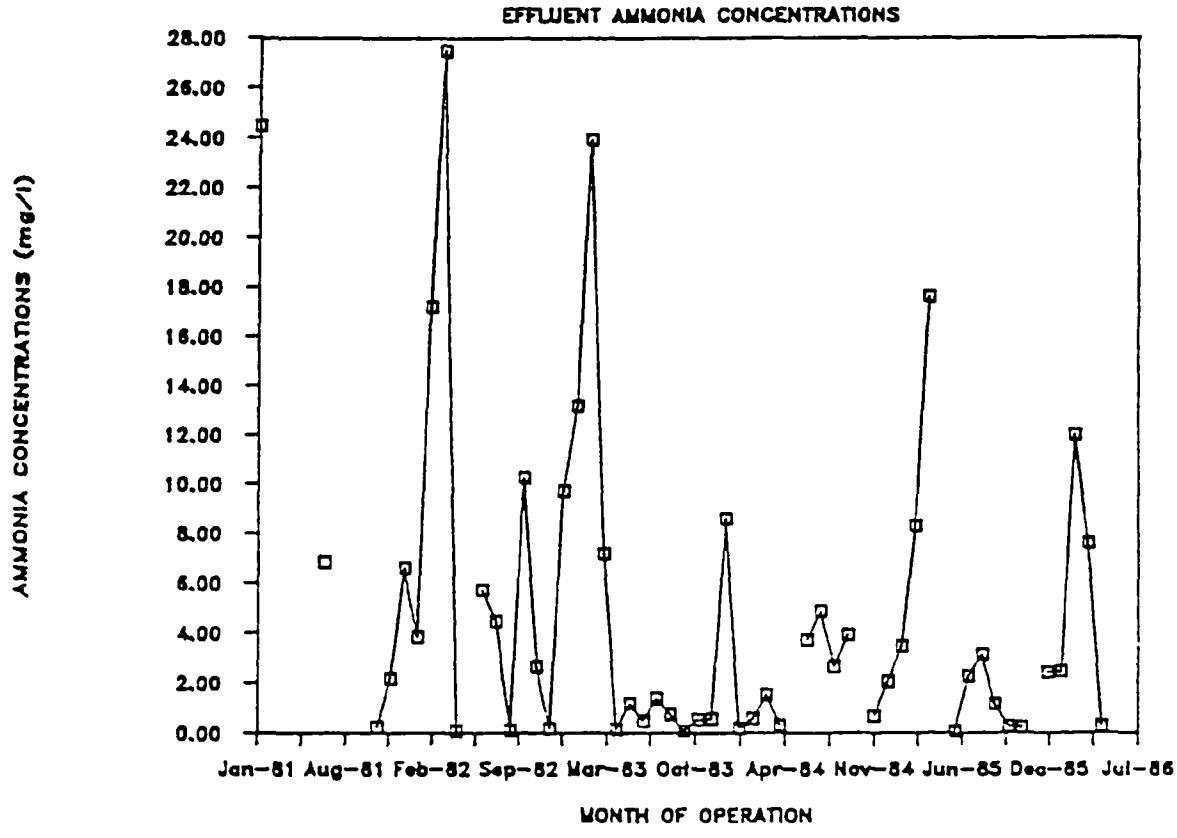


FIGURE 6-10

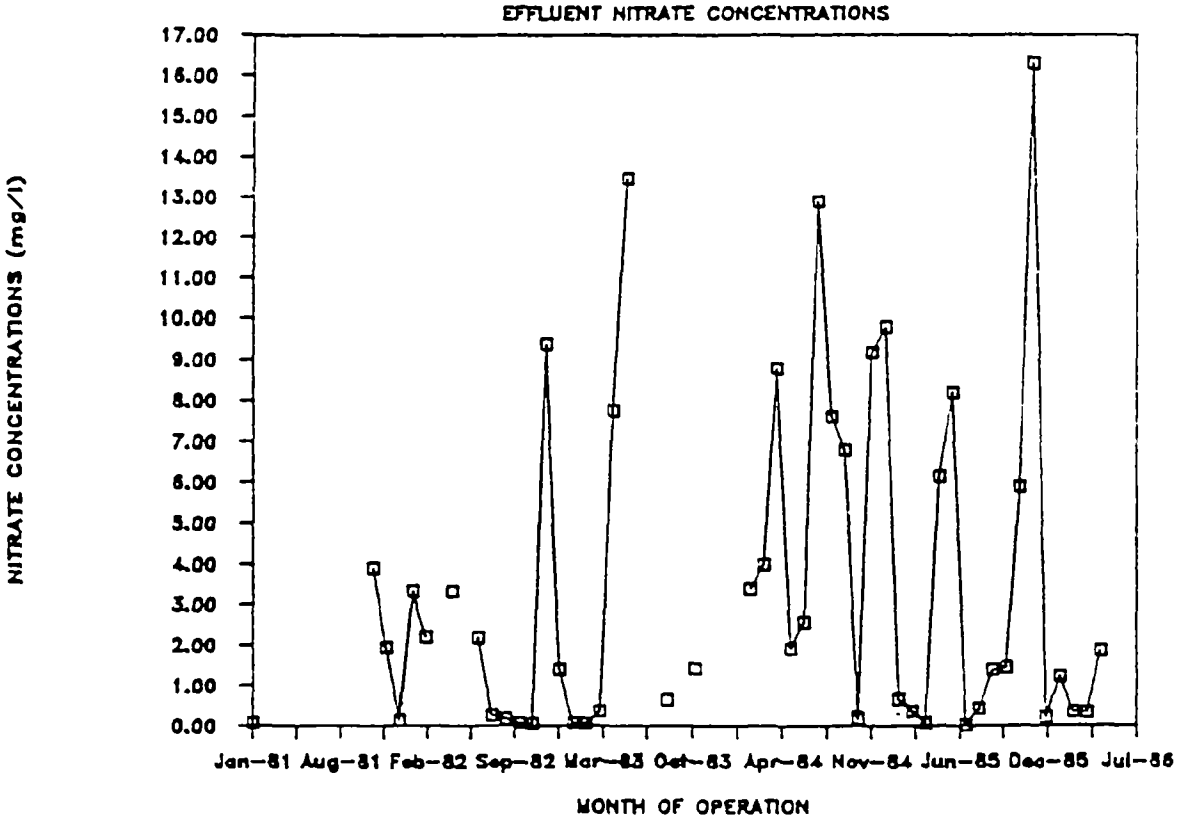


FIGURE 6-11

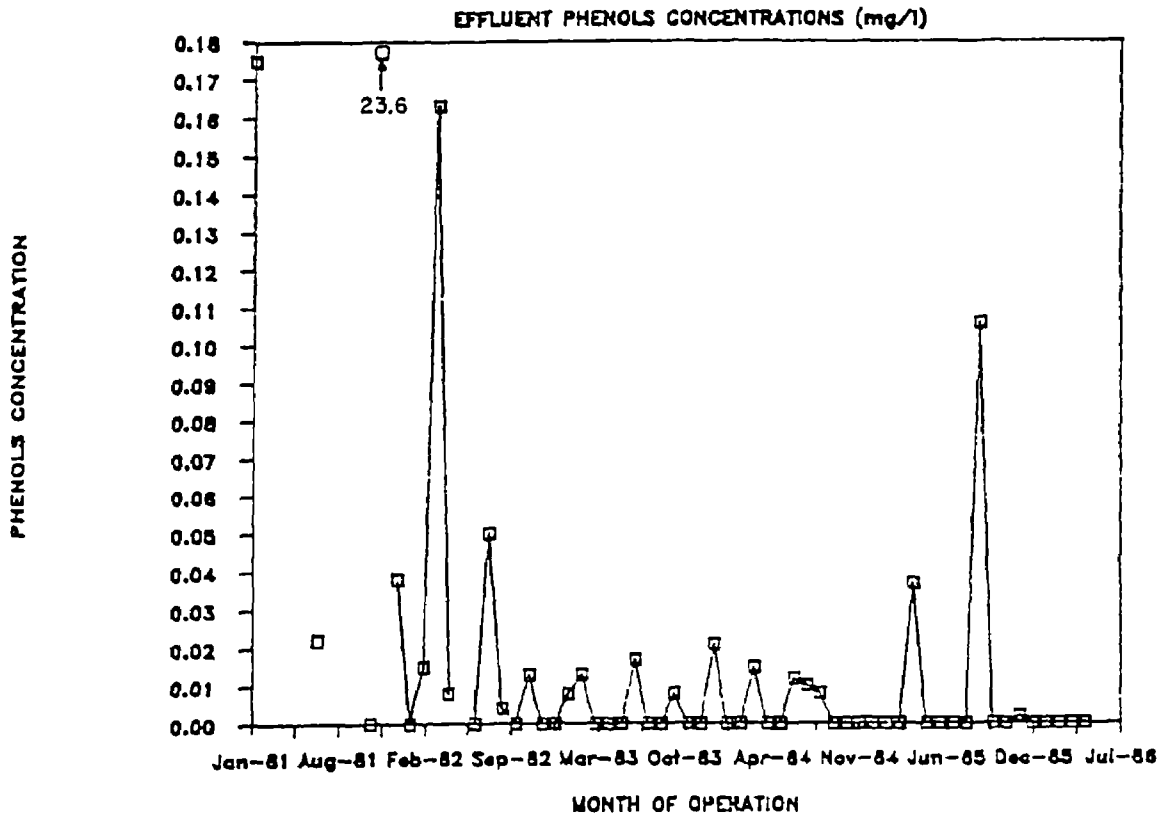
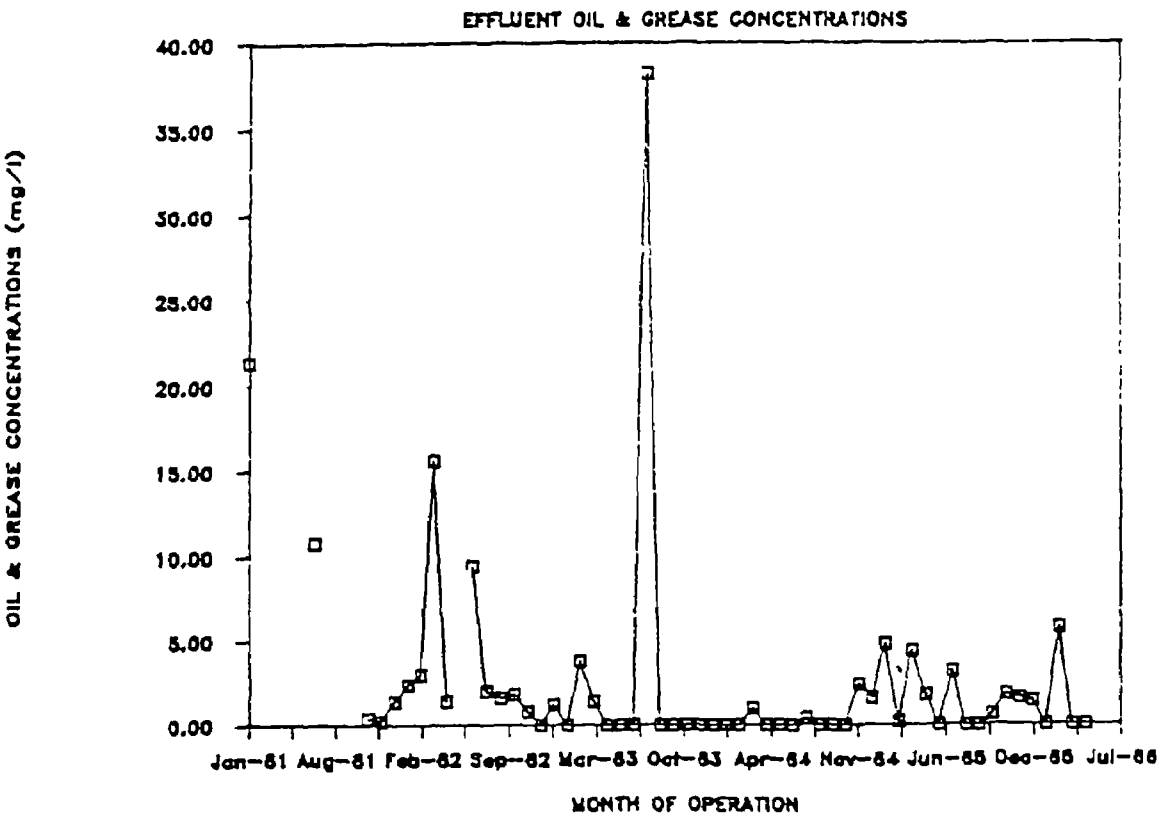


FIGURE 6-12



level of TDS is rapidly diluted to near-background levels after injection into the receiving aquifer, as will be shown later.

Because of the strictly domestic (as opposed to industrial) origin of the wastewater at Teton Village, there is little likelihood that significant quantities of synthetic organic chemicals will enter the wastewater collection system. The principal contaminants of concern in the Teton Village effluent are ammonia (as ammonium ions) and nitrate. These two chemical species both contain nitrogen, and are closely related in both the sewage treatment and ground-water regimes. In the sewage treatment plant, nitrogen-containing organic compounds which occur naturally in sewage are converted to ammonia and then to nitrate by a series of biochemical reactions. The conversion of ammonia to nitrate continues, although at a much slower rate, in oxygenated ground water such as exists at Teton Village.

There is no drinking water standard for ammonia at the federal level, and there is no health threat associated with drinking water having ammonia concentrations similar to those in the Teton Village effluent. Class I ground waters of Wyoming are, however, limited to containing 0.5 mg/L ammonia (NH_3 as N) by State standards. There are both federal and state standards for nitrate in drinking water. The nitrate standards of 10 mg/L are based on the observed occurrence of adverse health affects in infants drinking water with nitrate concentrations in excess of the standard.

Ammonia in ground water tends to attenuate with time due to a) ion exchange onto chemically active sites on clay and silt particles in the aquifer, and b) ultimate biochemical conversion to nitrate as described

above. In oxygenated ground water, however, nitrate is attenuated very slowly. In view of these facts, we have chosen to treat ammonia and nitrate in the Teton Village effluent as a single contaminant, measured as the sum of nitrate-nitrogen and ammonia-nitrogen. This approach implies that all ammonia-nitrogen in the injected effluent is eventually converted to nitrate. Typically, the concentration of ammonia/nitrate nitrogen in the effluent approaches or exceeds the EPA interim primary drinking water standard for nitrate, which is 10 milligrams per liter (mg/L) as nitrogen. It is conceivable, therefore, that the injection of Teton Village effluent could render the receiving ground-water unsuitable for domestic purposes near the injection wells.

Effect of Injection on Ground Water

The nine monitor wells whose locations are shown on Figure 6-1 were installed by various methods in 1978, 1980 and 1981. Monitor well OH-10 is the only well installed in 1978 which is currently being monitored. The remaining wells constructed in 1980 and 1981 were permitted with the State Engineer's Office. Monthly data exist for these wells, and for this report the wells are considered to provide reliable and consistent water quality data. Construction and completion details are listed in Table 6-5, and a typical well completion is depicted on Figure 6-6.

Nine wells surrounding the wastewater treatment recharge system are currently being monitored. The nine monitor wells are identified as OH-4, OH-10, OH-11A, OH-13, OH-14, OH-15, OH-18, OH-19 and OH-20. Well OH-3 was designated an acceptable background or upgradient monitor well;

Table 6-5. Construction Details for Monitor Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming.

Item	Monitor Wells		
1. Name and Number	OH-3	OH-10	OH-11A
2. Location	SW¼ SW¼, Section 24, T42N, R117W Teton County, WY	SW¼ SW¼, Section 24 T42N, R117W Teton County, WY	SE¼ SW¼, Section 24 T42N, R117W Teton County, WY
3. Construction Start Date Construction Stop Date	1978	1978	4/14/80 5/10/80
4. Type of Well Construction	Continuous Flight Auger	Hollow Stem Auger	Cable Tool
5. First Use Date			
6. Hole Depth		28' 4"	44' 11"
7. Hole Diameter	4"	7"	8"
8. Surface Elevation at Well	6301.0	6292.2	
9. Static Depth (After Screen Installation)			25'
10. Casing Elevation	6301.5	6296.6	6292.4
11. Well Development			
12. Casing Description	2¼" I D Perforated PVC	4" I.D. Perforated PVC	8 5/8" New Gage Steel +1-15' / 6 5/8" New Gage Steel 53-60' 0.250" th.
13. Grout Depth			
14. Well Completion			Screened 15-53'
15. Screen Type			
16. Slot Size			40 slot size
17. Perforation Interval			N/A
18. Diameter x Length			

Table 6-5. Construction Details for Monitor Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming (cont'd).

Item	Monitor Wells
19. Effective Area	
20. Developed Yield (pumpout)	
21. Packer Installation	
22. Screen Installation	
23. Well Driller	Weber Drilling 1240 Gregory Lane Jackson, WY 83001
24. Land Ownership	

Table 6-5. Construction Details for Monitor Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming (cont'd).

Item	Monitor Wells		
1. Name and Number	OH-13	OH-14	OH-15
2. Location	NE¼ NW¼, Section 25 T42N, R117W Teton County, WY	NE¼ NW¼, Section 25 T42N, R117W Teton County, WY	SW¼, SE¼ Section 24 T42N, R117W Teton County, WY
3. Construction Start Date Construction Stop Date	5/11/80 5/20/80	5/21/80 6/5/80	4/14/80 6/4/80
4. Type of Well Construction	Cable Tool	Cable Tool	Cable Tool
5. First Use Date			
6. Hole Depth	30' 3"	34' 11"	41' 4"
7. Hole Diameter	6"	6"	6"
8. Surface Elevation at Well			
9. Static Depth (After Screen Installation	22'	24'	20'
10. Casing Elevation	6288.2	6291.5	6288.6
11. Well Development			
12. Casing Description	6 5/8" New Gage Steel 1-60'3" / 0.250" th. 1¼" x 3/8" mills perforations 13-36'	6 5/8" New Gage Steel +1-50'3" / 0.250 th. 1¼" x 3/8" mills perforations 15-34'	6 5/8" New Gage Steel +1-50' / 0.250 th. 1¼" x 3/8" mills perforations 15-38'
13. Grout Depth			
14. Well Completion	No Well Screen No Gravel Pack	No Well Screen No Gravel Pack	No Well Screen No Gravel Pack
15. Screen Type	1¼" x 3/8" mills perforations, 3 holes/ft	1¼" x 3/8" mills perforations, 3 holes/ft	1¼" x 3/8" mills perforations, 3 holes/ft
16 Slot Size	N/A	N/A	N/A
17. Perforation Interval	13' - 36'	15' - 34'	15' - 38'

Table 6-5. Construction Details for Monitor Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming (cont'd).

Item	Monitor Wells		
18. Diameter x Length			
19. Effective Area			
20. Developed Yield (pumpout)			
21. Packer Installation			
22. Screen Installation			
23. Well Driller	Weber Drilling 1240 Gregory Lane Jackson, WY 83001	Weber Drilling 1240 Gregory Lane Jackson, WY 83001	Weber Drilling 1240 Gregory Lane Jackson, WY 83001
24. Land Ownership	Snake River Associates	Snake River Associates	Snake River Associates

Table 6-5. Construction Details for Monitor Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming (cont'd).

Item	Monitor Wells		
1. Name and Number	OH-18	OH-19	OH-20
2. Location	NE¼ NW¼, Section 25 T42N, R117W Teton County, WY	NE¼ NW¼, Section 25 T42N, R117W Teton County, WY	NW¼ NE¼, Section 25 T42N, R117W Teton County,
3. Construction Start Date Construction Stop Date	9/23/81 9/24/81	9/21/81 9/23/81	9/25/81 9/28/81
4. Type of Well Construction	Air Rotary	Air Rotary	Air Rotary
5. First Use Date	9/23/81	9/24/81	9/25/81
6. Hole Depth	53' 4"	52' 3"	50' 4"
7. Hole Diameter	4"	4"	4"
8. Surface Elevation at Well	6289.99	6286.01	6284.82
9. Static Depth (After Screen Installation)	9/23/82 7'	9/24/82 7'	9/25/82 7'
10. Casing Elevation	6288.47	6287.89	6286.55
11. Well Development	Water Surge	Water Surge	Water Surge
12. Casing Description	New PVC Sch. 80 4" ø	New PVC Sch. 80 4" ø	New PVC Sch. 80 4" ø 0.250" th.
13. Grout Depth	12' Bentonite	10' Bentonite	5' Bentonite
14. Well Completion	Gravel Pack 10' Below Surface to Bottom Perf. Casing	Gravel Pack 10' Below Surface to 20' Below Surface Perf. Casing	Gravel Pack 5' Below Surface to Bottom Perf. Casing
15. Screen Type	1/8" ø holes, 6 per row, rows 6" o.c. vertically	1/8" ø holes, 6 per row, rows 6" o.c. vertically	1/8 ø holes, 6 per row, rows 6" o.c. vertically
16 Slot Size	N/A	N/A	N/A

Table 6-5. Construction Details for Monitor Wells, Teton Village Wastewater Treatment and Disposal Facility, Teton Village, Wyoming (cont'd).

Item	Monitor Wells		
17. Perforation Interval	14' - 51'	14' - 52'	5' - 51'
18. Diameter x Length	4" x 52.5'	4" x 53.5'	4" x 53.7'
19. Effective Area	N/A	N/A	N/A
20. Developed Yield (Pumpout)	N/A	N/A	N/A
21. Packer Installation	N/A	N/A	N/A
22. Screen Installation	Predrilled	Predrilled	Predrilled
23. Well Driller	Andrew Well Drilling 1268 E 17th Idaho Falls, ID 83401	Andrew Well Drilling 1268 E 17th Idaho Falls, ID 83401	Andrew Well Drilling 1268 E 17th Idaho Falls, ID 83401
24. Land Ownership	Snake River Ranch	Snake River Ranch	Snake River Ranch

it was plugged and abandoned, and was subsequently replaced by well OH-4. Samples from OH-4 are collected, analyzed and reported only when ground-water levels are high enough and sufficient water is present in the well to allow sampling. Data from all other identified monitor wells located downgradient of the Teton Village Wastewater Treatment and Disposal Facility are collected, analyzed and reported monthly, quarterly and annually, depending on the well and parameter. Monitoring includes measuring water levels and collecting samples for analyses. Sampling is performed according to procedures established and/or approved by WQD.

The monitor wells are used to monitor background and down-gradient ground water to provide early detection of any contaminants which may be injected at the Teton Village Wastewater Treatment and Disposal Facility. The facility permit provides two sets of constituent concentration limits for water quality in monitoring wells OH-18, OH-19, and OH-20. If the lower concentration limit is exceeded for any constituent in any of these monitoring wells, the permit directs that the permittee shall institute actions to reduce the amount of that constituent in the discharge. Exceedence of any of the upper concentration limits in these wells is considered a violation of the permit. For the remainder of this chapter, when permit limits are referred to, they will be the upper constituent concentration limits in the permit.

Ground-water monitoring data for well OH-18, which is typical of data from the downgradient wells, is shown on Figures 6-13 through 6-16. The chemical constituent concentrations shown on the figures are

FIGURE 6-13

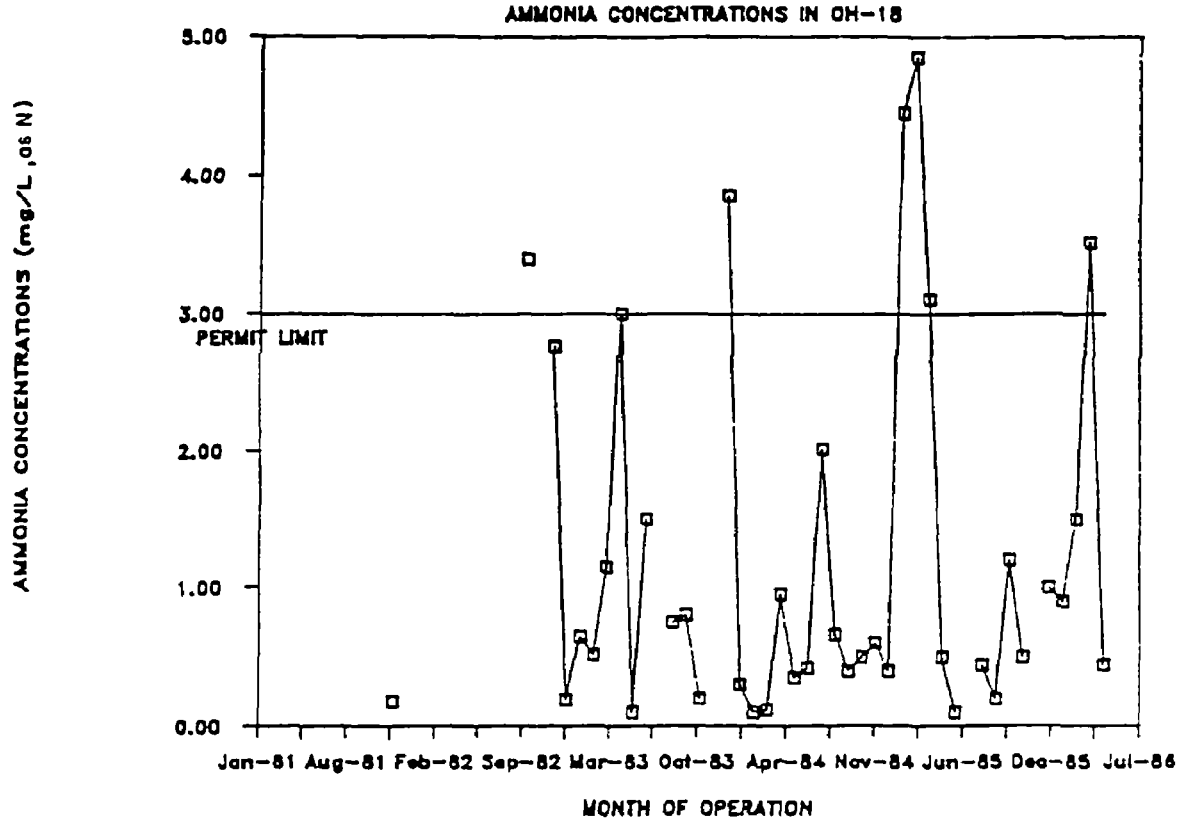


FIGURE 6-14

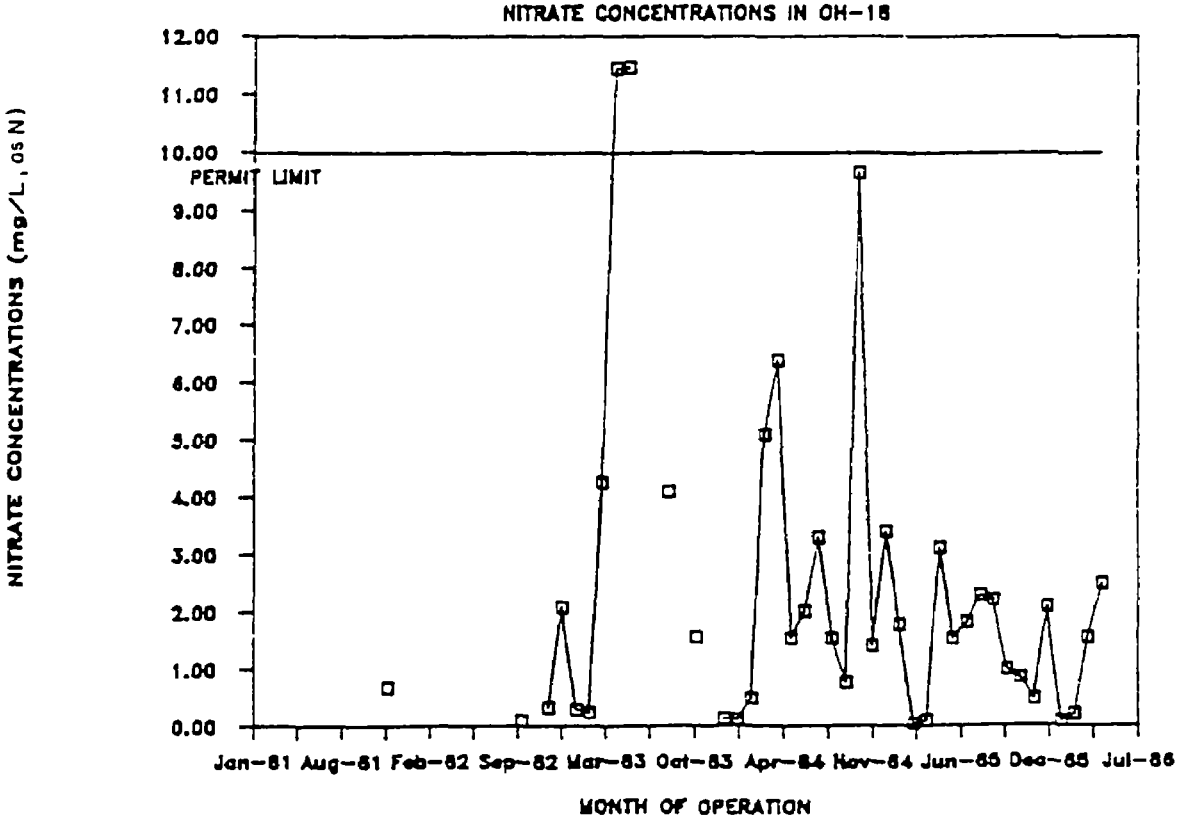


FIGURE 6-15

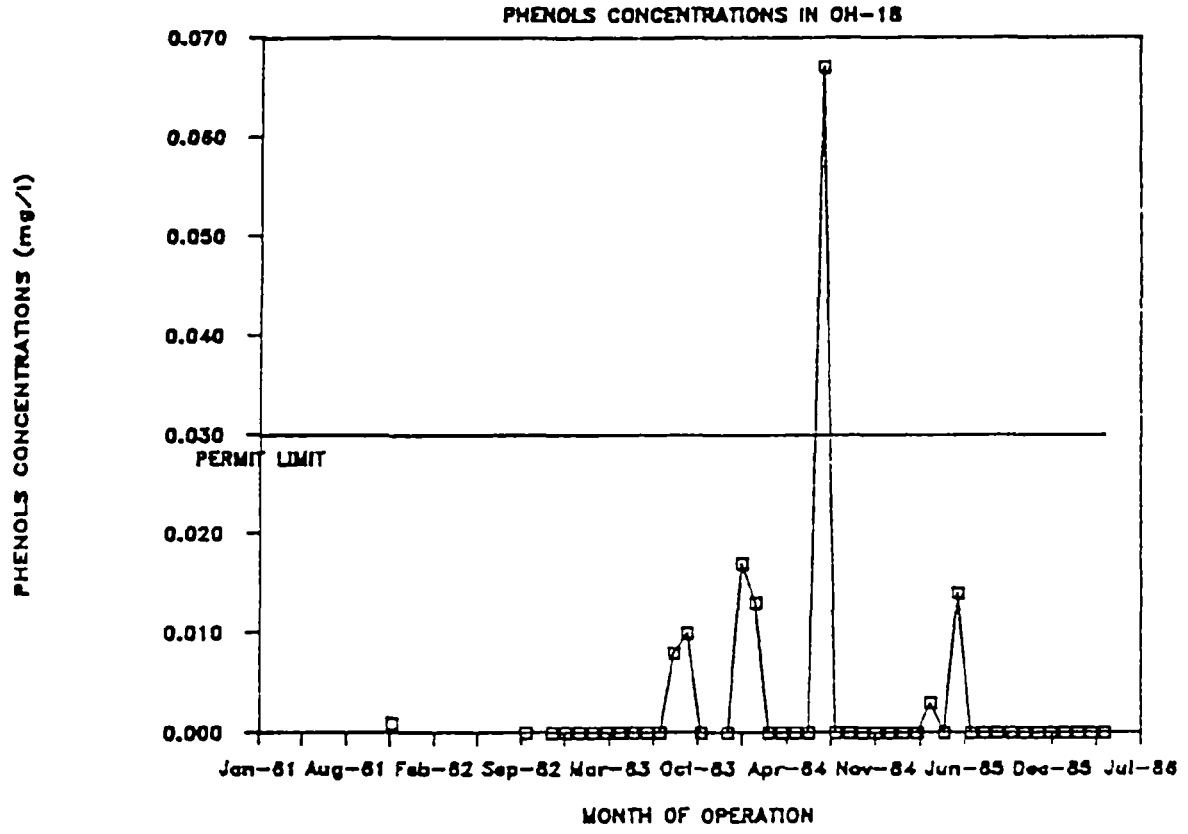
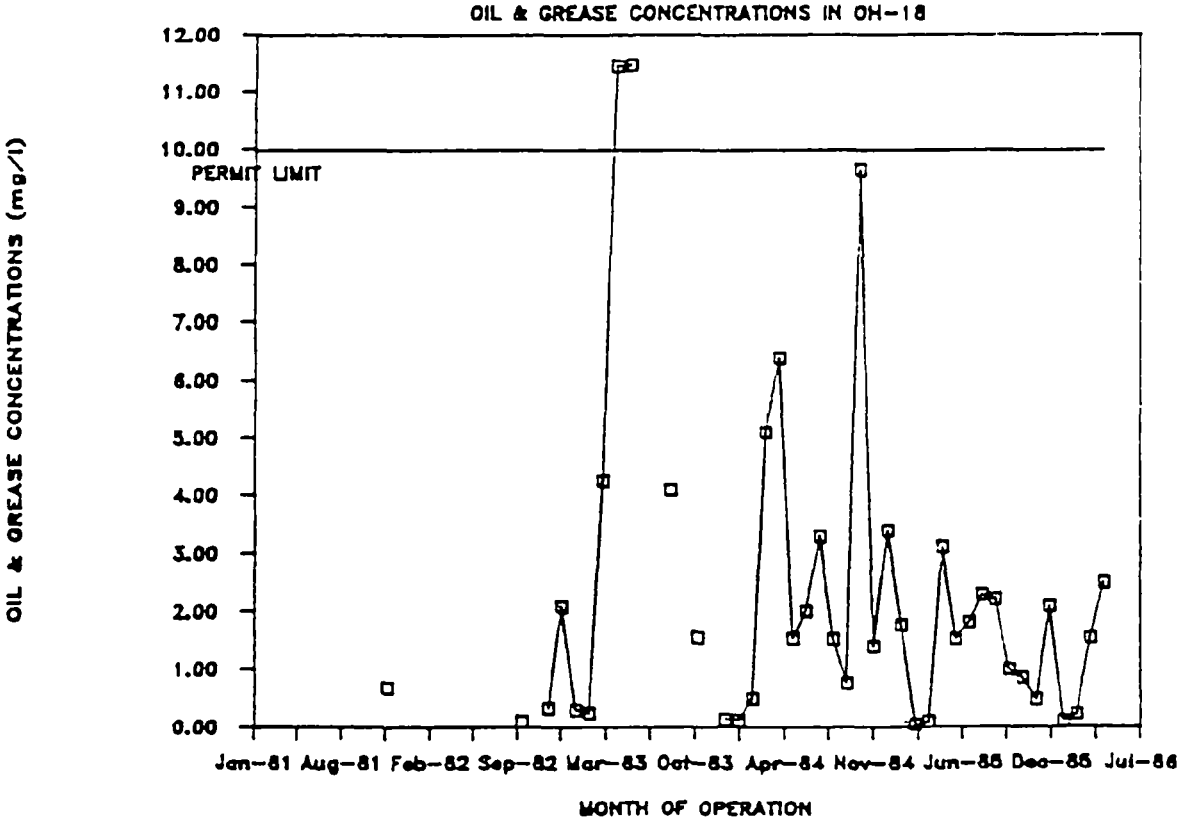


FIGURE 6-16



ammonia, nitrate, phenols, and oil and grease. The figures show that permit requirements have not been complied with on occasion. Although not shown on any of the figures, concentrations of chloride, aluminum, and magnesium have also sporadically exceeded permit limits.

One area of concern to the Teton Village Water and Sewer District has been the distance that exists between their operator-controlled effluent injection location and the OH wells. Their concern is that water quality is not monitored at the point of injection, but at points removed from the District's control and susceptible to influences other than their discharge. Possible outside influences include the facts that some OH wells are located in a cattle pasture and that the residential area immediately upgradient from the treatment and disposal facility contains numerous septic tanks. Surface drainage ditches have been noted within 10 feet or less of monitor wells OH-18 and OH-20. Monitor wells OH-18 and OH-13 are both in close proximity to stagnant surface water.

In summary, the effluent being injected at the Teton Wastewater Treatment and Disposal Facility receives tertiary treatment and is of a quality which generally does not exceed EPA Interim Primary Drinking Water Standards. Upon injection, the flow rate of the local ground water system is so great (4.9 gallons per day per square foot of cross-sectional area of the aquifer) that the effluent is dispersed through the permeable alluvium and diluted to such an extent that it is questionable whether monitored ground-water parameters are entirely attributable to the Teton Village recharge wells.

Model Description and Sensitivity Analysis

An analytic model of the dispersion of a contaminant plume was used to predict the impact of the Teton Village recharge wells on the local ground-water system. The model, developed by Allen (1985), provides an approximate analytic solution resulting from constant injection by a fully penetrating source. The equation as presented by Allen (1985) and modified to correct printing errors (J.L. Wilson, personal communication, June 1986) is as follows:

$$C = 1.603 \times 10^4 \frac{f_m \exp(x/B)}{4\pi nm(D_x D_y)^{1/2}} W[u,(r/B)]$$

in which:

$$D_x = a_x V \qquad D'_x = D_x/R_t$$

$$D_y = a_y V \qquad D'_y = D_y/R_t$$

$$B = 2D_x/V \qquad V' = V/R_t$$

$$\gamma = 1 + (2B\lambda/V)$$

$$u = r^2/(4\gamma D'_x t)$$

$$W[u,(r/B)] = \left(\frac{\pi B}{2r}\right)^{1/2} \exp[-(r/B)]\ \mathrm{erfc}\left[\frac{-(r/B) + 2u}{2u^{1/2}}\right],$$

and where:

C = the concentration of the substance in solution in parts per million (ppm)

m = the aquifer thickness or an estimate of the plume thickness, in ft.

f_m = mass injection rate of pollutant, in lbs/day.

x = distance along axis parallel to regional ground-water flow and with positive direction in the direction of flow, in ft.

y = horizontal distance perpendicular to and measured from the X axis, in ft.

a_x = longitudinal dispersivity (in direction of flow), in ft.

a_y = transverse dispersivity (perpendicular to flow), in ft.

R_t = retardation factor due to ion exchange or adsorption; a factor equal to or greater than one, dimensionless

g = decay constant in $days^{-1}$. This factor is zero when there is no decay

V = the uniform ground-water flow velocity in the positive x direction, ft/day. This velocity is equal in magnitude to KI/n where K is the hydraulic conductivity, ft/day, I is the slope of the free water table, dimensionless, and n is defined next

n = the aquifer porosity, dimensionless

1.603×10^4 = the conversion factor from lbs/ft^3 to ppm

Parameters used as input to the model include longitudinal dispersivity, transverse dispersivity, ground-water velocity, thickness and porosity of the aquifer, pollutant loading rate, decay constant and pollutant retardation (factors describing pollutant concentration attenuation due to such phenomena as adsorption, ion exchange and biochemical reation).

Assumptions behind the foregoing equations are: the flow is uniform and unlimited in lateral extent, mixing in the vertical is complete, molecular diffusion is negligible, the function W(u,r/B) contains an argument greater than 1, and the flow regime is entirely saturated. Where more than one source exists, the superposition of plumes is assumed to be appropriate. The pollutant is assumed to be completely soluble (Allen, 1985).

The model's assumptions are met to a degree that will allow the modeling to generate reasonably reliable results. The nature of the sediments is such that uniform, areally extensive lateral flow can be presumed, the velocity of the ground water makes molecular diffusion negligible, and the flow regime is entirely saturated. Calculations indicate that vertical mixing of the pollutant load through the saturated zone should be complete beyond a distance of about 3,000 feet from the recharge wells, so beyond that distance from the site the modeled results should mimic the real world.

The model used a nitrogen loading factor of nitrate-nitrogen plus ammonia-nitrogen as an indicator of the spread of the contaminant plume downgradient from the recharge wells. Nitrogen was chosen because of the frequency with which the ammonia/nitrate-nitrogen concentration in the effluent approaches or exceeds the EPA interim primary drinking water standard for nitrate.

For this situation, the pollutant retardation factor was assumed to be 1.0, indicating no attenuation. This is in keeping with the above discussion of nitrogen pollutant species and the very large ground-water velocities existing in the area, and results in a conservative model. Other model input are:

Longitudinal Dispersivity, 50 ft.

Transverse Dispersivity, 10 ft.

Ground Water Velocity, 30 ft/day

Aquifer Thickness, 50 ft.

Aquifer Porosity, 0.35

Loading Rate, 6.56 lbs/day; and

Decay constant, 0.0

These parameters are also quite conservative with respect to the local ground-water situation. Longitudinal and transverse dispersivities were not available for the sediments at the site, so values representative of Recent alluvium and outwash were used. Values of both parameters were varied in the model sensitivity analysis, and it was shown that the representative values used gave a conservative estimate of the nitrogen plume migration. The ground water velocity was calculated from existing hydraulic gradient and hydraulic conductivity data, and an assumed porosity of 0.35, which is typical of the type of sediments present at the site. The aquifer thickness was taken as the depth of the injection zone, and the loading rate was assigned the average injection rate of ammonia-nitrogen plus nitrate-nitrogen. The decay constant of 0.0 is for non-radioactive species.

The model generates results in terms of concentrations of the parameter of interest at selected coordinates downgradient from the pollutant source. In this case, those results are the increase in nitrate-nitrogen concentrations over background.

Input parameters were varied to assess the sensitivity of the model, particularly the values of parameters that were estimated for this site. The input parameters that were varied include porosity, aquifer thickness, dispersivities, ground-water velocities and pollutant loading. Of these parameters, only the pollutant loading was known; the remaining parameters were estimated for input to the model.

The value of porosity was varied from 0.15 to 0.50; the model used a value of 0.35, as the range of porosity values applicable to the area is small, between 0.25 and 0.40. Pollutant concentrations in the plume

were found to vary inversely and linearly with changes in porosity. The effect of porosity on the pollutant concentrations is small.

Aquifer thickness had an effect similar to porosity, and the value of 50 feet was used because of the injection well completion depths and because it would give a conservative result in modeling. The aquifer thickness probably increases rapidly to the east of Teton Village, but vertical expansion of the contaminant plume would not be as rapid. Pollutant concentrations to the east and southeast of Teton Village would likely be lower than predicted by the model because of increased aquifer thickness.

Pollutant loading had a direct and linear effect on concentrations in the plume. The pollutant loading was calculated from the monthly records of the quantity and quality of effluent injected, which were submitted to WQD by the permittee.

Dispersivities and ground-water velocity were also varied separately in the sensitivity analysis. The velocity affected both the length and width of the plume, as well as pollutant concentrations within the plume. The effect on concentrations and lateral spreading was inverse but not linear, as the velocity term occurs in several places in the model equations. A greater velocity results in the contaminant traveling greater distances but in smaller concentrations. Ground-water velocity was varied from 10 ft/day to 50 ft/day. The value of 30 ft/day was retained, as it give a conservative estimate of plume distribution. Dispersivities, both longitudinal and transverse and the ratio between the two values, were varied over an order of magnitude in the sensitivity analysis. Longitudinal dispersivity was varied from 10

feet to 100 feet, and transverse dispersivity was varied from 1.15 feet to 50 feet. The results showed that the value of transverse dispersivity (a_y) controlled the pollutant concentrations along the longitudinal axis of the plume more strongly than did the longitudinal dispersivity (a_x). Small values of a_y produced a long, narrow plume with large pollutant concentrations near the longitudinal axis of the plume; concentrations decreased drastically within a short distance of the plume axis. Very large values of a_y resulted in a wider, more dilute plume. As expected, larger values of a_x did produce a longer plume than did small values of a_x, but the length difference was not significant when the pollutant concentrations were considered. The effect of different values of a_x might be more significant if very small pollutant concentrations (a few tens of micrograms per liter) were of concern, but in this case an increase of up to several milligrams per liter ammonia-nitrogen plus nitrate-nitrogen would not affect the use suitability classification of the ground water. The results produced by longitudinal and transverse dispersivities of 50 feet and 10 feet, respectively, were felt to be most representative because a moderately wide plume with moderate nitrogen concentrations was produced.

Overall, the results of the model fit with the monitoring data from wells OH-18, OH-19, and OH-20. These wells are at most only about 250 feet from the recharge wells, and no other data were available for greater distances from the recharge wells. Calibration of the model was therefore very restricted areally, but was felt to be adequate for the purposes of this report. Regulatory and planning decisions, however, should be based on more thorough modeling of the area, which would

require additional calibration data at greater distances downgradient from the facility.

Figure 6-17 shows the results of modeling nitrogen loading at the present rate. The figure indicates that at a distance of 7,500 feet downgradient from the injection wells the increase in total nitrogen concentration is only 0.7 mg/l after 10 years of injection. This result indicates that the present injection from the Teton Village sewage treatment facility has no significant adverse impact on the local ground water. This conclusion is not unexpected, since a permit was issued by the WDEQ-WQD for the injection wells, and no major problems (other than the previously described problem with phenol in the effluent) have been indicated by the results of sampling and analysis of ground water from the monitoring wells.

Model Results

The model was also used to predict the minimum nitrogen loading that would cause the nitrate-nitrogen standard of 10 mg/L to be exceeded downgradient from the recharge facility. The results indicated that the total ammonia-nitrogen plus nitrate-nitrogen load could be safely doubled from the present average for about 1 year without causing the 10 mg/L standard to be exceeded at distances greater than 100 feet from the facility. However, continuation of that same loading rate would cause the standard to be exceeded within five years. The maximum loading rate considered safe for the long term (10 to 20 years), based on the model's predictions, is about 50 percent above the present average loading rate. As cautioned earlier, however, any planning or regulatory decisions

should be based on more detailed modeling than was conducted for this report.

Summary

The injection of treated wastewater from Teton Village into the local ground water is not causing violation of any of the Standards of Class I Wyoming ground waters. The lack of such violation is attributable to:

1. The high level of wastewater treatment afforded by the Teton Village sewage treatment facility, and resulting high quality of injected effluent;
2. The nature of the local ground-water system; a thick alluvial injection receiver which features extremely good quality water and very high ground-water flow rates for dilution of the effluent; and
3. The permit requirements of the WDEQ-WQD, which require the Teton Village Water and Sewer District to routinely monitor the quality of injected effluent and ground water in nearby monitoring wells, thus requiring the Company's continued attention to maintenance of the treatment plant and injection system.

The major environmental question concerning the future of the Teton Village wastewater effluent injection is the possibility of increased use of the ground water in this area for both water supply and disposal of treated wastewater. The only apparent way to adequately regulate this situation is by careful application of the requirements contained

in Chapters VIII and IX of the Wyoming Water Quality Rules and Regulations. It has not been explicitly stated thus far, but future wastewater injection projects in this area will probably require more extensive modeling of the ground water. The results of such modeling will be needed to determine whether to allow additional projects of this kind in the Jackson Hole area (or elsewhere), and to develop appropriate permit limitations and conditions for such projects. This in turn will require the collection of more complete baseline data and the installation of monitoring wells which are completed in a standardized manner.

Additionally, if future projects of this type are undertaken in this area, a standardized method of data input, storage and retrieval will be necessary to make realistic use of the monitoring data which are gathered and submitted by permittees as part of their operations. Lack of such a standard database makes it difficult to use the monitoring data which is presently submitted by the Teton Village Water and Sewer District.

Conclusions

The Teton Village recharge wells do not cause any significant degradation of ground-water quality. The small impact is due to the high degree of effluent treatment afforded by the Teton Village Wastewater Treatment and Disposal Facility, and the dilution of the effluent by the high-quality ground water into which the effluent is injected.

The results of this assessment, while specific only to the Teton Village recharge wells, can be modified for general application to similar facilities and settings. The Teton Village facility generates only domestic sewage effluent, and does not handle substances which are difficult or impossible to treat conventionally. Such substances as phenols, chlorinated hydrocarbons and polynuclear aromatics are more typically generated by industrial facilities than by residential or resort-area developments.

Industrial development would be unlikely in a setting like that of Teton Village, where the site overlies a shallow aquifer with exceptionally good water quality. These waters are rare outside mountainous areas with glacial outwash or Precambrian aquifers. Residential or resort-type development would be the norm for alpine settings, and injection well disposal of tertiary-treated effluent would likely present only a small hazard. Careful stipulation of ground water pollution control permit conditions to require close monitoring of system operation, effluent quality, and downgradient water quality would minimize any degradation of ground-water quality.

The conditions to the Teton Village Ground-Water Pollution Control permit contain sufficient stipulations regarding operation of the system and ground-water and effluent quality monitoring, that significant water-quality impacts will be avoided if the permit conditions are adhered to by the operators. The shortcomings of baseline hydrologic data mentioned earlier in this chapter developed because the permitting system for facilities such as this was not fully developed when the Teton Village facility was undergoing development in the mid-1970's.

Enforcement of the regulations presently in place, and careful review and response by WDEQ-WQD to proposals for similar development should adequately protect receiver units.

SECTION 4.3.6

TITLE OF STUDY:
(or SOURCE OF INFORMATION)
"Waste-Water Injection: Geochemical and Biochemical Clogging Processes", Ground Water, Vol. 23, No. 6

AUTHOR:
(or INVESTIGATOR)
June A. Oberdorfer and Frank L. Peterson

DATE:
November-December, 1985

FACILITY NAME AND LOCATION:
Oahu, Hawaii, USEPA Region IX

Site A: Waimanalo Wastewater Treatment Plant, Waimanalo
Site B: Paalaa Kai Wastewater Treatment Plant, Waialua

NATURE OF BUSINESS:
Wastewater treatment

BRIEF SUMMARY/NOTES:
Two experimental injection sites were installed in order to study clogging that occurs in the near vicinity of wells used for injection of treated sewage effluent. Numerous data, including injection head distribution, analyses of sediment cores taken from injection strata, and analyses of water collected from the injection strata (pore water), were studied. Results showed that filtration of suspended solids is not a long-term cause of clogging. Particulate filtration may be a short-term cause of clogging, but the injected organics are biodegraded once the microbial mass becomes established.

Waste-Water Injection: Geochemical and Biogeochemical Clogging Processes

by June A. Oberdorfer[a] and Frank L. Peterson[b]

ABSTRACT

Examination of near-well clogging processes at two experimental injection sites in Hawaii shows that filtration of suspended solids is not a long-term cause of clogging While particulate filtration is probably a short-term cause of clogging at the start-up of injection, the injected organics are biodegraded once the microbial biomass becomes established The injection head gradient determined from monitoring wells shows that most of the initial head loss is immediately adjacent to the well, but that after several weeks it shifts to a region over 0 5 m from the well Denitrifying bacteria become sufficiently numerous to produce significant amounts of nitrogen gas, which in turn produces a gas-bound zone about 0 5 to 1 m from the well With continued injection the nitrogen gas-bound zone is slowly extended farther out into the injection stratum Dissolution of the carbonate aquifer also occurs, but its effects are partially masked by gas binding

INTRODUCTION

Waste-water disposal into injection wells almost inevitably produces aquifer clogging and reduced injection capacity In Hawaii, overflows from wells injecting secondary treated sewage effluent have created numerous public health, legal, and financial problems. To determine the causes of clogging, geochemical and biogeochemical processes that occur in the near vicinity of the injection well were examined utilizing observation well and sediment core and pore-water analyses

Although injection wells are widely used in the United States and throughout the world for waste disposal and artificial recharge, few detailed investigations of injection well clogging processes have been reported Probably the most comprehensive study is a compilation by Olsthoorn (1982) of clogging problems associated with recharge wells. Other studies most pertinent to this work are examination of injection well problems in Hawaii by Petty and Peterson (1979), aquifer clogging caused by the injection of primary treated sewage effluent at Richmond, California (California Water Pollution Control Board, 1954), and clogging at Bay Park, New York as a result of injection of tertiary treated sewage effluent (Ehrlich *et al* , 1972; Ehrlich *et al* , 1977, Ragone, 1977, Vecchioli and Ku, 1972, Vecchioli *et al* , 1980) The most significant conclusions from these studies are the following

1. The major cause of clogging at most of these sites is filtration by the porous media of suspended solids contained within the injectant

2 The second major cause of clogging results from microbial growth at the well face and within the aquifer

3 Of lesser significance are chemical precipitation processes

4 On occasion, clogging may result from entrapped air and gas bubbles introduced by the injectant

5 Most of the clogging activity occurs at or very near the injection well-aquifer boundary, and

[a]Assistant Professor of Hydrogeology, San Jose State University, San Jose, California 95192

[b]Professor of Hydrogeology, Department of Geology & Geophysics, and Researcher, Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii 96822

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in many instances a mat of filtration material forms directly on the aquifer surface

The above conclusions were the preconceptions with which we commenced this study. As our research developed, they proved to be less relevant to the Hawaiian injection environment than originally thought. Other processes, particularly biogenic nitrogen gas binding, appear to be more important for well clogging in the Hawaiian injection situations studied.

DESCRIPTION OF FIELD SITES AND EXPERIMENTS

Despite the recognition that clogging occurs in the near vicinity of the well, no previous investigations have examined sediment samples or pore water taken from the injection formation within the first few meters of the well The nearest observation wells are generally located several meters from the injection well To obtain more direct evidence of the processes occurring in this very near-well environment, two experimental injection sites were installed and numerous data were collected and analyzed The most useful of these included measurements of injection head distribution, analyses of sediment cores taken from the injection strata, and analyses of water collected from the injection strata (pore water)

The experimental sites were selected to duplicate as closely as possible the general conditions at operating Hawaiian injection sites Most disposal wells in the Hawaiian Islands inject secondary-treated sewage effluent into coastal plain aquifers consisting of marine carbonate and alluvial sediments or highly permeable basaltic flows, all generally saturated with brackish water The wells range typically in diameter from 0 10 to 0 15 m, are less than about 30 m deep, and have injection rates less than 6.3×10^{-3} m^3/s per well. The injection experiments described were all conducted into a fine carbonate sand aquifer (Waimanalo) and a coral reef and rubble aquifer (Paalaa Kai).

Site A

This site is located on the grounds of the Waimanalo Wastewater Treatment Plant at Waimanalo, Oahu, Hawaii The injection formation at this site is a fine to medium carbonate sand layer approximately 3 m thick, overlain by a dense impermeable clay layer and underlain by a low-permeability clayey coral rubble layer. The hydraulic conductivity of the sand layers was determined by pump testing to be about $3\ 5 \times 10^{-4}$ m/s This formation, which is representative of some of the least permeable receiving formations available for waste disposal in Hawaii, was selected for these experiments because of its susceptibility to clogging Five injection wells, three of 0 10 m diameter and two of 0 15 m diameter, were utilized for injection experiments. All of the injection wells were cased with PVC pipe and slotted throughout their entire length. Figure 1 shows the location of injection wells, observation wells, and sampling sites. Figure 2 shows a hydrogeologic cross section through the three wells where sediment samples were collected

The injectant was secondary treated domestic sewage which contained BOD_5 averaging about 10 to 15 mg/ℓ, suspended solids of 5 to 15 mg/ℓ, and total chlorine residual of 1.5 mg/ℓ. Injection experiments were conducted from May 1980 to June 1982 Sediment cores were taken adjacent to Well 4-5 in October 1980 after five months of injection, and additional cores were collected at Wells 4-4 and 6-2 in April 1981 Observation wells were installed in each of these latter coring sites Cores were taken at 0 3, 0 6, and 0 9 m from the injection well and at depths of 2.4 and 2.7 m below ground surface.

Site B

This site is located on the grounds of the Paalaa Kai Wastewater Treatment Plant, Waialua, Oahu, Hawaii. The injection formation is a 3 m thick layer of coral and recemented reef rubble lying at a depth of 11 to 14 m below ground surface. This formation is much more permeable than the one at Waimanalo and has a hydraulic conductivity of about 0.01 m/s. It is representative

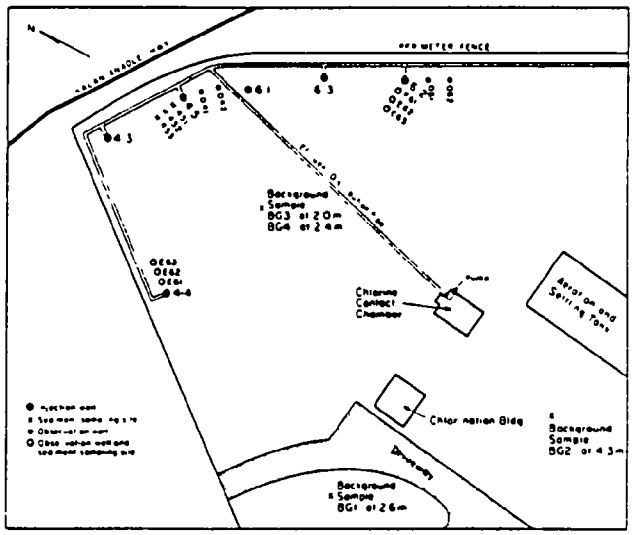

Fig. 1. Waimanalo experimental well layout and sampling sites, Oahu.

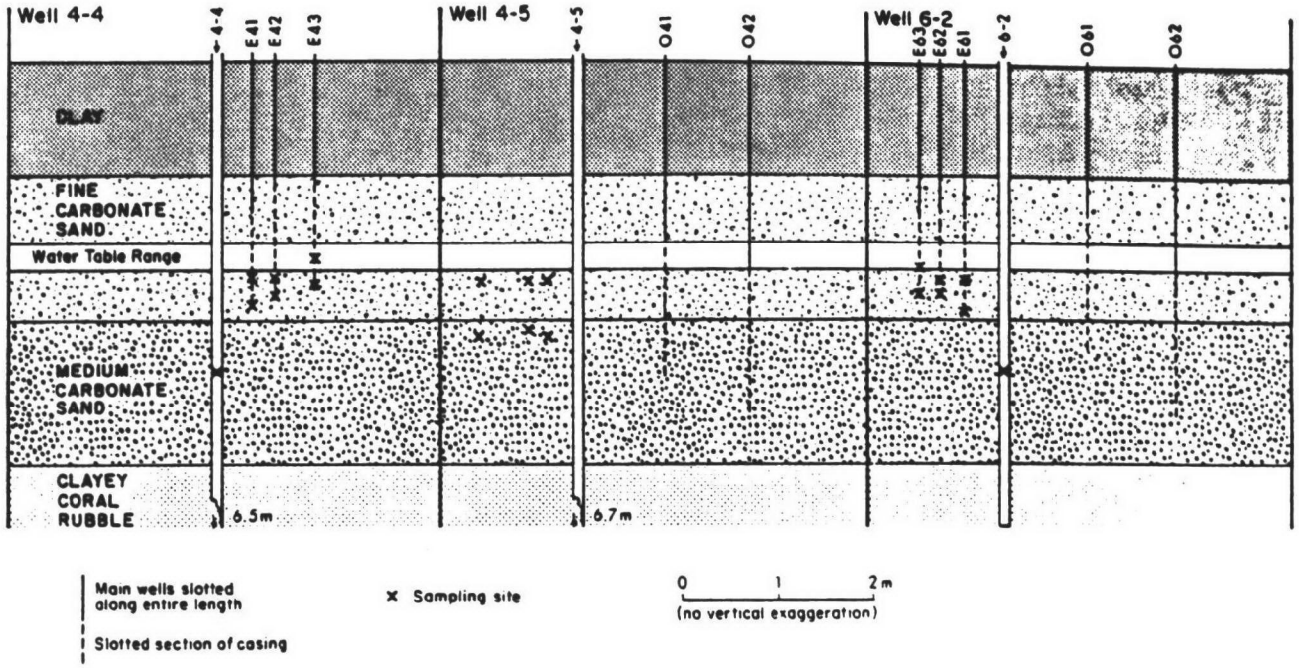

Fig. 2. Cross section at Site A Waimanalo Wells 4-4, 4-5, 6-2, including observation wells and sampling sites.

of some of the better sedimentary receiving formations on Oahu. One injection well (PK-1) and three observation wells (at 0.6, 1.3, and 2.0 m from the injection well) were used. Like the Waimanalo wells, PK-1 is cased with 0.10 m PVC casing slotted throughout its entire length. The injectant is of excellent quality, having been filtered through a rapid sand filter after receiving biological secondary treatment. The BOD_5 and suspended solids averaged less than 5 mg/ℓ. Injection took place from July 1981 to June 1982.

METHODS

Sediment samples were collected with a hand auger. Water from the observation wells was sampled at the pump discharge or with a thief sampler after sufficient bailing to remove the water originally in the well bore. The injectant was sampled at the discharge into the well. A complete description of chemical analytical methods is given in Oberdorfer (1983) or Oberdorfer and Peterson (1982). Briefly, sediment analyses included:

1. ATP-Biomass Index: Two cc of sediment were injected into 10 mℓ boiling phosphate buffer to extract ATP. Analysis performed on SAI Technology Co. ATP Photometer Model 200 (see Karl and LaRock, 1975).

2. Iron: Sample was ashed at 550° C for 4 hr to remove organics. Sample then digested in acids in a teflon crucible (see Bernas, 1968). Detection by atomic adsorption (APHA *et al.*, 1980), Part 301A with standard addition.

3. Organic Carbon: Performed on a Hewlett Packard 185-B carbon and nitrogen analyzer (see Smith *et al.*, 1981).

Pore-water samples were obtained with a thief sampler except in the case of dissolved oxygen which was measured in the well. Analyses include:

1. Alkalinity: APHA Part 403.

2. Chlorides: APHA Part 408A.

3. Dissolved Nitrogen (ammonia, nitrate/nitrite, total): APHA Part 604 on a Technicon Autoanalyzer II after filtration with a 0.45 m membrane filter.

4. pH: Measured with a Photovolt pH Meter 126A, calibrated with pH 7 and pH 10 buffer.

5. Dissolved Oxygen: Measured with a YSI Model 57 Oxygen Meter.

6. Dissolved Nitrogen Gas and Methane Gas: 5 mℓ samples taken immediately from the thief sampler with a glass syringe; dissolved gas extracted into 5 mℓ of carrier gas (helium) in syringe head space during one minute of agitation; head space gas then run through gas chromatograph with 1.8 m by 0.003 m O.D. stainless steel column filled with Molecular Sieve 5-A-80/100 and measured with thermal conductivity; procedure slightly modified from Martens and Van Klump (1980).

7. Dissolved Cations (calcium, magnesium, strontium): Samples filtered with a 0.45 m membrane filter and analyses performed by inductively coupled plasma spectroscopy (see Peck *et al.*, 1979).

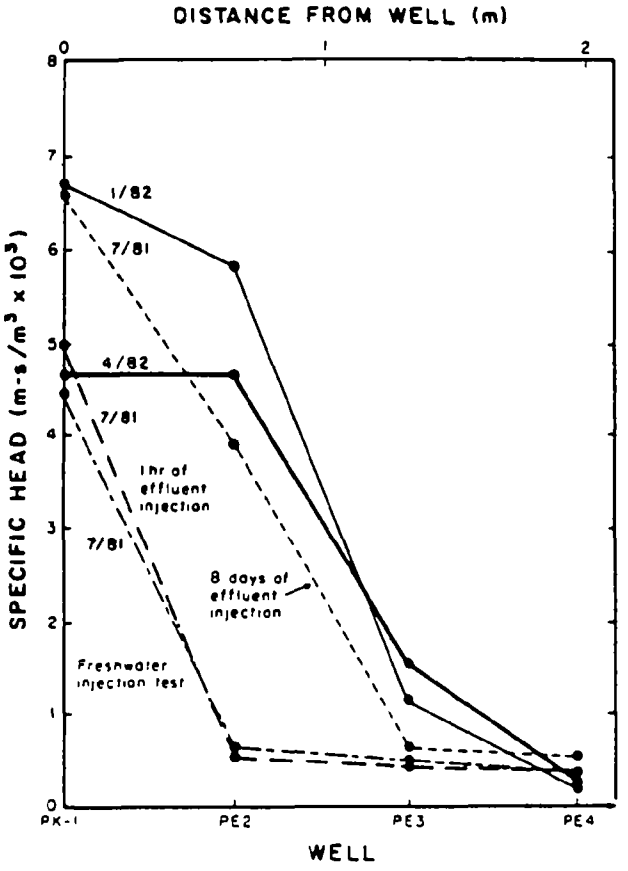

Fig. 3. Specific hydraulic head, Paalaa Kai Well PK-1.

RESULTS AND DISCUSSION

Formation Head Distribution

With a number of observation wells close to the injection well, the head distribution within the injection stratum in the near vicinity of the well can be monitored and its evolution with time observed. Figure 3 shows the specific head buildup (injection head buildup divided by the injection rate) for the site B well at various times during its injection history These times included at the initial fresh-water injection test, twice shortly after the start-up of injection, and twice after prolonged periods of injection. The Site A wells showed similar patterns

The head distribution curves for the wells indicate that a maturation process occurs in the injection stratum over the first several weeks after the start-up of injection. The head buildup at the time of the fresh-water injection test for each of the wells represented a normal appearing cone of impression The major head loss was observed immediately adjacent to the well and the gradient leveled off with distance In the first few days after the start-up of injection, head loss increased immediately adjacent to the well An increase in head loss indicates a decrease in hydraulic conductivity, i e , clogging Thus, during the first few days of injection, virtually all of the clogging took place immediately adjacent to the well and there was little indication of any clogging beyond the first observation well As injection continued, there was a shift outward of the clogging. Although head loss remained significant adjacent to the well, a marked increase in head loss beyond the first observation well was observed after eight days. Clogging was now occurring in a zone farther out from the injection well. This outward progression of clogging proceeded thereafter at a more gradual rate Ultimately almost no head loss occurred in the zone nearest the well where almost all of the initial head loss took place This decreased head gradient indicates an increase in permeability over initial conditions and may indicate dissolution of the porous medium. At all of the observed wells, the clogging initially occurred in a zone within about 0 5 m from the injection well After a few weeks to a month of injection, most of the clogging occurred in a zone anywhere from 0 7 to 1 3 m from the injection well

Figure 3 also shows the effects that redevelopment can have on head distribution Redevelopment by acid treatment and pumping after the January 1982 observations produced a lower specific head and a reduction in head as far out as observation well PE2 (0 6 m from the injection well) The effects of redevelopment probably extend a meter at this site, although in general the effectiveness of redevelopment will depend on which redevelopment technique is used For this well the clogging did not extend beyond 2 m. This limit was also true for most of the Site A wells, except for one in which the clogging extended well beyond 2 m

Sediment Cores

Because particulates in the injectant were expected to play a major role in clogging, the accumulation of particulates in the sediment was closely examined Sediment cores were taken from the injection strata adjacent to three of the wells at Site A, each within a meter of the injection well. Figure 4 shows the concentration of several of the most significant constituents in the sediment cores as a function of distance from the wells As described previously, the samples were collected after several months of injection so the clogging processes were well established The points plotted in this figure are averages of analyses of two samples collected at slightly different depths at each coring site Since multiple analyses were frequently performed on each sample, a point

often represents the average of more than two data. Depth may affect some processes, particularly where closeness to the water table might play a role; however, no consistent pattern of variation with depth was observed. A large variability frequently occurs in values obtained for a single parameter at a given coring site This is a result of the variability found in natural systems, and is typical of environmental sampling Microbial biomass (measured as ATP) is particularly susceptible to environmental variability. To understand the system, the major trends should be observed, rather than focusing on a single anomalous result. Background samples were collected at three locations relatively far from the injection wells and their averages are plotted to the right-hand side (Figure 4) for comparison. Generally, the sample farthest from the well

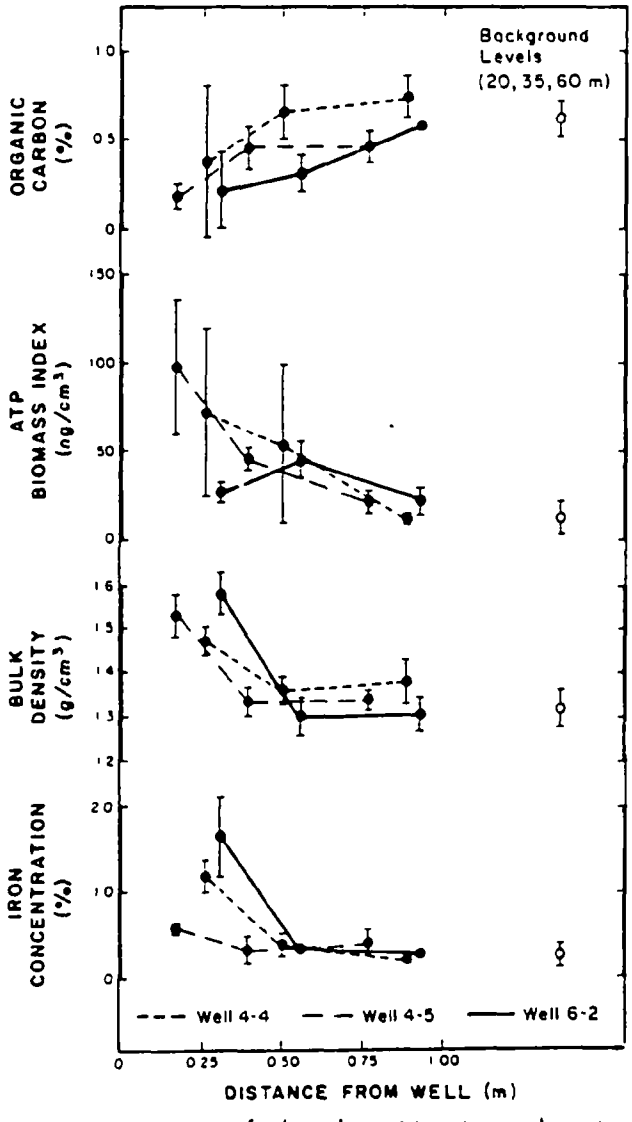

Fig. 4. Concentration of selected constituents in sediment samples from Site A vs. distance from well.

(0 80-0 94 m) had concentrations similar to the background samples Cores taken closest to the well showed the greatest difference from background levels. This is to be expected as the processes involving particulates are initiated by filtration and thus take place immediately adjacent to the well.

Percent organic carbon in the sediment as a function of distance from the well revealed a depletion of organic carbon adjacent to the well This depletion was unexpected; instead an increase in organic carbon from accumulation of injected particulate matter was expected to occur (the injectant has a suspended solids load of 10-15 mg/ℓ of which 95% is volatile, i.e , organic) Particulates have long been considered to be a major cause of clogging, but these data contradict that The most probable explanation of the near-well depletion is that the microbial population metabolizes all of the organic carbon put into the system plus, due to the high metabolic rate induced near the well, the refractory compounds which persist at a greater distance from the well Organic carbon concentrations at 1 m are similar to background concentrations so there does not appear to be an accumulation of particulates that have simply travelled farther out into the formation

The microbial biomass (ATP) nearest the well is an order of magnitude greater than background levels. The large error bars on this plot reflect the variability found in environmental samples, however, major trends are still clearly discernible Injectant ATP levels of 0 5 to 5 ng/mℓ would not account for this biomass accumulation by simple filtration. This biomass increase in a nutrient-rich environment indicates that most of the metabolism of organics occurs very close to the well and is consistent with the organic depletion discussed above The bacteria at 1 m, while not quantitatively significant, are qualitatively significant, particularly in mediating redox reactions The injectant chlorine residual (averaging 0 5 to 3 0 mg/ℓ) decreases but is still detectable at 1 m from the well, yet the bacterial community can persist, even fluorish, in the chlorinated environment. They may inhabit more protected microenvironments, such as in cavities in the sand grain surfaces or at contact points between grains, where they would be less exposed to continuous contact with the high chlorine residual.

Immediately adjacent to the well, bulk density increases markedly due partially to the addition of fine particulate matter which can be seen in the sediment cores as a brown discoloration

at the time of sampling Iron, aluminum, and phosphorus also show increases in this region. Part of this fine particulate matter is present as iron monosulfide. The sulfide is produced by biologically mediated sulfate reduction which must occur in microenvironments in the porous medium since sulfate-reducing bacteria are strict anaerobes and could not survive in the aerated bulk pore water The hydrogen sulfide quickly reacts with iron in the system to form iron monosulfide. The iron levels are much greater at the 10-mo sampling (Wells 4-4 and 6-2) than at the 5-mo sampling (Well 4-5), indicating that this iron accumulation is a rate dependent process. Additional iron is present in iron-rich clays (typical in Hawaii) which are introduced with the injectant and filtered out shortly after entering the system

To summarize, analyses of sediment cores indicate that particulate processes occur in the first few tens of centimeters from the injection well, but at a distance of a meter away there is little to distinguish the sediments in the injection stratum from background samples. An increase in biomass occurs adjacent to the well where there is a high nutrient influx, but it does not appear to be massive enough to be a major cause of clogging This is supported by detailed microscopic examination of the sediment cores and by the injection head data described earlier. In the first days after injection start-up, head increased immediately adjacent to the well, probably because particulate organics accumulated there before the microbial population became well enough established to consume all of the incoming particulates. It should be remembered, however, that after a few weeks the zone of high head loss, and hence clogging, shifted farther outward from the injection well (Figure 3). We think this occurred when the microbial population became well enough established after the first few weeks to metabolize the organics which had accumulated near the well, thus reducing the clogging there. To be sure, deposition of fine particulate matter, as indicated by the bulk density increase, was observed adjacent to the well throughout the injection experiments However, the deposition was not massive enough to substantially increase clogging, and the loss of permeability caused by the addition of these particulates seems to be overshadowed by dissolution of the carbonate aquifer Thus the results from our work suggest that although clogging by particulate matter may be important for the first few weeks of injection, it apparently is not a major contributor over the long run

Pore Water

Analysis of the sediment cores has mainly indicated what does not cause clogging. To determine what is causing the clogging, it is necessary to examine the pore waters taken directly from the injection stratum. Thus, pore-water samples were collected several different times and analyzed for over 25 different constituents. Given here is a summary of only the most significant results. The complete data set is available in Oberdorfer (1983)

All of the pore-water data presented in this paper were collected after extended periods of injection During this time chloride levels in the formation water in the near vicinity of the wells (2-20 m) were identical to the levels in the injectants and significantly lower than chlorides in the native ground water prior to the start-up of injection. Since chloride is a conservative tracer whose concentration does not change in the formation except by mixing with waters of different chloride concentration, the results indicate that the effluent has displaced all of the ground water in the vicinity of the well, and dilution effects cannot account for changes in formation water quality

Figure 5 shows the concentration of several key pore-water constituents versus distance from the injection well (zero distance represents the injected effluent). Since the injectant quality can be highly variable, concentrations are expressed in terms of changes from input concentrations, as the changes in water quality reflect the processes occurring. Additional wells sampled at Site A showed similar trends The error bars are in large part a reflection of sample variability for different sampling times, often a result of injectant concentration variability. Again, major trends rather than details should be noted. The data from Figure 5 suggest that there are two processes of major significance to clogging which occur immediately adjacent to injection wells. The first of these is dissolution of the carbonate aquifer material, a process that actually decreases rather than increases clogging potential. The injectant is mildly acidic which contributes to carbonate dissolution. In addition, bacterial metabolism of the injected organics consumes oxygen (see decrease in dissolved oxygen with distance from well in Figure 5) and produces carbon dioxide and water which rapidly convert to carbonic acid. Carbonic acid dissociates to bicarbonate and hydrogen ions in the pH range in question, as shown by equation (1)

$$CH_2O + O_2 = CO_2 + H_2O = H_2CO_3 = HCO_3^- + H^+ \quad (1$$

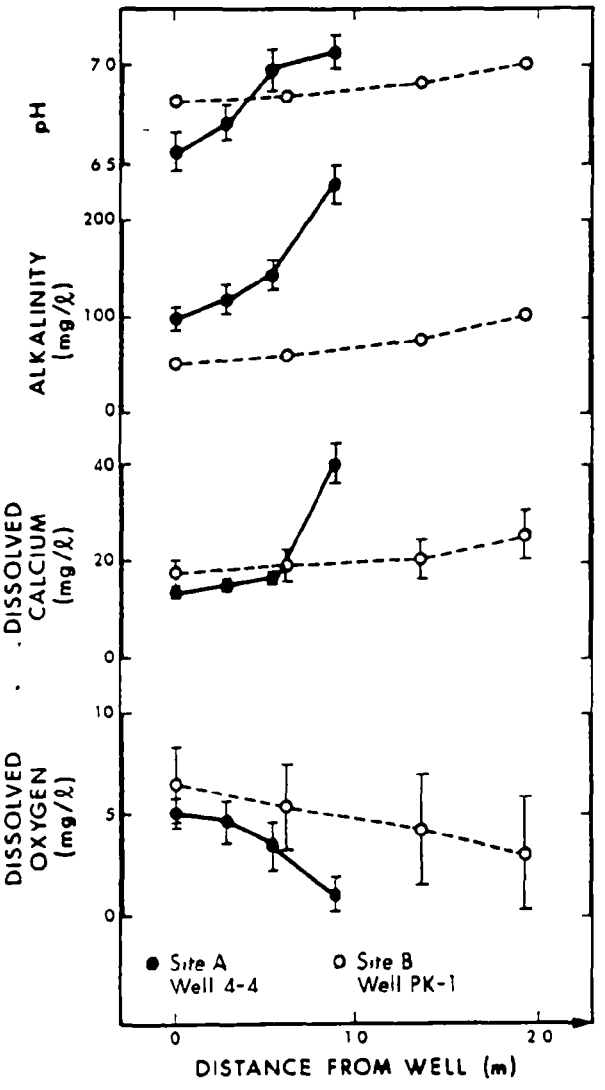

Fig. 5. Concentration of selected constituents in pore water vs. distance from well.

This would be expected to cause the pH to decrease However, the pH increases because carbonate solution neutralizes the acid, by the reaction,

$$H^+ + CaCO_3 = Ca^{++} + HCO_3^- \qquad (2)$$

This reaction increases the pH, alkalinity, and calcium concentration, all of which are shown in Figure 5 to increase with distance outward from the well. The saturation indices (a measure of the aggressivity of water towards a given mineral) for the pore water sampled indicate that the water is undersaturated with respect to calcite and aragonite. At the current rates of dissolution based on the calcium results and typical flow rates (3×10^{-4} m^3/s at Site A, 7×10^{-3} m^3/s at Site B), between 0 7 and 7% of the carbonate porous medium is lost each year from the near-well region

The second process of major consequence for injection well clogging is the production of nitrogen gas by denitrifying bacteria which leads to gas binding of the aquifer pore spaces. Nitrogen species concentrations are given in Figure 6 Dissolved organic nitrogen was determined to be insignificant so that total dissolved nitrogen has been calculated as the sum of ammonia nitrogen and nitrate + nitrite nitrogen. Organically bound nitrogen in the domestic waste water is bacterially decomposed to ammonia. The ammonia, in the presence of oxygen and nitrifying bacteria, is oxidized first to nitrite and then to nitrate, according to the reaction,

$$NH_4^+ + 2O_2 = NO_3 + 2H^+ H_2O \qquad (3)$$

which does not show the intermediate step to nitrite. Under mildly reducing conditions and in

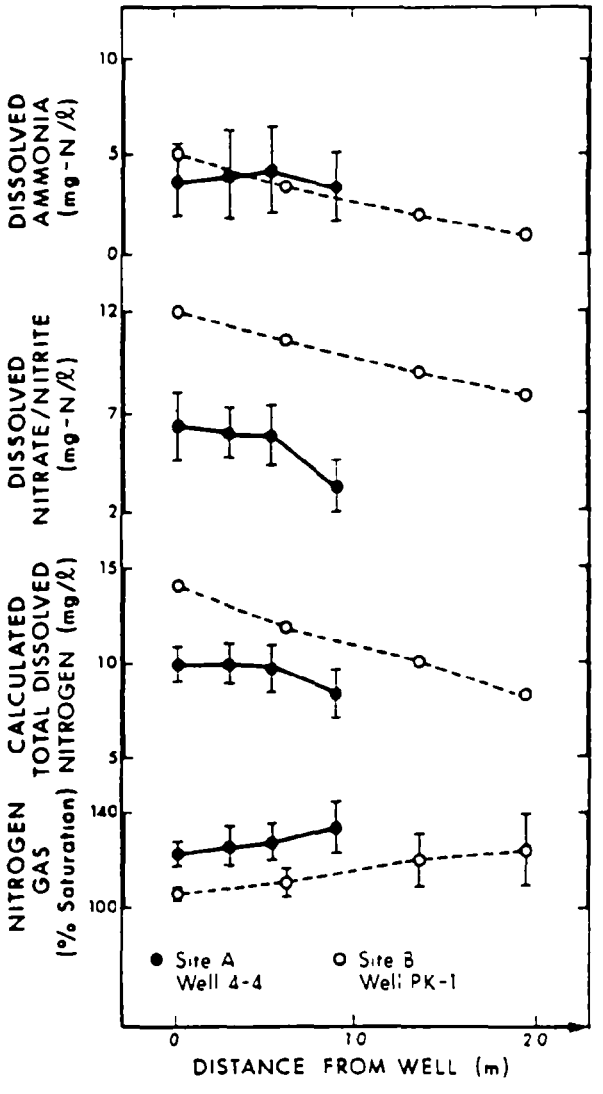

Fig. 6. Concentration of nitrogen species in pore water vs. distance from well.

the presence of organic matter, nitrate + nitrite can be removed from a system by bacterially mediated denitrification producing nitrogen gas, as shown by the reaction,

$$CH_2O + 4/5\ NO_3^- = 2/5\ N_2 + HCO_3 + 1/5\ H^+ + 2/5\ H_2O \quad (4)$$

Because of the source/sink relationship between ammonia and nitrate + nitrite, total dissolved nitrogen (TDN) should be considered when evaluating nitrogen removal from an aqueous system The TDN provides a measure of the dissolved organic, ammonia, and nitrate + nitrite nitrogen in the system, but not the gaseous forms. The TDN curves show significant decreases outward from the wells, as do the ammonia and nitrate + nitrite curves Since nitrogen loss to cation exchange or bacterial uptake should be minimal in the quasi-steady-state system after one to two years of injection, the only reasonable cause for nitrogen removal from the TDN is denitrification In Well 4-4 most of the decrease takes place in the zone between 0 53 and 0 91 m (the zone where most of the clogging occurs), while at PK-1 the decrease appears to occur uniformly over the 2 m radial distance monitored

Nitrogen gas, the end product of denitrification, increases in concentration with distance outward from the well. The data were somewhat erratic due to the difficulty of sampling for nitrogen gas without contamination by atmospheric nitrogen The decrease in TDN, however, provides a positive indication for nitrogen gas production by denitrification. Furthermore, methane gas was also detected in some of the pore waters at site A at concentrations up to 1 5 mg/ℓ Methane production occurred primarily in those zones where there was a major decrease in TDN. Methanogenic bacteria are strict anaerobes and produce methane gas only in strongly reducing environments Again, this is a strong indication that these bacterial reactions take place in microenvironments as the methanogenic bacteria could not tolerate the oxygen in the bulk pore water It also indicates that enough exchange occurs between microenvironments and bulk pore water for the anaerobic microenvironment processes to affect the bulk pore-water quality Thus, while the amount of methane detected was small, it is qualitatively significant because, thermodynamically, denitrification should precede methane production So while methane in itself does not make a significant contribution to clogging, its presence is important as an indication that denitrification reactions are likely to be taking place.

The injectant was well aerated during treatment and could expectedly be close to nitrogen gas saturation. As nitrogen gas concentration increases because of denitrification, the N_2 will become supersaturated (saturation is approximately 14 mg/ℓ at pore-water temperature of 25°C and pressures found in the injection formation). A portion of the nitrogen gas will come out of solution and form gas bubbles. The gas bubbles can cause gas binding of the porous medium by blocking the pores in the same way that a particle would Lance and Whisler (1972) and Rice (1974) concluded that the major reduction in hydraulic conductivity observed in soil columns saturated with secondary-treated effluent was caused by nitrogen gas binding Nitrogen removal from Lance and Whisler's columns averaged 34%, which is approximately the amount removed up to the farthest-out observation well at both sites.

Using the total dissolved nitrogen results and typical flow rates, crude calculations were made as to how fast nitrogen gas production could cause clogging of the aquifer. Calculations for Well 4-4 indicated it would take roughly 60 days for the zone between 0 5 and 0 9 m to become completely gas bound and about 30 days for its porosity to be reduced by 50% Since it is quite likely that some of the bubbles escape, these time periods are probably too short, but they should give an idea of magnitude for the rate at which clogging would occur They also match well with the measured rates of clogging at this site.

CONCLUSIONS

Under the conditions that prevailed during this study (injection of secondary-treated sewage effluent into carbonate receiving formations) filtration of suspended solids does not appear to be a long-term cause of clogging, a finding contrary to results commonly reported in the literature Although filtration was not a long-term cause of clogging, it is very likely to have short-term clogging effects An interpretation that is consistent with our data is that in the first days after the start-up of effluent injection, the head gradient that was observed to increase in the region immediately adjacent to the well was most likely due to the filtration of injected suspended solids in that region The microbial population was not yet established and thus could not biodegrade the largely organic injected particulates After the bacterial colony established itself over the first few

weeks of injection, two significant changes that affect clogging occurred. First, the bacterial population immediately adjacent to the well metabolized all of the injected particulate organic matter, thus removing much of the clogging from this region where all of the clogging initially took place. Second, when the denitrifying bacteria became sufficiently well established, they produced significant amounts of nitrogen gas, which resulted in a gas-bound zone farther out in the aquifer This was revealed by the steep head gradient which became established over half a meter out from the injection well in a zone where there was originally almost no head loss. With continued injection, the nitrogen gas-bound zone slowly extended farther out into the injection stratum Superimposed on this, but with its effects masked in part by the gas binding, was dissolution of the carbonate porous medium The increase in permeability that resulted from carbonate dissolution in the non-gas-bound region near the well caused the flattening of the head gradient immediately adjacent to the injection well The high degree of clogging created farther out in the aquifer by denitrification overrode the permeability increase caused by carbonate dissolution, and the wells underwent major losses of injection capacity. While this is not the only possible scenario for clogging to occur, it is strongly supported by repeated patterns at both of the injection sites studied and certainly warrants further investigation.

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June A Oberdorfer received a B A. from Brown University in 1970, studied Geology at the University of Stockholm, Sweden in 1976-77, and received a Ph D in Hydrogeology from the University of Hawaii in 1983 She presently is Assistant Professor of Hydrogeology at San Jose State University, California

Frank L. Peterson received a B A in Geology from Cornell University in 1963, and an M S in 1965 and a Ph D in 1967 from Stanford University in Geology/Hydrology Since 1967 he has been on the faculty of the University of Hawaii in Honolulu where he presently is Professor of Hydrogeology and Chairman of the Department of Geology and Geophysics, and Researcher with the Hawaii Water Resources Research Center

SECTION 5

Mineral and Fossil Fuel Recovery Related Wells

Section 5.1

Mining, Sand, or Other Backfill Wells Supporting Data

SECTION 5.1.1

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Inspection of slurry injection procedures at the Old Darby Mine Works (or Black Mountain Mine)
AUTHOR: (OR INVESTIGATOR)	USEPA Region III
DATE:	March 30, 1985
FACILITY NAME AND LOCATION:	Powell Mountain Coal Company - The Bonny Blue Site, Big Stone Gap, Virginia, USEPA Region III
NATURE OF BUSINESS:	Coal preparation

BRIEF SUMMARY/NOTES: The facility utilizes strategically located and hydrogeologically suited abandoned underground mine workings as a settling basin where coal fines can separate out of preparation plant wash water. Wash water is discharged into the upgradient end of the mine workings via injection wells. Water is pumped from the workings at the down-gradient end and recycled for coal preparation.

A state permit was granted in February 1984, at which time underground injection of coal preparation refuse was initiated. A wet cleaning process during coal preparation produces refuse and a coal "fine", which is approximately 30% solids, at a rate of 30 ton/hour. Injection of this material occurs only during wet weather, when surface disposal into a refuse pile (covered under an NPDES permit) is not feasible.

The disposal site is the abandoned workings of the Old Darby (Black Mountain) Mine. Surveys conducted by the operator indicate that the estimated 100 feet of sandstone overburden is stable, and that total storage volume is about 3.1 million cubic feet. The mine is totally sealed with only one discharge point.

The injection slurry is monitored weekly for flow, pH, and suspended solids. Acidity, alkalinity, total iron, total manganese, sulfate, ammonia, nitrate, nitride, and total dissolved solids are monitored on a monthly basis. Two downgradient monitoring wells are located downgradient from the abandoned workings (about 10 feet below the coal seam). Monthly reports on operations and discharges are submitted to the Division of Mined Land Reclamation and the State Water Control Board.

March 30, 1985
Ref: 8402-040-94015

SUBJECT: Powell Mountain Coal Company
(The Bonny Blue Site)

PURPOSE: Inspection of slurry injection procedures at the Old Darby Mine Works (or Black Mountain Mine) in Big Stone Gap, Virginia

INTRODUCTION

On Tuesday, March 5, 1985, SMC Martin met with the Virginia Division of Mined Land Reclamation (DMLR) in Big Stone Gap, Virginia. In attendance were Christopher Agoglia of SMC Martin; and Sam Easterling, Lynn D. Haynes, Mark Trent, Jerry Brown, Terry Brown, and Tina Stephens of DMLR. The meeting served a twofold purpose: 1) to familiarize SMC Martin with the Powell Mountain plant and injection operation; and 2) to explain to DMLR the purpose of this EPA Region III investigation. The DMLR had on file and readily provided extensive information on the operations of the Powell Mountain Preparation Plant. That information was reviewed, collected where pertinent, and is summarized in this report.

On Wednesday, March 6, 1985, SMC Martin met with Mark Trent, DMLR Geologist, for a tour of the Powell Mountain Bonny Blue Site. Mr. Agoglia and Mr. Trent met with Mr. John Paul Jones, Environmental Engineer, Powell Mountain Coal Company, Inc., to briefly present the objectives of this study and to tour the site.

The Powell Mountain coal preparation facility is unique in that it is able to utilize strategically located and hydrogeologically suitable abandoned underground mine workings as a giant subsurface settling basin where coal fines can settle out of preparation plant wash water. The plant discharges wash waters into the abandoned workings on their upgradient end via injection well, hence EPA Region III's interest in the facility (EPA administers Virginia's Underground Injection Control program). Before injection, a flocculant is added to these wash waters to facilitate settling of the suspended coal fines. Upon injection into the workings, the preparation plant wash waters migrate downgradient through the workings, the coal fines settling out during the process. On the downgradient side of the workings, the water is pumped from the workings for

recirculation through the coal preparation cycle. By this time, the fines have settled out and the water can be reused with little or no special treatment. Built into this "closed loop" system, as will be described below, are numerous safeguards designed to monitor and protect surface water and ground-water integrity.

SITE GEOLOGY

The rocks outcropping in and adjacent to the permit area are contained within the Wise Formation and are of Pennsylvanian age. There are two principal coal seams outcropping within the permit boundaries--the Creek (No. 6) and the Darby (No. 5) coal beds. Other thin, inconsistent seams are also locally present.

The strata at the site are representative of cyclic sedimentation dominated by thick, massive sandstone with lesser amounts of shale, sandy shale, coal, and underclay. The sandstones are gray, fine to medium-grained micaceous, cross-bedded, and poorly sorted. The grains are subrounded to angular with a matrix of fine rock fragments and occasionally with feldspar and other detrital minerals, making up greater than 15 percent of the total rock volume. They contain low interstitial porosity and varying degrees of secondary porosity as well as permeability. These same sandstones constitute the 100 feet of overburden above the Old Darby Mine Works.

The shale, sandy shales, and underclay contain greater than 75 percent matrix material. These are nonbedded to thinly laminated and sideritic. The underclays are highly rooted and generally plastic. Except for the underclays, these rocks are slightly porous to porous; but because these pore spaces are not interconnected, they are generally impermeable to ground-water flow. The underclays are nonporous or permeable.

Regionally, the strike and dip of the strata are highly variable. In the immediate permit area, strike is Nw-Sw and dip is to the northwest at approximately 3 percent. There are no known structural faults in or adjacent to the permit area.

The map in Appendix B shows a ground-water flow diagram of the abandoned mine workings generated from borehole data. The ground-water flow direction, according to this map, is northwest

toward the downgradient end of the mine workings. As this portion of the workings is deep within the mountain, there are no exit points for mine waters on the upgradient side of the workings.

OPERATION DESCRIPTION

Preparation Plant

The Powell Mountain Coal Company built the Bonny Blue Coal Preparation Plant in early 1981, and on November 2, 1981, the first coal load passed through the plant. The initial coal waste disposal system was a refuse or spill pile adjacent to the plant. Drainage problems arose during inclement weather and continued to plague the area around the refuse pile quite frequently. Therefore, on January 31, 1984, Powell Mountain Coal submitted a permit revision to initiate slurry injection into the nearby Old Darby Mine Works (or Black Mountain Mine). The permit was reviewed by the DMLR and the State Water Control Board and, after some revisions, was approved. In late February 1984, underground injection of coal preparation refuse began.

The plant produces a high grade, low sulfur coal product. Final clean coal yield from the system is about 70 percent of raw coal input. The remaining 30 percent of raw material removed during the processing consists of high sulfur coal and rock impurities. This refuse product is placed on the refuse pile where it dries out and is reworked into the landscape.

The wet cleaning process also produces a refuse and coal "fine" slurry which is approximately 30 percent solids by weight at a rate of about 30 tons per hour. The slurry can be and generally still is placed on the refuse pile during dry weather. However, during periods of wet weather or drainage problems, the slurry is injected into the disposal mine.

Underground Disposal Site

The injection disposal "site" for the Bonny Blue Coal Preparation Plant is the abandoned underground room and pillar workings of the Old Darby or Black Mountain Mine. The Old Darby Mine workings were surveyed by Powell Mountain Coal Company to

estimate total holding capacity. Many of the pillar supports in the workings had reportedly been removed in the later stages of the mines's operation. This factor was significant in determining mine capacity. Although it increased the available volume of storage capacity, removal of these roof support pillars greatly increases the likelihood of cave-ins which could reduce the mine capacity. In the case of these specific abandoned workings, it is believed by Powell Mountain Coal Company that the 100 feet of sandstone overburden above the mine workings is sufficiently stable to stay intact despite the noted pillar removal. On the basis of these considerations, the abandoned mine's storage capacity was estimated at slightly over 3.1 million cubic feet.

Because of its location and physical layout, it was possible to totally seal off the Old Darby Mine leaving a single mine discharge point #4 (see Appendix A). This point, which used to be a large opening, was sealed with the exception of two 4-inch steel pipes, and dictates the "high water" point within the mine workings, preventing excessive pressures from being placed on the sealed entries farther downgradient that now constitute a part of this mine pool's confining wall or barrier. Under normal conditions, the water level in the workings never reaches this elevation, thus there is no surface discharge.

MONITORING

The map in Appendix A shows the locations of the wells, the preparation facility, and the adjacent abandoned mine workings. Well P-18B, located in the extreme downgradient end of the mine, is the makeup water supply well for the coal preparation plant. This well essentially closes the "loop" in the preparation plant's water supply/treatment system. The 15 HP pump on Well P-18B is set to turn on automatically, even when water is not required by the preparation plant, if the water level in the mine reaches a predetermined high water level. Note that the pipe discharge point mentioned earlier is also at this high water level as a secondary precaution to insure that water levels in the workings do not rise excessively. If water is not required by the preparation plant and the water level in the abandoned workings reaches this high water level, the automatic switch still turns the pump on, but the water is diverted to

either a large surface storage tank (capacity unknown) or a small settling pond (approximately 100 feet in diameter and 6 feet deep) until the plant requires water once again. There is a manual override cutoff switch to turn the pump off, if needed. There is also a field treatment system that can adequately handle any water overflow from the tank or pond, should either of these become full. Water would be allowed to discharge from point 4 only in an emergency, if needed, to maintain the integrity of the mine pool barriers. Note that a monitoring schedule for this plant supply well is specified in the facility's NPDES permit.

The slurry being injected is sampled and analyzed for flow, pH, and suspended solids weekly. On a monthly basis, the slurry is also tested for acidity, alkalinity, total iron, total manganese, sulfate, ammonia, Nitrate, Nitride, and total dissolved solids.

Two wells, numbered P-18J and P-18O, are located downgradient from the abandoned workings and approximately ten feet below the coal seam. These wells are monitored according to the NPDES permit to determine the hydrogeological impact of the mine pool/slurry disposal operation on the ground water adjacent to the abandoned mine. Baseline samples were taken from each of the wells before injection started, and the results were used in compiling the NPDES permit.

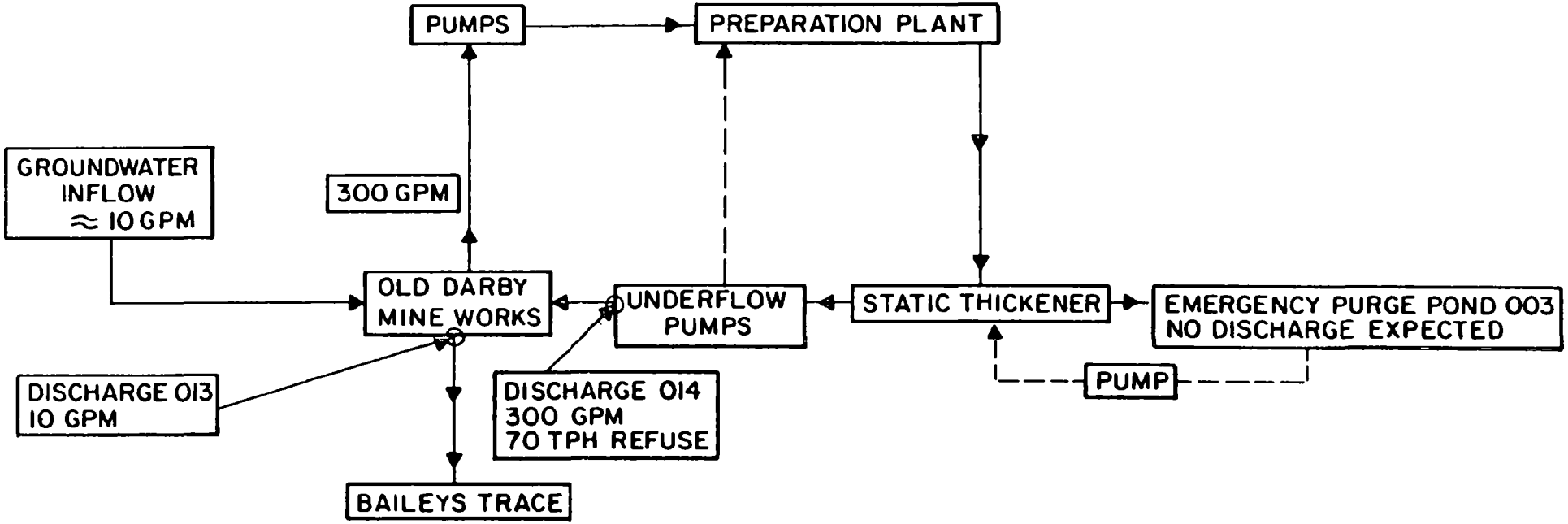
All samples are grab samples and all analytical results are included in a monthly report which is sent to the DMLR and the State Water Control Board. All sample analyses are conducted by Powell Mountain Coal Company.

In addition to the underground slurry disposal system noted above, this coal preparation facility also utilizes a refuse pile to dewater and store the coarser coal refuse or reject material. Roughly 30 percent of the raw material run through the preparation plant is very high in sulfur content and is ultimately sent to the refuse pile. The pile has a dike completely around it with proper drainage facilities. The refuse pile runoff is monitored and checked periodically, and if it exceeds surface water disposal limitations set up by the Water Control Board, it is treated before release to the receiving stream.

If any problems occur in the monitoring or treatment systems at Powell Mountain, the maintenance staff must immediately report the incident to management who in turn report it to the DMLR and the Water Control Board. After the problem has been resolved, a full report is submitted to the DMLR and Water Control Board.

CONCLUSIONS

It would appear, based upon the general information presented in and with this brief report, that the Powell Mountain Coal Company's coal refuse slurry underground injection system is an efficient, well-designed operation with adequate safeguards built in to prevent contamination of both surface and ground waters. The system is a novel design making efficient use of abandoned mine workings that might otherwise represent an environmental problem, rather than a solution to an environmental problem. Monitoring within the system itself and adjacent to the abandoned workings appears adequate for detection of any problems that might develop.



GROUNDWATER FLOW DIAGRAM
FOR THE OLD DARBY MINE WORKS

SECTION 5.1.2

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Inventory and Assessment of the Disposal of Coal Slurry and Mine Drainage Precipitate Wastes into Underground Mines in West Virginia
AUTHOR: (OR INVESTIGATOR)	Diane Smith and Henry Rauch - Department of Geology and Geography, West Virginia University
DATE:	December 1986
FACILITY NAME AND LOCATION:	West Virginia, USEPA Region III
NATURE OF BUSINESS:	Not applicable

BRIEF SUMMARY/NOTES: The emplacement of slurry waste from coal preparation plants and sludge resulting from treatment of acid mine drainage into underground mines is the most widely practiced Class V activity in West Virginia. Slurry waste is produced when bituminous coal is processed to reduce levels of sulfur and other impurities. Acid mine drainage, once produced, is often neutralized by alkaline materials, causing dissolved metals to precipitate. The resultant sludge is composed of hydrated iron oxyhydroxides and other metallic oxyhydroxides.

Previous studies conducted by EPA Region IV included a site in Kentucky where waste disposal of this type potentially threatened a drinking water supply withdrawn from the same mine into which slurry was emplaced. A study conducted in Virginia demonstrated no effect on groundwater from this type of disposal, whereas an Ohio study demonstrated a case where sludge and water injected into a mine actually improved groundwater quality.

For the West Virginia study, two sludge injection sites and one slurry injection site were chosen for site investigations. Samples of waste sludge or slurry were taken along with water samples of mine discharges. Water samples were analyzed for parameters addressed in National Primary and Secondary Drinking Water Regulations. Sludge and slurry samples were studied using various elemental and mineralogical analyses.

Results of inventory efforts in this study revealed that approximately 46 companies have practiced underground disposal of sludge and slurry at 65 different projects in West Virginia. Some projects were begun as early as 1958. Methods of waste emplacement include gravity or pressurized injection into boreholes, air shafts, or drift openings. Slurry injection was shown to generally increase water quality within mine pools, whereas sludge injection generally caused an increase in iron, manganese, and total dissolved solids.

A PRELIMINARY SUMMARY REPORT

INVENTORY AND ASSESSMENT OF THE DISPOSAL OF COAL SLURRY AND MINE DRAINAGE PRECIPITATE WASTES INTO UNDERGROUND MINES IN WEST VIRGINIA

by: Diane Smith and Henry Rauch
Department of Geology
and Geography
West Virginia University
Morgantown, WV 26506

December, 1986

Submitted to: Mr. David Long
Underground Injection
Control Program
Division of Water Resources
1260 Greenbrier Street
Charleston, WV 25311

INTRODUCTION

Definition and Scope of Problem

The emplacement of coal mining wastes into underground mines is a practice which is performed by some coal companies in the state of West Virginia, and somewhat less commonly in neighboring states. Such underground disposal is of concern to the United States Environmental Protection Agency (EPA), as it falls under jurisdiction of the EPA's Underground Injection Control (UIC) program.

As mandated by EPA, all UIC activities are to be assessed to determine their extent and their probable hydrologic impact. It is regard for the maintenance of good ground water quality that prompted EPA officials to institute the UIC program. Any ground water which contains < 10,000 ppm TDS (total dissolved solids), is considered as a potential future underground source of drinking water by EPA. In West Virginia, the state Department of Natural Resources (DNR), administers the UIC program for the federal government. Federal UIC regulations have been adapted for West Virginia as Chapter 20, Article 5A of the 1983 (Series IX) West Virginia Administrative Regulations of the State Water Resources Board. Section 4.00 of these regulations

rigidly defines four classes of fluids which may be injected or emplaced underground. The fifth class of possible injected fluids covered by the UIC program includes the injection of any fluids not covered in the other four classes.

After the effective date of the regulations pertaining to the UIC program in West Virginia (1-9-86), it was determined by DNR that the most widely practiced Class V activity in the state is the emplacement of slurry waste from coal preparation plants and sludge resulting from treatment of acid mine drainage into underground mines.

This study attempted to fulfill two objectives, as requested by DNR:

1) To conduct an inventory of the past and present practice of the disposal of slurry from coal preparation plants and sludge from mine drainage treatment into underground mines in the entire state of West Virginia for at least the most recent calendar year.

2) To assess the probable hydrologic impact of this activity by using information gained by collecting data for the inventory.

Background

To reduce sulfur content, and levels of other undesirable impurities, bituminous run-of-mine coal is often prepared or processed to render the coal suitable for its intended use. Two waste product materials are created by this process; fine coal slurry (<1/16 inch diameter particles) and coarse gob (>1/16 inch diameter particles). The slurry is composed mainly of fine coal particles and some fine mineral matter. Buttermore, Simcoe and Maloy (19--). It is of concern in this project, as it is sometimes pumped into underground mines as a means of disposal. Likewise, acid mine drainage, once produced, is often neutralized by alkaline materials, as per state regulations, so that concentrations of metals originally dissolved in the water are precipitated out of solution as the pH is increased. This process results in the production of sludge, which is an accumulation of the solids which were precipitated out of the original mine drainage. Thus, the solids in the sludge (which usually comprise less than 10% of the total volume) are largely composed of hydrated iron oxyhydroxides and other hydrated metallic oxyhydroxides. Simonyi, Akers and Grady (1977). The sludge is also sometimes emplaced into underground mines as a means of disposal.

As far as it is known, no research such as this, which emphasizes concern for the possible hydrologic impact of the underground emplacement of slurry or sludge has ever been performed. Still, many references in the literature were of value in this project, as they dealt with related topics, such as the nature of slurry and sludge wastes. Other references did discuss the underground disposal of mining wastes, but did not address the hydrologic effects of the practice in detail. Some of the most useful references came not from published reports, but from verbal communication with officials in states adjacent to West Virginia or unpublished reports of investigations by private consultants or government agencies. It was learned through these sources that the injection of slurry and/or sludge has occurred to some extent in Pennsylvania, Ohio, Kentucky, Virginia, and Illinois. Heine and Associates (1983), Moody and Associates (1986), U.S. EPA Region IV (1985), Haynes (1986 personal communication) and Oertel (1986 personal communication). Although no other neighboring states are conducting inventories such as this, it seems that the officials in those states believe that underground disposal is much more widely practiced in West Virginia than in any other state. Oertel (1986 personal communication), Haynes (1986 personal communication)

and Schuster (1936 personal communication).

EPA Region IV reports of investigations documented the history of a very controversial slurry injection operation located in Kentucky. EPA investigators had concluded in this case that the slurry injection did pose a possible threat to a drinking water supply withdrawn from the same mine into which the slurry was emplaced. U.S. EPA (1985). A slurry injection site in Virginia, on the other hand, did not seem to display any obvious changes in water quality, according to Haynes (1986 personal communication). No monitoring sites located downgradient of this slurry injection ever fell out of compliance with state water quality standards.

A mixture of sludge and water from the Ohio River was injected into a mine in Ohio, resulting in an apparent improvement in the quality of the mine pool into which it was injected, although of course the influence of the river water probably had much to do with this. Moody and Associates (1986). A sludge injection operation in Pennsylvania began to show long-term improvement in mine pool water quality after sludge injection began according to Heine and Associates (198_).

It is apparent from these few examples that the possible impact of slurry and sludge disposal into

underground mines is not clear and is worthy of examination. The variations in geologic and hydrologic settings of underground mines used for disposal and the original water quality within the mine as well as the compostion of the injected waste, is of course, of utmost importance in this evaluation and will vary with location.

Scope of Summary Report

The intent of this summary report is to bring the West Virginia Department of Natural Resources (DNR) and the U.S. Environmental Protection Agency (EPA) Region III Headquarters up to date on the progress of a major portion of the West Virginia Class V well assessment. This report does not include tables and figures showing raw or summary data and detailed results. The final report will include all such figures and will also provide more refined interpretation of data analysis results than is presented here.

METHODS OF INVESTIGATION

Inventory Study

In order to develop an adequate data base for this project, it was decided to review information already available to the state of West Virginia as a first step in compiling inventory data. It was determined early after the beginning of this process, that to prepare the most accurate inventory possible, all coal companies which operate underground mines should be contacted and questioned as to their underground disposal practices. To accomplish this, a series of questionnaires were prepared and mailed to pertinent coal companies to determine first which companies utilized underground disposal, and then to seek specific detailed information pertinent to the assessment portion of the study for any facilities where the disposal of slurry and/or sludge in underground workings had ever occurred. Hereafter, a company which utilized or now utilizes the method of underground mine disposal of slurry and/or sludge will be said to have been operating or be operating disposal projects. The term disposal project will also be used to reference these Class V activities at specific sites.

State National Pollutant Discharge Elimination System (NPDES) permit files on coal preparation plants, acid mine drainage treatment plants, and underground mines were first examined for any information which would be applicable to assessing potential hydrologic impacts of waste disposal for this study. Any files examined prior to receiving replies to initial questionnaires sent to the companies were of cases originally known to Mr. Steve Meador, an engineer in charge of reviewing NPDES permits for mine companies for the West Virginia Department of Energy (DOE).

Prior to the initial examination of the NPDES permit files, a preliminary mailing of a brief questionnaire called for all companies operating underground mines to supply volumetric information for all wastes disposed of into the underground mines in the years 1980-1986. Company names, addresses and mailing labels were supplied by the Mines and Minerals Division of the West Virginia Department of Mines for 953 facilities (including 149 preparation or loading facilities and 814 underground mines) for this preliminary mailing.

As these preliminary inventory responses were received, it was realized that clarification of many replies was necessary. It was then decided that no particular year should serve as a cutoff point, before

which no information should be sought, instead the entire history of disposal of slurry and sludge was sought under the constraints of time, money, and availability of records and/or knowledgeable persons. Thus, for all ambiguous replies concerning past waste disposal projects, phone calls were made to the pertinent companies to determine with certainty whether underground disposal had been used prior to 1980 or not.

After a reasonable time period beyond the deadline stipulated in a cover letter accompanying the preliminary questionnaire, responses in reference to approximately 415 facilities had been received; this represented less than one-half of the 963 facilities to which inquiries were addressed. Approximately eight weeks elapsed during this time. Response was limited, due in part to the ambiguity of whether or not companies which did not utilize underground disposal were obliged to respond.

After it became evident that all companies which planned to respond to the preliminary questionnaire had done so, an official State memorandum from the DOE was mailed to the companies which had not responded to the first mailing. The memorandum was mailed approximately eleven weeks after the initial mailing of the preliminary inventory. This made it clear that

responses from all companies were expected, regardless of whether they utilized underground disposal or not, and that replies should clearly state what involvement the company had had at any time with disposal of slurry or sludge underground. After the deadline dictated in this memorandum, approximately 205 companies, responsible for 259 facilities (24 preparation plants or loading facilities and 235 underground mines), still had not responded, and many replies still needed clarification.

An attempt was then made to contact by telephone each of the 205 companies which had not responded to either mailing. After contacting various state agencies (West Virginia Department of Energy, and the West Virginia Geological and Economic Survey), it was discovered that these agencies do not maintain reliable current telephone numbers for coal companies, as the state of flux in the industry would make it a very time consuming endeavor to do so. The most reliable source of current telephone numbers for these outstanding companies was discovered in local telephone books and from telephone operators. After researching telephone numbers, approximately 68 additional companies were contacted.

In another attempt to contact companies with responses still outstanding, addresses of 53 mining

consulting firms in West Virginia were obtained from local telephone books, and each was mailed a letter listing several coal companies in their immediate area, requesting that they either reveal any companies on the list that had utilized underground disposal, upon the permission of that company, or reveal information on how to contact the companies. These letters resulted in the revelation of two underground disposal projects previously unknown, and in the contact of approximately five additional companies in reference to 17 underground mines.

Letters were also sent to addresses of approximately 75 public water suppliers in West Virginia which derive their supply from underground mines. This letter asked system operators to indicate whether their water supply, or any other flooded mine that they knew of, had ever had mining wastes injected into it. These letters resulted in an extremely poor response.

After these efforts, 136 companies responsible for 155 facilities (12 preparation plants or loading facilities and 143 underground mines) had not been contacted. To determine if any had ever disposed of waste into underground mines, Mr. Steve Meador, an engineer of DOE, agreed to provide copies of a list of these companies to the state mine inspectors for their

comments on the status of the Class V injection well activities at the facilities under their jurisdiction. After this task was completed, the inventory portion of the study was to be considered complete. Unfortunately, this task never was completed, leaving some doubt as to whether these remaining companies had utilized underground disposal of mining wastes.

A detailed questionnaire was then prepared and mailed to gain information on each disposal project that had been revealed by the preliminary questionnaire. The content of this questionnaire was greatly influenced by the recommendations found in Meador (1983) and by brief NPDES questionnaires. Information was sought on the technique of mine waste disposal, the mine used for disposal, the hydrologic setting of the mine used for disposal, water quality information for mine discharges (if the data were deemed representative of the mine pool water quality), the source of the waste, and the problems with and effects of disposal. Pertinent information on the analyses, volumes and means of assessing the impact of the injected waste, was thereby obtained, when it was available and when companies completed the detailed questionnaire. At this point, although 58 disposal projects were known, detailed questionnaires could only be sent to inquire upon approximately 55 of these as

three companies were untraceable. Thus, 61 questionnaires were sent to 48 companies. Detailed information requests on certain disposal projects were mailed to more than one company in some cases when it was known that more that one company had occupied a site, or that one company had been responsible for the operation of a preparation plant or acid mine drainage treatment facility, while another company had operated the mine used for disposal. Out of these detailed questionnaires that were mailed, 30 were received completed to some extent. It was after receiving questionnaires that five additional disposal projects were created, when it was learned that different mines or sections of a mine were being used for disposal. Also, one disposal project was taken off the list after one company verified that they had not disposed of slurry underground when previously, it was believed that they had. Despite repeated phone calls to company officials urging them to finish and return the detailed questionnaires, the remaining questionnaires never were received.

The accuracy and completeness of the inventory prepared for the Underground Injection Control (UIC) program were the highest practically obtainable. The coal industry is in a state of constant flux in West Virginia, and the operation of coal preparation plants,

acid mine drainage treatment plants, and underground coal mines frequently changes ownership. Thus, information on underground disposal which may have been practiced before the present facility owners commenced operations is often very difficult to obtain. Even if former owners, operators, or company officials can be contacted in some of these cases, they are reluctant to provide anything but minimal information on any activities for which they are no longer legally responsible. Also, in the case of companies which have gone out of business, and/or left abandoned facilities behind in years prior to abandonment regulations, virtually no information exists on any aspect of the original facility; even such vitals as the whereabouts of former owners of the facility, much less information on underground disposal. Finally, the possibility of dishonest answers to questionnaire forms does exist, albeit hopefully slight. Negative replies to queries involving revelation of underground disposal of slurry or sludge were not field checked in any way. One operator indicated by telephone that it would be very easy for a company to dispose of waste underground surreptitiously.

Numerous unexpected delays have affected the timely completion of this project. Difficulties were encountered in obtaining detailed inventory responses

from the coal industry. Over three-quarters of the information obtained was received one to two months after the stipulated deadline (which had allowed four weeks for response). In many cases, the companies had to be contacted repeatedly to urge them to send in their inventories and later to clarify some of the information they finally did supply.

Assessment of Inventory Data

To assess the hydrologic impact of slurry and sludge disposal into underground mines, it was necessary to have water quality data to examine. Whenever sufficient water quality information was obtained from the mine inventory data, a comparison was made between mine waters not affected and potentially affected by the waste injection. Water quality data were compared between pre-waste-injection time periods and post-waste-injection time periods for the same sampling points located downgradient of waste injection sites, or post-injection water quality data were compared between points upgradient of the waste injection location and points downgradient of the waste injection location. Monitoring points were determined to be upgradient or downgradient of waste injection sites by examination of topographic maps and structure

contour maps for the mined coal seam, or by an understanding of the underground piping systems in some cases. In all cases, it was indicated by a company official that no complicating variables which could bias results were known to exist. All of the comparisons were made from existing data, knowing that many variables which could possibly affect results could not be accounted for with certainty. The water quality monitoring points used in the above comparisons were either dewatering wells or gravity mine discharges and all those used were deemed to be indicative of the mine pool water quality by key personnel of the company which operated the mine. Avoided were pumps located in air shafts which in some cases divert water from shallow aquifers into the mine pool at that location; although such pumps would produce water from the mine level, they would not be indicative of the quality of the actual mine pool because of mixing effects.

The Mann-Whitney U test, a powerful nonparametric statistical test which determines the liklihood of two samples having come from the same population, was employed to statistically make the water quality data comparisons. The Mann-Whitney U value was obtained by use of a Basic computer program, which was translated into Fortran by Mr. Randy Crowe, an electronic and computer technician for the Geology and Geography

Department of West Virginia University, for use on the Geovax computer system available to that department. Another algorithm written in Fortran by Mr. Crowe, computed T values for all comparisons, so that correction for rank ties was employed in all cases. One example done by hand was used to check the results obtained by both programs to ensure that the programs were working correctly. As referenced in Siegel (1956), depending on the number of observations (water samples) in the larger data group involved in the comparison, either an exact probability, a critical U value, or a z probability was determined so that the significance of the U value could be determined.

In the case of mines for which no water quality data were available, all information obtained was simply organized, sorted, and tabularized in various ways, so that the inventory data will be available for use to interested parties in the future. The appendices of the final report will contain this information, and private files are available from this study for use of State agencies on every mine in West Virginia which this study disclosed as having ever had slurry or sludge deposited into it, (although, in some cases, the information is scant).

One potential problem associated mainly with the disposal of slurry waste resulting from coal

preparation is contamination of mine waters by chemicals used in the preparation process. An understanding of what types of chemicals are used is vital as they would become emplaced into an underground mine used for disposal, along with the slurry. Most coal companies stated that they know only the "N-derivative" name, a trade name used by Dow Chemical Company, Inc., when asked what type of frothers and flocculants are utilized at the coal preparation plant they operate. An attempt was therefore made to gather information from Dow Chemical Co., Inc., which would have revealed the generic names of chemicals used for processing coal in preparation plants. Although no additional information was obtained, data already compiled by Mr. Steve Meador of the West Virginia DOE were organized and presented in tables for the final report for the purpose of providing some information on these chemicals and their possible behavior in the mine environment. Other trade name chemicals known to be used in coal preparation are supplied by American Cyanamid, Inc., Nalco Chemical Co., and Union Carbide. Any information obtained on these chemicals was also included in the appendices for the final report.

Assessment of Mines Used for Detailed Study

It had been agreed upon, before commencement of work on this project, that field investigations of two to four sites would take place to better evaluate the hydrologic impacts of the underground waste disposal. Shortly after the research began, it was decided that an attempt would be made to study a northern coalfield slurry injection site, a northern coalfield sludge injection site, a southern coalfield slurry injection site, and a southern coalfield sludge injection site. It seemed that the natural geographic division between the northern, high sulfur coalfield and the southern, low sulfur coalfield, as well as the two basic waste types being investigated, lent themselves well as useful criteria by which to guide the intitial site selection process.

Site selection criteria also included the following:

1) The company must be willing to cooperate with the project.

2) Water quality data must be available for either pre- and post-injection time periods, or for upgradient and downgradient points with respect to the point of injection.

3) A sample of waste which is injected into

the mine must be available.

4) Water samples of points located upgradient and downgradient of the injection site, must be available.

It was with difficulty that mines suitable for the detailed site investigations were located. Approximately two months of screening sites, asking for permission to study sites (which often required formal written requests), and waiting for the decision of the main company offices was spent on this task. After contacting 15 companies in reference to 32 facilities, it became apparent that certain compromises of these criteria would have to be made, so that the field work could be undertaken. Three sites, one northern coalfield sludge injection site, one southern coalfield sludge injection site, and one southern coalfield slurry injection site, were eventually selected for detailed study. A northern coalfield slurry injection was never selected as the few that exist were either complicated by other factors or the company which operated them was uncooperative. When permission to use these three mine sites was finally granted by the companies and the other selection criteria were satisfied to some degree, at least one sampling trip

was made to each selected site. For each mine, samples of the waste material (sludge or slurry) which was being injected were taken along with water samples of mine discharges or deep wells tapping the mine pool. At a later time in the laboratory, after the solids had settled from the sample of waste material injected into the mine, the supernatent was drawn off and also analyzed. This was done with the help of coal company personnel, especially with gaining access to the sampling locations and selection of the locations.

The first field trip to one of the mine sites proved futile, as prevailing drought conditions and mechanical failures of mine dewatering pumps did not allow any water sampling, although a sample of slurry was obtained. Fortunately at this mine site, (DPN 30) the company representative agreed to collect the necessary water samples; although this was not done according to optimum field techniques, it was necessary for obtaining the samples. The site is located approximately 300 miles from Morgantown, West Virginia, and therefore time and expense constraints prevented the undertaking of repeated site visits by the senior author to determine when the dewatering pumps were operating. After approximately two months, a second trip was taken to the mine site, whereupon it was learned that this site did not satisfy an important

criterion after all; the control mine (unaffected by waste injection) was found to be located in a different coal seam than the nearby mine sampled for waste impact assessment. This fact was not initially known during the first mine visit. Fortunately, near the same site two mines both located within 5 miles of the Kentucky border with West Virginia could provide experimental and control discharges as one mine was used for slurry injection and the other not used for slurry injection. With the exception of slurry injection, the mines are similar in every other way. Therefore, two mines located in Kentucky together comprise the third detailed study site. Although located in Kentucky the geologic and hydrologic settings of this mine are similar to those found in western West Virginia, therefore results should be representative for West Virginia.

Water samples were analyzed for the inorganic chemical parameters listed by EPA for primary and secondary quality standards wherever possible, as well as other selected chemical parameters. Since the protection of possible potable drinking water sources is of interest, extensive chemical analyses were deemed to be necessary. Parameters measured in the field included pH, specific conductance, temperature and flow. Every water sample was split into three factions

as they were taken in the field. One portion was left raw, one portion was filtered and acidified and one portion was acidified but not filtered. The samples were refrigerated in a cooler until they were analyzed. Time-critical analyses such as acidity, alkalinity and nitrate were performed by the senior author at the West Virginia University geochemistry laboratory on a room temperature split of the raw water sample within 24 hours of its collection. Total hot acidity was titrated using approximately 0.02 N NaOH, and alkalinity was titrated using approximately 0.02 N H_2SO_4. Nitrate was determined by use of the HACH Company spectrophotometer. Other water analyses were performed by the COMER chemistry laboratory of Mr. Larry Nice and Mr. Tom Simonyi at West Virginia University or by the chemistry laboratory of Mr. Harry Johnson of the West Virginia Department of Natural Resources (DNR). Sludge and slurry waste samples were subjected to elemental and mineralogical analyses. A list of parameters for which the wastes were analyzed is shown in table 1. The analyses of sludge and slurry were performed by technicians of the West Virginia University and West Virginia Geological and Economic Survey analytical laboratory of Dr. John Renton and by the DNR chemistry laboratory of Mr. Johnson.

The COMER laboratory performed metal analyses of

Table 1. Slurry and Sludge Parameters

% Sodium
% Magnesium
% Potassium
% Aluminum
% Silicon
% Titanium
% Iron
% Manganese
% Zinc
% Strontium
% Phosphorous
% Sulfur

14 Angstrom Clays
Ilite - $K_{0-2}Al_4(Si_{8-6}Al_{0-2})O_{20}(OH)_4$
Coquimbite - $Fe_2(SO_4)_3$
Gypsum - $CaSO_4 \cdot 2H_2O$
Kaolinite - $Al_2Si_2O_5(OH)_4$
Jarosite - $KFe_3(SO_4)_2(OH)_6$
Anhydrite - $CaSO_4$
Szomonolnokite - $FeSO_4$
Quartz - SiO_2
Orthoclase - $KAlSi_3O_8$
Plagioclase - $Ab_{100}An_0$-Ab_0An_{100}
Ab = Albite - $NaAlSi_3O_8$
An = Anorthite - $CaAl_2Si_2O_8$
Calcite - $CaCO_3$
Bassanite - $CaSO_4 \cdot 1/2H_2O$
Dolomite - $CaMg(CO_3)_2$
Siderite - $FeCO_3$
Pyrite - FeS_2

water samples using ASTM method D2576, Metals in Water and Wastewater by Atomic Absorption Spectrophotometry, with a Perkin-Elmer model 2380 atomic absorption spectrophotometer. Titration for chloride was performed by use of ASTM method D512, Method C, Colorimetric Method for Chloride. Sulfate was analyzed by use of ASTM method LN-D516, Sulfate Ion in Water and Wastewater, and TSS (total suspended solids) was performed by ASTM method LN-D1888, Particulate and Dissolved Material in Water.

The Department of Natural Resources performed water analyses by Standard Methods, using a Perkin-Elmer model 503 spectrophotometer for metal analyses. Elemental sludge and slurry analyses, also completed by this agency, were done through the use of Standard Methods, on dried, homogeneous sub-samples.

To prepare sludge samples for mineral group analysis, homogeneous sub-samples were obtained and then subsequently oven-dried. The slurry waste sub-samples were likewise taken and dried and a low temperature ash then prepared; this was done to remove organics and thus prevent interference of organics with the determination of mineral matter composition. The laboratory technicians of Dr. Renton then utilized x-ray diffraction and x-ray fluorescence techniques to provide the information on mineral groups and elements

found in the wastes.

Knowledge of the steady state (equilibrium) effects of sludge and slurry waste on water was desired in order to help make an assessment of the hydrologic impact of waste disposal. Therefore, laboratory tests were designed in order to help determine what kind of interactions may occur between the solid-containing wastes and water. This information was desired to aid in the interpretation of results and to predict future effects of underground mine sludge and slurry disposal on mine waters.

In these laboratory tests, sub-samples of waste material from the visited mine sites were mixed in one set of containers with distilled and deionized water and in another set of containers with samples of mine pool water from parts of the mine which were unaffected by the waste injection. The ratio of water to waste emplaced varied from approximately 5:1 to about 17:1. The samples were contained within buckets or flasks and were covered to prevent evaporation.

These tests were originally intended to be long-term equilibrium tests. However, equilibrium was apparently not reached after a month of occasional stirring and monitoring of specific conductance values for the container samples. By comparison, Schuller, Krapac and Griffin (1981) had achieved solid-liquid

equilibrium in their similar long-term equilibrium tests only after a period of about 21 weeks. This amount of time was not available in our project. Supernatant was therefore drawn off of the samples after at least one month of containment and was analyzed for the same chemical parameters tested on the mine waters as described above. All chemical analysis results will be displayed in an appendix to the final report.

Also, water samples were withdrawn from the supernatant above samples of settled waste material that had been obtained at the mine site. The material from which these samples were derived represented the actual material pumped into the mine. These chemical analysis results will likewise be available in an appendix of the final report. These analysis results were obtained to help document the quality of the water pumped into the mine as part of the slurry or sludge suspensions, since such water may itself potentially cause changes in water quality in the mine.

In addition to the field sampling and laboratory testing done at the mines used for detailed study, statistical testing of pre-existing water quality data was performed. This data had been collected by the coal companies for their NPDES reports. The Mann-Whitney U Test was employed as the means of

testing water quality trends, as described previously in the Assessment of Inventory Data section of this summary report. Data collected by the senior author was not included in this testing. Although monitoring information does not exist on any but a very few parameters, samples obtained from discharges and/or wells located upgradient or downgradient from waste injection points should provide a basis for a one time comparison, on the basis that no other known variables should influence water quality, except for the waste injection.

Some investigation was also done into the hydrogeologic, structural and stratigraphic settings at the three visited mine sites. This examination was undertaken in an attempt to help determine what the potential may be for leakage of mine waters into adjacent aquifers in case the enhanced contamination of the mine pool water from injected wastes had occurred, and to better document the conditions present at the mines investigated.

RESULTS

Inventory Data Assessment

The collected inventory data revealed that approximately 46 companies (or different branches of certain companies) had been known at one time or another to have practiced underground disposal of sludge or slurry in West Virginia. A total of 60 mines are known to have been utilized as repositories for these coal mining wastes. The difference in numbers here reflects not only the fact that one company may use more than one mine for disposal but that, in some cases, transfers in ownership and/or operation of a mine or preparation facility took place. It should be noted, however, that in many cases only the current operator is known.

As described previously, the term disposal project will be used to refer to the emplacement of slurry and/or sludge waste from the mining industry into underground mines. Because the data were entered onto the West Virginia Network computer for the purpose of sorting it and computing some volumetric totals, some mines have been split into separate disposal projects. For instance, if it was clear from data received that

distinctly separate sections of a mine were used for disposal, each mine section was treated as a separate disposal project. Likewise, where both slurry and sludge were emplaced into one mine, two separate disposal projects were created. Thus, 65 disposal projects were defined to most effectively describe these known disposal activities.

From this study, the first year in which sludge was known to have been injected into an underground mine was 1975. The first year of known slurry injection was 1958. It is apparent that an increase in underground disposal of slurry occurred after 1972, the year in which the Buffalo Creek Dam disaster occurred when a large slurry impoundment failed, causing the death of over one hundred people. Davies (1973). The injection of sludge has risen fairly steadily since 1975 which is probably simply a result of increased sludge production as acid mine drainage treatment increased, reflecting increased mined acreage and tougher mining regulations.

In general it is clear that sludge injection occurs primarily in the northern coalfield and slurry injection occurs primarily in the southern coalfield in West Virginia. The absence of sludge injection in the southern coalfield is to be expected, as the low sulfur characteristics of the coal seams commonly mined there

usually produces alkaline rather than acidic drainage. An explanation of the deficiency of slurry injection in the northern coalfield is less obvious. Perhaps companies which operate preparation plants in the north realize that the slurry produced could potentially be acid toxic, whereas in the south slurry is usually naturally alkaline.

Of the 65 disposal projects defined, 41 are located in the southern coalfield and 24 in the northern coalfield of West Virginia. Of the 41 southern coalfield disposal projects, 38 of them are slurry injection sites. Of the 24 northern coalfield disposal projects, 18 of them are sludge injection sites.

Methods of emplacement of waste include gravity or pressurized injection into boreholes, airshafts or drift openings. Slurry injection is generally practiced yearround while sludge injection usually occurs on a semi-annual basis as impoundments are cleaned.

Table 2 shows the approximated total volumes of slurry and sludge known to have been injected into underground mines in West Virginia for each year for which the information exists. A greater than sign indicates that the provided figure is known to be low with certainty when certain companies indicated they

Table 2. ANNUAL VOLUMES OF WASTE PUT UNDERGROUND

YEAR	WASTE	VOLUME (MG/YR)
1958	SLUDGE	0
1959	SLUDGE	0
1960	SLUDGE	0
1961	SLUDGE	0
1962	SLUDGE	0
1963	SLUDGE	0
1964	SLUDGE	0
1965	SLUDGE	0
1966	SLUDGE	0
1967	SLUDGE	0
1968	SLUDGE	0
1969	SLUDGE	0
1970	SLUDGE	0
1971	SLUDGE	0
1972	SLUDGE	0
1973	SLUDGE	0
1974	SLUDGE	0
1975	SLUDGE	>0
1976	SLUDGE	>0
1977	SLUDGE	>10
1978	SLUDGE	>48.66
1979	SLUDGE	>48.66
1980	SLUDGE	>86.46
1981	SLUDGE	>71.36
1982	SLUDGE	>91.6
1983	SLUDGE	>93.29
1984	SLUDGE	>120.02
1985	SLUDGE	122.51
1986	SLUDGE	198.7

Table 2 continued. ANNUAL VOLUMES OF WASTE PUT UNDERGROUND

YEAR	WASTE	VOLUME (MG/YR)
1958	SLURRY	0.1
1959	SLURRY	0.1
1960	SLURRY	0.1
1961	SLURRY	0.1
1962	SLURRY	0.1
1963	SLURRY	>0.1
1964	SLURRY	>0.1
1965	SLURRY	>0.1
1966	SLURRY	>0.1
1967	SLURRY	>0
1968	SLURRY	>0
1969	SLURRY	>0
1970	SLURRY	>0
1971	SLURRY	>0
1972	SLURRY	>0
1973	SLURRY	>0
1974	SLURRY	>24.3
1975	SLURRY	>24.3
1976	SLURRY	>24.3
1977	SLURRY	>24.3
1978	SLURRY	>97.4
1979	SLURRY	>106.86
1980	SLURRY	>222.03
1981	SLURRY	>158.79
1982	SLURRY	>105.61
1983	SLURRY	>207.26
1984	SLURRY	>355.48
1985	SLURRY	>463.97
1986	SLURRY	>455.38

had injected waste underground during those years but could not provide a volume estimate. The figures provided here would then represent a conservative estimate of the total volume of waste injected each year, including the liquid portion of the waste. On average, the injected waste (in the case of both sludge and slurry) probably contained anywhere from 5-25% solids, according to several references on the typical nature of these wastes. Tables showing the volume estimates for injected waste for each disposal project will be included in the final report, as will a map of the location of the disposal projects. The number of disposal projects for which no injected waste volume estimates are available will therefore be apparent.

The data obtained during this study are largely based on estimates made by coal industry officials. The companies contacted in many cases acknowledged that their quantitative estimates were rough and that they could not verify their accuracy. This is often true for volumetric information and for calculations of waste repository void space. It is unknown in most cases what degree of roof collapse and/or floor heaving has occurred within abandoned mines or abandoned sections of mines, which could limit void space.

Some of the information requested from the companies is simply unknown by them as such records

were not kept or were not available. Also political situations involving a recent reorganization of the State mine regulatory agencies and a strained relationship between the coal industry and these state regulatory agencies, combined with economic difficulties being experienced by the coal industry, served to make the task of data collection very difficult.

Still, it appears that other than information becoming scarcer going back in time, as was expected, no geographic trends in missing data are apparent by visual examination. That is, it does not appear that there are biasing concentrations of missing data in any major subgroup of the northern or southern coalfield, waste type or position of the mines with respect to drainage.

This inventory was meant to be exhaustive. Still, as mentioned earlier, the possibility exists that some disposal projects exist that were not revealed by the data collection process. However it is believed that the data collection process was not biased, and therefore the information presented, if not exhaustive, is representative, especially for the more recent years (1980-1986).

Effects of Waste Injection on Mine Water Quality

Of the 65 disposal projects known, seven, including those used for detailed study, satisfied criteria necessary to make statistical comparisons between mine waters unaffected by injected waste and nearby mine waters that have potentially been affected by injected waste (are downgradient of injected waste). It must be cautioned, however, that the determination of whether or not a discharge point for mine water would be considered to be upgradient or downgradient of emplaced mine waste was based solely on the direction of the dip of the coal seam between the point of waste injection and the discharge point. It is possible that noflow barriers such as intact coal barriers, seals or ventilation stoppings within the mine could create diversions in the expected water flow paths. Even the accumulation of solids from slurry or sludge injection could potentially cause changes in ground water flow paths. Also, where floor heaving, cuts or shots in the floor, or roof falls in longwall or retreat mined areas occur, additional water diversions are possible. This is especially true when gobs are tight. It is also possible that localized reversals in the hydrologic gradient may be developed within mines. This could happen where the dip of the coal seam is slight and noflow barriers combined with the presence of low resistance flow paths upgradient of these barriers

occur.

Also, although the absence of obvious confounding variables was confirmed before these statistical comparisons were made, other variables not considered in this study could also affect results. For instance, variations in coal seam lithology and chemical quality across a mine were not examined. Also the locations of and quality and quantity of sources of ground water recharge to underground mines, the residence time of water within the mine, and the dynamics of the mine flow system are unknown for this study. These variables could affect background water quality in mines. Thus, injected slurry or sludge waste would not be the only potential factor affecting mine water quality, and in fact may be minor in effect compared with some other factors.

Still, results obtained thusfar for the seven disposal projects at mines which have been used for statistical testing do show some interesting trends, which to the best of existing knowledge may be attributable to waste injection. All data used in these analyses were supplied by the coal industry as part of their NPDES monitoring requirements. Data collected by the senior author was not used in the Mann-Whitney U Test analyses, but instead was used to provide a one-time comparison of complete analyses for

samples unaffected and potentially affected by waste injection. Wherever possible, the Mann-Whitney U Test was run on the following parameters: pH, total iron, total manganese, total suspended solids, acidity and alkalinity, as these parameters are most frequently included by the coal industry in the water quality data submitted to the state of West Virginia as part of their NPDES reports. Some of the results obtained are briefly summarized below, first for the slurry injection sites, and then for the sludge injection sits. Statistically significant results are emphasized here.

Slurry Injection Sites

DPN 26 is a southern coalfield slurry injection site located in the Pocahontas no. 3 seam. A comparison between pre-injection data and post-injection data at one sampling point located downgradient of the slurry injection point showed that pH was higher during the post-injection period at the 0.025 alpha significance level. Both total iron and total manganese were lower at 0.01 and 0.05 alpha significance levels, respectively, during the post injection period.

Comparison of a downgradient post-injection water

quality sampling point (point 1) against an upgradient post-injection water quality sampling point (point 2) showed that total iron was lower at the 0.025 alpha level at point 1 and alkalinity was higher at sample point 1 also at the 0.025 alpha level.

Finally, a comparison was made between pre- and post-injection data at sample point 2, a point which is upgradient of the slurry injection point. During the post-injection period, pH was significantly up at 0.01 alpha and total iron, total manganese, and total suspended solids were significantly down at the 0.1, 0.01, and 0.1 alpha levels, respectively. These results tend to indicate that the injection of slurry may have improved water quality in the mine, but that water quality was improving with time anyway.

DPN 27, a southern coalfield slurry injection site, located in the No. 2 Gas seam lent itself to only one comparison. Pre- and post-injection water quality from a point located downgradient of the slurry injection site showed that the total manganese was lower and alkalinity was higher during the post injection period at alpha levels of 0.01 and 0.1, respectively. Based on this one comparison, it appears that the injection of slurry has improved water quality.

DPN 34 represents a northern coalfield slurry

injection project located below drainage in the Upper Freeport Seam in Upshur County. Two water quality sampling points were used for the statistical comparison. Sample point 1 is downgradient of a slurry injection area, while sample point 2 is upgradient of all slurry injection. All available analyses were during the post injection time period. It is interesting to note that total iron and total manganese were lower at point 1 by <0.001 alpha level. Also, alkalinity was higher at point 1 by <0.001 alpha and pH was higher at sample point 1 although not statistically significant. These results seem to indicate that the injection of the slurry improved the water quality in the mine pool.

DPN 99 is located in Martin County, Kentucky, but is within five miles of southwestern West Virginia. Only two water quality monitoring points were available for statistical comparison. All data used were from samples taken by the coal company after slurry injection began. Sample point 1 drains a mine that was as completely filled to capacity with slurry as possible, and sample point 2 drains a mine that was never used for slurry injection. Both mines are located in the Coalourg coal seam and are above regional drainage level.

The statistical comparison between sample point 1

and 2 showed that at sample point 1, pH was lower, total iron was lower, total manganese was lower, total suspended solids was lower, and alkalinity was higher at <0.001 alpha significance level. These results tend to indicate that the injection of slurry into the mine from which sample point 1 drains improved the water quality at that mine.

Results of analyses of water samples obtained in the field, supernatent of pumped slurry, and supernatent withdrawn from the laboratory geochemical testing have not yet been received.

As seen in these few examples for which water quality data was analyzed, circumstances indicate that slurry injection may be improving water quality within the mine for those parameters investigated. It is possible that the injection of the alkaline slurry is increasing the pH and alkalinity of the mine pool and thus the waters within the mine are less apt to dissolve metals, thus explaining the decreases found in iron and manganese levels.

Sludge Injection Sites

Disposal project number (DPN) 23 is a southern coalfield sludge injection site in the Campbell Creek coal seam (both the Peerless and No. 2 Gas seams were

mined here). The mine is situated above the regional drainage level. Four sampling points (discharge sites) located along the downdip side of this mine differ only in that one, sample point 1, is most likely to show some effect of the injected sludge due to its location with respect to the mine entrance used for sludge injection.

Mann-Whitney U tests were used to compare the water quality at sample point 1 with that for the other three sample points. The results of the testing showed that total iron and total manganese were higher at sample point 1 than at sample points 2, 3 and 4, all at the 0.001 alpha significance level. A slightly higher pH was evident at sample point 1 compared to point 4 which is significant at the 0.1 alpha level. Total suspended solids was higher at sample point 1 than at the other three sample points at the 0.05 or less alpha level. Alkalinity was significantly lower at sample point 1 in comparison to sample point 3 at 0.1 alpha. This information suggests that the injected sludge may be responsible for the higher iron and manganese levels evident at sample point 1.

Results of analyses performed on water samples collected in the field by the senior author at this mine at the same four monitoring points showed that sample 1 was higher in nitrate, dissolved and total

iron, dissolved and total manganese, sulfate, total dissolved solids, aluminum, lead, potassium, and chloride compared to the other three samples. The supernatent of the pumped sludge contained high levels of sulfate (818.1), Ca (182.60), Mg (6.88), As (4.74), Na (52.85) and K (3.78) ... all values being given in mg/l.

Results of laboratory analyses performed by the West Virginia University COMER laboratory on the supernatent decanted off the sludge/water mixtures which comprised the laboratory equilibrium tests were interesting. The COMER laboratory results indicated that each sludge sample had added significant amounts of sodium, sulfate and arsenic to levels originally seen at sample point 4. Four separate sludge samples which had been taken from different sections of the two settling ponds at the minesite were used in these equilibrium tests.

The decanted waters from the mixture of distilled and deionized water and the same four sludge samples was analyzed by the West Virginia DNR chemistry laboratory. Every sludge sample contributed significant amounts of alkalinity, nitrate, total iron, total manganese, sulfate, total dissolved solids, aluminum, calcium, magnesium, zinc, copper, barium, sodium and chloride to the sampled water. Both sets of

samples were withdrawn from the holding containers after 63 days had elapsed since the commencement of the tests. The mixtures were stirred approximately once a week.

DPN 25 is a northern coalfield sludge injection site located below regional drainage in the Pittsburgh coal seam. The sludge, which is injected into the mine at two locations, results from the treatment of acid mine drainage from the Pittsburgh coal seam. Three discharge points used for the water quality comparisons are pumped discharges, two of which (points 1 and 2) might be affected by the sludge injection, by examination of their location relative to the sludge injection locations and the dip of the coal seam. Sample point 1 is downgradient of one sludge injection hole, but upgradient of the other. Point 2 is downgradient of both sludge injection holes by virtue of the structure contours, but lies in an area of the mine not directly connected to the area in which the nearest sludge injection hole is located. Sample point 3 is located quite close to, but upgradient of one sludge injection borehole. Comparison between sample points 2 and 3 showed that water from sample point 2 had a higher total iron level and a higher acidity both at the 0.001 alpha level.

However, it must be noted that a comparison

between sample points 1 and 2 showed significant differences at the 0.001 alpha level for all available parameters. It was observed that pH, alkalinity and total suspended solids were much higher at sample point 1, while total iron and acidity were higher at sample point 2. These differences could mask the other differences observed. The difference may be due to unknown sources of recharge entering the mine from overlying aquifers.

DPN 37 is a northern coalfield sludge injection site located in the Lower Kittanning coal seam. Statistical comparisons became slightly complicated at this site; two well discharge points (1 and 2) which are both located downgradient of the one sludge injection borehole by virtue of the coal dip trend alone, were in reality downgradient for separate periods of time once injection started. This is because the water overflow from the area used for sludge injection was alternately piped to the two mine sumps from which either well pump discharges (1 and 2) are derived. Thus, whether a sample is located upgradient or downgradient of the sludge injection area depends on the date the sample was taken at each location. The exact date that the change in underground piping occurred was noted by the company so that it was known when the overflow was routed to each

sump. Thus, it is possible that a sample was upgradient at one point in time and downgradient at another point in time. Sample point 4 is located upgradient of the sludge injection point. Both pre- and post-sludge injection data are available at each of these sample points. (Sample 3 was a special sample taken underground for this project by the coal company so that a sample which was indisputably upgradient of the sludge injection area would be available on which to run a complete suite of analyses).

A comparison between sample point 1 downgradient post-injection data and sample point 1 pre-injection data showed that after injection, pH went down significantly at the 0.001 alpha level, while total iron increased significantly at the 0.05 alpha level, total manganese decreased significantly at the 0.025 alpha level, and alkalinity decreased significantly at the 0.001 alpha level. The only significant difference between sample point 1 downgradient post-injection data and sample point 1 upgradient post-injection data was that total manganese was significantly higher at the 0.01 alpha level downgradient.

Total manganese is lower for sample point 1 downgradient post-injection data than for sample point 4 upgradient post-injection data at the 0.001 alpha significance level. Comparing sample point 2

downgradient post-injection water quality to sample point 2 upgradient post-injection water quality revealed that total manganese and total suspended solids were higher when sample point 2 was downgradient (with overflow routed to the sample point 2 pump sump), both at the 0.01 alpha significance level. Also, alkalinity was lower when the sample was downgradient at the 0.1 alpha significance level.

Post-injection comparisons between sample point 2 (downgradient) and sample point 4 (upgradient) showed that for sample point 2, pH was higher at 0.1 alpha, total iron was lower at 0.1 alpha, total manganese was higher at 0.1 alpha, total suspended solids was higher at 0.1 alpha, and alkalinity was higher at 0.1 alpha.

However, data also showed that sample point 2 downgradient post-injection water quality differed significantly from sample point 1 downgradient post-injection water quality in several ways; sample point 2 had lower total iron at 0.01 alpha, higher total manganese at 0.05 alpha, higher total suspended solids at 0.001 alpha and higher alkalinity at 0.001 alpha.

Also, post-injection data compared between upgradient sample points 1 and 2 showed that, for sample point 2, total manganese was higher at 0.05 alpha, total suspended solids was higher at 0.01 alpha,

and alkalinity was higher at 0.01 alpha.

Finally, a comparision of pre- and post-injection data at sample point 4, which is upgradient of the sludge injection point, showed that during the post-injection time period, pH was lower at 0.001 alpha, and total iron and total manganese were higher both at the 0.025 alpha significance level.

Interpretation of these results for DPN 37 is complicated and will be better understood by referencing data and figures that will be available in the final report. A factor at this mine which may tend to lower the integrity of comparisons involving sample points 1 and 2 is that, in reality, it is unknown what length of time would elapse before a change in the underground piping system would actually dictate that the overflow of the sludge injection area would be routed to one or the other pump sump in its entirity. Also, the possibility exists that either pump sump could sometimes receive a portion of the overflow by gravity. Also, sample 4, although upgradient of the sludge injection showed significant changes in water quality between the pre- and post-injection time periods. This also serves to lend some doubt as to the validity of making conclusive statements on the effect of the sludge injection at this site.

Results of analyses of water samples collected in

the field, supernatent of pumped sludge, or supernatent withdrawn from geochemical tests in the laboratory have not yet been received.

The results obtained thusfar from the sludge injection sites tend to indicate that the injection of sludge may be responsible for an increase in iron and manganese levels within underground mines in some cases. This might occur where the pH of the mine pool is low enough to redissolve the sludge to some extent. Theoretically, depending on the dynamics of the mine pool, this condition could reverse itself as continued injection of sludge, which virtually always contains excess alkalinity, begins to neutralize acidity within the mine pool and raise the pH to a level which could preclude the dissolution of the metals. This might occur when a steady source of acidic water is not recharging the mine pool which would maintain the acidity of the pool.

Concluding Remarks

It is difficult to make conclusions with certainty from information revealed during this project. Still, for the limited parameters on which statistical analyses were performed, data suggests that alkaline slurry injected into an alkaline mine pool may improve

water quality of the mine pool. The injection of alkaline sludge into an acidic mine pool may result in redissolution of a portion of the sludge, resulting in somewhat higher levels of iron, manganese and total dissolved solids in the mine pool, at least initially.

The interaction of slurry and sludge wastes with mine waters was concentrated upon in this project, as in most cases, this can be considered as the ultimate source of possible enhanced contamination from the emplacement of these wastes into underground mines. Thus, the migration of waters potentially contaminated by this disposal method into adjacent aquifers was not addressed specifically by this study, but furthur speculation on this possibility will be available in the final report.

Continued interpretation of results is still underway, and those found within this report are from initial speculation and must be considered tentative. Receipt of additional laboratory analyses from the West Virginia DNR laboratories will provide more information to aid in this interpretation, if they become available.

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KEY FOR INTERPRETATION OF DATA TABLES

DPN = disposal project number
WVFACILCODES = West Virginia facility code number
DRAIN PROX = position of the mine with respect to drainage (AB = above, BE = below, AT = at or both above and below)
NUMBER OF INJECTION POINTS OF STATUS:
- UC = under construction
- AC = active
- TA = temporarily abandoned
- PA = permanently abandoned with state approval
- AN = permanently abandoned without state approval

A dot or blank indicates missing information

REF	DRILLING OPERATOR	FUEL FIELD	IMPORTS (TONS)	TYPE OF WASTE	BRAIN FROM	COMPANY	SOURCE OF WASTE	MINE AND SECTION OF MINE PAID FOR DISPOSAL	NUMBER OF INJECTION POINTS OF STATES BC	AC	TA	PA	AB
01	DRS4201330001 PIC50013300I	B	PERSIUS (BIENVILLE)	SLUDGE	AB	S AND T COAL	MINE NO 1 AND PLANT	MINE 1/5 PATT 0 00	0	1	0	0	0
02	DRS4201330002 PIC50013300I	B	BROOKS (BROWN MTN)	SLUDGE	AB	BROOK FORGE	44 BOILER AND PLANT	D/B DITCH/SW 0	1	0	1	0	0
03	DRS4201330003 PIC50013300I	B	BARBOUR (BIRIDAN)	SLUDGE	AB	BARBER COAL	BIRIDAN MINE PREP PLANT	BIRIDAN MINE	0	0	0	0	1
04	DRS4201330004 PIC50013300I	B	BURBURCILLA (BIRMINGVILLE)	SLUDGE	BA	SOUTH BRIDR	AND PLANT	PONA MINE	0	0	0	0	1
05	DRS4201330005 PIC50013300I	B	BIRDWELL (FRIENDS)	SLUDGE	AB	OUTLET CREEK	FRIENDS NO 8 PREP PLANT	FRIENDS NO 8 MINE	0	0	0	0	0
06	DRS4201330006 PIC50013300I	B	NICHOLAS (TIOGA)	SLUDGE		ISLAND CREEK	TIOGA PLANT COMPLEX	TIOGA NO 1 MINE	0	0	1	0	0
07	DRS4201330007 PIC50013300I	B	GRANT (MT STORM)	SLUDGE	AT	CANNEL DEV	MINE NO 1 AND PLANT	NO 1 MINE	0	1	0	0	0
08	DRS4201330008 PIC50013300I	B	RANDO (RACELAND)	SLUDGE	OE	EMORY COAL	HOLDEN NO 25 PREP PLANT	RACELAND MINE	0	0	0	0	2
09	DRS4201330009 PIC50013300I	B	EDCAR (EDCAR)	SLUDGE	BE	ISLAND CREEK	UPPER NO 5 PREP PLANT	UPPER NO 5 MINE	0	0	0	0	10
10	DRS4201330010 PIC50013300I	B	CABANNA (CABIN CREEK)	SLUDGE	AB	CAPITOL PREP	NO 5 PREP PLANT	NO 5 MINE/I MINE	0	0	0	0	1
11	DRS4201330011 PIC50013300I	B	GRANT (RACELAND)	SLUDGE	BE	ISLAND CREEK	ALPINE PREP PLANT	MINES MINE	0	0	1	0	0
12	DRS4201330012 PIC50013300I	B	GRANT (RACELAND)	SLUDGE		ISLAND CREEK	BOONE BRANCH PREP PLANT	LOGANS MINE	0	0	1	0	0
13	DRS4201330013 PIC50013300I	B	MCDONNELL (CAPLIN)	SLUDGE	BE	SEAM POCAHON	SHANNON PREP PLANT	SHANNON BRANCH/I M	0	0	0	0	1
14	DRS4201330014 PIC50013300I	B	MCDONNELL (CABELLA)	SLUDGE	BE	OMEGA COAL CO	OMEGA PREP PLANT	WAR CREEK NO 5	0	2	0	0	10
15	DRS4201330015 PIC50013300I	B	CABANNA (CABBOT)	SLUDGE	BE	PA STEEL MIN	NO 9 PREP PLANT	CABB CREE NO 9/2E	0	0	0	0	1
16	DRS4201330016 PIC50013300I	B	BIRCH (TRACIE)	SLUDGE	AB	OLD NEW COAL	NO 24 MINE PREP PLANT	CRENT MINE NO 8	1	0	0	0	1
17	DRS4201330017 PIC50013300I	B	BIRCH (BASS)	SLUDGE	AE	POND CREEK	SPRUCE CREEK PREP PLANT	POND CREEK NO 1	0	2	0	0	0
18	DRS4201330018 PIC50013300I	B	WEIRTON (MARIANNA)	SLUDGE	AE	BURNSS CREEP	MARIANNA NO 1 PREP PLANT	MINE NO 1					
19	DRS4201330019 PIC50013300I	B	BARBOUR (EMMITAS)	SLUDGE	AE	NO OHIO COAL	GREEN BIR AND SITE AND PLANT	MARIENNA/I LIKE	0	1	1	0	0
20	DRS4201330020 PIC50013300I	B	WEIRTON	SLUDGE	AB	BIG BEAR MIN	BIG BEAR PREP PLANT	NO 1 MINE					

DCD	SPECIFICATION	COAL FIELD	COUNTY (TOWN)	TYPE OF WASTE	BRANCH MINE	COMPANY	SOURCE OF WASTE	BRIEF DESCRIPTION OF MINE WASTE AND DISPOSAL	SPECIFIED OR NOT	PRECIPITATION AT	PRECIPITATION AT	POINTS OF STATUS Pa	POINTS OF STATUS AB
21	8PS4704455645 PIC5804455645	E	LOGAN (SEALE)	SLUDGE	AT	ARMBENT COAL	BALLOONING PREP PLANT	PARAMUS MINE	0	0	0	0	0
22	8PS4701959936 PIC5801959936	S	KANAWHA (DUNBAR)	SLURRY	AB	ISRAEL CREEK	DUNBAR PREP PLANT	RD 11 BIRD/OH	0	0	0	0	0
23	8PS4701[illegible] PIC5801[illegible]	S	BOONE (SUPERIOR)	SLUDGE	AB	EASTON ANNEX	PORD CREEK AND TENT PLANT	SUPERVISION RD 1/0	1	0	0	0	0
24	8PS4700455001 PIC5800455001	S	BOONE (WALTON)	SLURRY	AB	OSAR BIRING	CENTERFIELD PREP PLANT	CENTERFIELD RD 1/2LE	0	0	0	0	0
25	8PS4701350001 PIC5801350001	W	BARBISON (SHINNSTON)	SLURRY	WV	CONSOLIDATED	MAIN MAIN AND OSBORNE AND PLANTS	SUBTASK RND 33/20	0	2	0	0	0
26	8PS4704750003 PIC5804750003	W	MCDOWELL (SUPERIOR)	SLURRY	WV	KANAWHA IRON	SUPERIOR PREP PLANT	RD 3 AND 4 MINES	0	1	0	0	0
27	8PS4701950003 PIC5801950003	S	KANAWHA (CARBOLINE)	SLURRY	AT	FIBERITE IRON	EAST BRAE PREP PLANT	105/115 FURNACES	0	1	0	0	0
28	8PS4706425002 PIC5806425002	S	RICHLAS (HARTSELL)	SLURRY	WV	SEWELL COAL	RD 1 PREP PLANT	PANTHER MINE/RD	0	1	0	0	0
29	8PS4710950001 PIC5810950001	W	WYOMING (ERROL)	SLURRY	AB	BIG BEAR MIN	BIG BEAR PREP PLANT	RD 2 BAUER MINE	0	1	0	0	0
30	8PS4701595002 PIC5801595002	S	MINGO (KERMIT)	SLURRY		ELBERT COAL	RD 1 PREP PLANT	RD 1 MINE					
31	8PS4706150001 PIC5806150001	W	MCDOWELL (EDEN)	SLURRY	WV	CONSOLIDATED	SPENT AND PLANT	PERMIT (S/105-3 BY	0	0	1	0	0
32	8PS4706150003 PIC5806150003	W	MCDOWELL (PINEVILLE)	SLURRY	WV	CONSOLIDATED	EAST AND PLANT	RENEW 7/1981 55/50	0	0	1	0	0
33	8PS4704750001 PIC5804750001	W	MCDOWELL (GARY)	SLURRY	WV	US STEEL MIN	AIRLOCK PREP PLANT	GARY RD 10 MINE	0	1	0	0	0
34	8PS4709250001 PIC5809250001	W	MCDOWELL (ADDIAN)	SLURRY	WV	BRANCH COALS	ADDIAN PREP PLANT	NUCLEAR AIR WORKS	0	1	0	0	0
35	8PS4704750002 PIC5804750002	S	MCDOWELL (EAGLE)	SLURRY		PIGEON CORUS	RD 1 PREP PLANT	BIG ASH MINE	0	0	0	0	0
36	8PS4705950003 PIC5805950003	W	MINGO (WILLIAMSON)	SLURRY		SOUTH BRAY	RD 1 PREP PLANT	RD 1 MINE	0	1	0	0	0
37	8PS4700615001 PIC5800615001	W	RANSOME (CAVE CREEK)	SLURRY	WV	EAST ENERGY	TREATED BEFORE DROP	EAST RD 1/C3 HOB	0	1	0	0	0
38	8PS4705950004 PIC5805950004	S	MINGO (BAY)	SLURRY	AB	BUCKE RUSSIN	SPRAYING CREEK PREP PLANT	BUCKET BUILDR MINE	0	0	0	0	0
39	8PS4700550003 PIC4700550003	S	BOONE (BREDA)	SLURRY	AT	OSAR BIRING	CENTERFIELD PREP PLANT	CENTERFIELD RD 5	0	0	0	0	0
40	8PS4704556645 PIC5804556645	S	LOGAN (RACCOON)	SLURRY	WV	ISLAND CREEK	BORDER RD 20 PREP PLANT	BORDER RD 21	0	0	0	0	0

PFN	[illegible]	Coal Field	County (Code)	Type of Waste	Basin Code	Company	Source of Waste	Mine and Section of Mine Used for Disposal	Number of PC	Objectives A1	Objectives 1A	Objectives 2A	Objectives AM	Stages
41	WV5470455001 PI[illegible]	S	[illegible] (WAR)	SPOIL	4B	Pocahontas	Pocahontas Prep Plant	Jane Amb No 3/8	0	M	0	0	1	
42	WV5470455001 PI[illegible]	B	Boone (Barrett/Tom)	SLURRY	05	Tomahawk/Mash	Washington and Export	No 7a Mine S S 1P	0	1	0	0	0	
43	WV5470595006 PI[illegible]	B	Mason (Quinon)	SLUDGE	02	East Assoc	Quinon and Facility	Pleasant No 1	0	1	0	0	M	
44	WV5470595001 PI[illegible]	S	Wirt (Isaac)	SLURRY	4B	Pete White	Pete White Prep Plant	Old Works						
45	WV5470655001 PI[illegible]	B	Ohio (Bridgeport)	SLUDGE	4B	Valley Camp	Ark Plant	No 1 Mine	0	M	0	M	1	
46	WV5470515001 PI[illegible]	B	Barbour (Whiting)	SLURRY	05	Consolidate	Shoregate Prep Plant	Shoregate Mine	0	M	M	M	1	
47	WV5470515002 PI[illegible]	B	Barbour (Whiting)	SLURRY	05	Consolidate	Island Prep Plant	Island Mine	0	M	M	M	1	
48	WV5470335001 PI[illegible]	B	Barbour (Sandy)	SLUDGE	4B	Barnes Bourne	Ark Plant	Bare Bourne Mine A						
49	WV5470555004 PI[illegible]	S	Kanawha (Elkhorn)	SLURRY	4B	Bethune Mine	Shawnee Prep Plant	Shawnee No 1 Dam	0	0	0	0	1	
50	WV5470455002 PI[illegible]	S	[illegible] (Dick)	SLURRY	05	Bidwell Min	Bidwell Prep Plant	Bidwell Mine						
51	WV5470455005 PI[illegible]	S	[illegible] (Millville)	SLURRY	05	Ritchie Ridge	Ritchie Prep Plant	Jane Amb Ritchie						
52	WV5470555004 PI[illegible]	S	[illegible] ( )	SLURRY		Appalachian Mine	Cabin Prep Plant	No 5A Mine	M		0	0	0	
53	WV5470655002 PI[illegible]	S	Boone (Sheiba)	SLURRY	02	Bar Bent	Bar Bent Prep Plant	Ophelia (Fee SW						
54	WV5470235001 PI[illegible]	B	Grant (Bayard)	SLUDGE		Island Creek	Boone Branch and Plant	Boone Branch Mine						
55	WV5470455005 PI[illegible]	B	[illegible] (Holden)	SLURRY		Rowe Coal	Holden No 22 Prep Plant	Holden No 22						
56	WV5470235002 PI[illegible]	B	Grant (Bayard)	SLURRY	05	Island Creek	Alpine and Plant	Alpine Mine	0	0	1	0	0	
57	WV5470235001 PI[illegible]	B	Grant (Bayard)	SLUDGE		Island Creek	Boone Branch and Plant	Kammer Mine	0	0	1	0	M	
58	WV5470555001 PI[illegible]	S	Boone (Omilia)	SLURRY	4B	Omar Mining	Consolidated Prep Plant	Consolidated No 1	0	0	0	0	M	
59	WV5470815001 PI[illegible]	S	Raleigh (Sear Rose)	SLURRY	05	Sear Inds	No 1 Prep Plant	No 8 Mine	0	0	0	0	0	
60	WV5470595002 PI[illegible]	S	Mingo (Greenwood)	SLURRY		Kimball Dense	Mine No 1 and Plant	Sycamore Mine No 1	0	0	0	0	1	

DFR	[illegible]	COAL RANK	[illegible]	TYPE OF BASIN	BASIN CODE	COMPANY	SOURCE OF DATA	SIDE AND SECTION OF SIDE ASSOCIATED WITH	NUMBER OF PL	OBJECTIONS PC	TO	PS	AN
61	[illegible]	B	[illegible]	SIMPLE	AB	BEEBIVE BIDE	TREATED BRINE DROPP	BATCHED BO 1/B	0	0	0	0	0
62	[illegible]	S	[illegible]	SIMPLE	BI	FOR COST LOW	FREE PLANT	BIDE BU 1 BIDE	0	0	0	0	0
63	[illegible]	B	[illegible]	BIOMAP	AI	BO OBIO COAL	OPTION BOB AND BIDE AND PLANT	BABTIBLA/2C/OBIO IB	0	1	0	0	0
64	[illegible]	B	[illegible]	SIMPLE	AI	WIB BEB COAL	2U BIDE PREP PLANT	BO 2U BIDE	0		0	0	0
65	[illegible]	B	[illegible]	SIMPLE	AI	BRENB PLANNE	BIB A SAMIB AND PLANT	BIB BIDE/A AN					

OPN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
1	T AND T ENERGY, INCORPORATED BOX 206 BRUCETON MILLS, WV 26525	PAUL THOMAS/(304)379-2260	OM MAGOON/(304)379-2260
2	WINDSOR POWER HOUSE COAL COMPANY P O BOX 220 WINDSOR HEIGHTS, WV	WILLIAM J. MATHEWS/(304)394-5357	DANIEL P CARNEY/(304)394-5301 WILLIAM BOSWORTH
3	BADGER COAL COMPANY (TAKEN OVER BY PITTSTON)		R E BOGERT/(304)472-0612 (NOW OF EASTERN ENERGY)
4	SOUTH UNION COAL COMPANY * NORTH MAIN STREET GREENSBURG, PA 15601		DAVID S JANISON/(412)834-1980
5	ROYALTY SMOKELESS COAL COMPANY P O BOX 770 WELCH, WV 24801		SAMUEL HATCHER/(304)436-3344
6	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 486 CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
7	LAUREL RUN COAL COMPANY STAR ROUTE BOX 425 MOUNT STORM, WV 26739	HANK GEARY/(304)259-5214	HANK GEARY/(304)259-5214
8	ENOXY COAL COMPANY		
9	ISLAND CREEK COAL COMPANY HOLDEN DIVISION BOX 940 HOLDEN, WV 25625		DANNY COX/(304)239-2361
10	CAPITOL FUELS, INCORPORATED P O BOX 598 EAST BANK, WV 25067	P J HALSTEAD/(304)949/6847	R R PYLES/(304)949-6847 OLIVER B WHITE/(304)949-6847

* = Out of Business

DPN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
11	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 486 CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
12	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1 BOX 486 CRAIGSVILLE WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
13	SHANNON POCAHONTAS COAL COMPANY P O BOX 770 WELCH, WV 24801		SAMUEL HATCHER/(304)436-3144
14	OLGA COAL COMPANY DRAWER B COALWOOD, WV 24824	MARTIN VALERI/(304)297-2115	DONALD WINSTON/(304)297-2135
15	U.S STEEL MINING COMPANY, INC 43905 MALCOMLEF AVENUE CHESAPEAKE, WV 25315	P R BOYLE/(304)340-2215	JIM CANTERBURY/(304)340-2215
16	OLD BEN COAL COMPANY P O. BOX 47 THACKER, WV 25694	MARKUS J LADD/(304)426-8804	OID W MAYNARD/(304)426-8804
17	POND CREEK COAL COMPANY P O BOX 763 MATEWAN, WV 25678		GORDON R STONE/(304)235-4290
18	ROBINSON PHILLIPS COAL COMPANY BOX 550 PINEVILLE, WV 24874		SAMUEL HATCHER/(304)436-3144
19	SOUTHERN OHIO COAL COMPANY P O. BOX 552 FAIRMONT, WV 26555	MICHAEL P MIANO/(304)366-5515	JAMES MCCALMONT/(304)366-5515
20	BIG BEAR MINING COMPANY, INC P O. BOX 407 LYNCO, WV 24857		BUTCH LESTER/(304)682-4748

* - Out of Business

DPN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
21	ARMPOST COAL COMPANY GENERAL DELIVERY LUNDALE, WV 25631		GREG BAIL/(304)583-6561
* 22	IMPERIAL COLLIERY P O BOX 8 BURNWELL, WV 25074	C LYNCH CHRISTIAN, III/(804)645-5918	BOB CHRISTIAN/(304)595-3101
23	EASTERN ASSOCIATED COAL CORPORATION CHARLESTON, WV	DENNIS M KOSTICK	T PAT MITCHELL/(304)247-6266 BOB FABIC/(304)247-6266
24	OMAR MINING COMPANY P O BOX 338 MADISON, WV 25130	RICHARD RICHMOND/(304)369-1041	SCOTTY ESON/(304)369-1041
25	CONSOLIDATION COAL COMPANY NORTHERN WEST VIRGINIA REGION VISTA DEL RIO P O. BOX 1314 MORGANTOWN, WV 26507-1314	D D AUCH/(304)296-3461	EDWARD A MOORE/(304)296-3461 DAVID L YANERO/(304)296-3461
26	CANNELTON INDUSTRIES, INCORPORATED P.O BOX 150 CANNELTON, WV 25036	N G CLONCH?(304)442-9575	CHUCK KUB/VNA/(304)442-9575
27	CANNELTON INDUSTRIES, INCORPORATED P O BOX 150 CANNELTON, WV 25036	N G CLONCH?(304)442-9575	CHUCK KUB/VNA/(304)442-9575
28	SEWELL COAL COMPANY STAR ROUTE 2 BOX 165 NETTIE, WV	RALPH DADO/(304)846-2525	RANDY MCMILLION/(304)846-2525
29	BIG BEAR MINING COMPANY, INC P O BOX 407 LYNCO, WV 24857		BUTCH LESTER/(304)682-4748
30	KERMIT COAL COMPANY P O BOX 198 KERMIT, WV 25674	GEORGE J ORENICK/(304)395-5361	RAYMOND SOMPTER/(304)395-5361

* - Out of Business

DPN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
31	CONSOLIDATION COAL COMPANY NORTHERN WEST VIRGINIA REGION VISTA DEL RIO P O BOX 1314 MORGANTOWN, WV 26507-1314	D D AUCH/(304)296-3461	EDWARD A MOORE/(304)296-3461 SHERRI FLETCHER/(304)296-3461
32	CONSOLIDATION COAL COMPANY NORTHERN WEST VIRGINIA REGION VISTA DEL RIO P O. BOX 1314 MORGANTOWN, WV 26507-1314	D D AUCH/(304)296-3461	EDWARD A MOORE/(304)296-3461 SHERRI FLETCHER/(304)296-3461
33	U.S STEEL MINING COMPANY, INC CENTRAL DIVISION P O BOX 430 GARY, WV 24836	JOHN F DICKINSON, II/(304)448-7201	WILLIAM D ALLEN/(304)448-7202
34	UPSHUR COALS CORPORATION P O BOX 789 BUCKHANNON, WV 26201	JERRY WESTFALL/(304)472-2900	HARRY T DUNNIRE/(304)472-2900
35	VIRGINIA CREWS COAL COMPANY P O. BOX 727 LAFOLIA, WV 24844	JOSEF EHRENGRUBER/(304)436-8451	HAROLD COLLINS/(304)939-2922
36	SMITH BROTHERS CONSTRUCTION COMPANY P O. BOX 1379 WILLIAMSON, WV 25661	FRANK SPARKS/(703)566-8944	FRANK SPARKS/(703)566-8944
37	KITT ENERGY CORPORATION RD 3 BOX 146 PHILIPPI, WV 26416	GORDAN COOK/(304)457-5797	JOHN FLY/(304)457-1992
38	ROCKY HOLLOW COAL COMPANY P O. BOX 773 NATEWAN, WV 25678		GORDON R SLONE/(304)235-4290
39	OMAR MINING COMPANY P O. BOX 338 MADISON, WV 25130	RICHARD ZIGMOND/(304)369-1041	SCOTTY ISON/(304)369-1041
40	ISLAND CREEK COAL COMPANY HOLDEN DIVISION BOX 840 HOLDEN, WV 25625		DANNY COX/(304)239-2361

* - Out of Business

DPN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
41	THE POWELLTON COMPANY BOX 8 MALLORY, WV 25639	DINO PAOLETTI/(304)583-6501	DINO PAOLETTI/(304)583-6501
42	CONSOLIDATION COAL COMPANY NORTHERN WEST VIRGINIA REGION VISTA DEE BIG P O BOX 1314 MORGANTOWN, WV 26507-1314	D D ABLOW/(304)296-3461	EDWARD A MOORE/(304)296-3461 DAVID I VANIHO/(304)296-3461
43	EASTERN ASSOCIATED COAL CORPORATION CHARLESTON, WV	DENNIS M KOSTIC/	AL MOORE/(304)449-1911
44	PETER WHITE COAL MINING CORPORATION DRAWER A ISABAN, WV 24846	D J PATTON/(606)233-4141	DAVID DANCY/(304)732-7070
45	VALLEY CAMP COAL COMPANY		JIM LITTMAN/(814)676-7733
46	CONSOLIDATION COAL COMPANY EASTERN REGION 450 RACETRACK ROAD WASHINGTON, PA 15301		EDWARD SUTER/(412)746-3400
47	CONSOLIDATION COAL COMPANY EASTERN REGION 450 RACETRACK ROAD WASHINGTON, PA 15301		EDWARD SUTER/(412)746-3400
48	DANIEL BOONE COAL COMPANY *		
49	BETHLEHEM MINES CORPORATION 7012 MACCORKLE AVENUE, S E CHARLESTON, WV 25304	T J BRISKI/(304)357-4242	J R WILLISON/(304)357-4230
50	BERACHA MINING		DICK BURGESS/(304)752-1434

* - Out of Business

DPM	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
51	BETCO MINING CORPORATION *		
52	BUFFALO MINING		
53	B A E WEST, INCORPORATED 41 EAGLES ROAD BECKLEY, WV 25801	D PAUL LIZER/(304)253-2721	MIKE MILAN/(304)253-2721
54	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 48K CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
55	ENOXY		
56	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 48K CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
57	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 48K CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
58	OMAR MINING COMPANY P.O. BOX 338 MADISON, WV 25130	RICHARD ZICKOND/(304)369-1041	SCOTTY ISON/(304)369-1041
59	SLAB FORK COAL COMPANY *		ADRIAN MCKINNEY/(304)787-3729
60	MCHANLE RESOURCES, INC BOX 1518 WILLIAMSON, WV 25661	ODIL ROJERS/	MARVIN VERNATTER

* = Out of Business

DPN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
51	METCO MINING CORPORATION *		
52	BUFFALO MINING		
53	M A E WEST, INCORPORATED 41 EAGLES ROAD BECKLEY, WV 25801	B PAUL BIZER/(304)253-2721	MIKE MILAM/(304)253-2721
54	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 48K CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
55	ENOXY		
56	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 48K CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
57	ISLAND CREEK COAL COMPANY NORTHERN DIVISION STAR ROUTE 1, BOX 48K CRAIGSVILLE, WV 26205	JIM HUNTER/(304)742-5501	KENNETH JOHNSON/(304)742-5501
58	OMAR MINING COMPANY P O. BOX 338 MADISON, WV 25130	RICHARD ZIGMOND/(304)369-1041	SLOTTY ISON/(304)369-1041
59	SLAB FORK COAL COMPANY *		ADRIAN MCKINNEY/(304)787-3720
60	MCNAMEE RESOURCES, INC BOX 1518 WILLIAMSON, WV 25661	ODEL BOYERS/	MARVIN VERNATTER

* = Out of Business

DFN	COMPANY NAME AND ADDRESS	LEGAL CONTACT/PHONE	TECHNICAL CONTACT/PHONE
61	BETHLEHEM MINES CORPORATION 7002 MACCORKLE AVENUE, S E CHARLESTON, WV 25304	T J BRISKY/(304)357-4242	L.R WILLISON/(304)357-4230
62	PARDEE AND CURTIN LUMBER COMPANY *		MIKE CARPENTER/(304)847-5384
63	SOUTHERN OHIO COAL COMPANY P O. BOX 552 FAIRMONT, WV 26555	MICHAEL P MIANO/(304)366-5515	JAMES MCCALMENT/(304)366-5515
64	OLD DEN COAL COMPANY P O. BOX 47 TRACEE WV 25694	MARKUS J LADD/(304)426-8804	GEO W MAYNARD/(304)426-8804
65	WINDSOR POWER HOUSE COAL COMPANY P.O BOX 220 WINDSOR HEIGHTS, WV	WILLIAM J MATHEUS/(304)394-5357	DANIEL P CARNEY/(304)394-5701 WILLIAM BOSWORTH

* - Out of Business

SECTION 5.1.3

TITLE OF STUDY: OR SOURCE OF INFORMATION)	In-Depth Investigation Program: Acid Mine
AUTHOR: (OR INVESTIGATOR)	West Virginia University Department of Geology (for USEPA Region III)
DATE:	December, 1986
FACILITY NAME AND LOCATION:	Consolidation Coal Company, Northern West Virginia Region (Monongalia, Marion, and Harrison Counties), West Virginia, USEPA Region III
NATURE OF BUSINESS:	Coal mining

BRIEF SUMMARY/NOTES: Consolidation owns and operates 21 injection wells of three basic types: 1) Sludge disposal wells used to dispose of precipitate from settling impoundments into abandoned portions of deep mines; 2) Leachate transfer wells used to inject leachate from gob piles to permit flow to a centrally located downdip treatment facility; and 3) Acid mine water transfer wells used to inject acid mine water into the updip portions of abandoned mines so that it can flow to a downdip treatment facility.

In the study area, Consolidation is mining the Pittsburg coal seam and overlying Sewickley coal seam. Natural flow of groundwater has resulted in pooling at the down-dip extremities of the abandoned portion of the mine. Acid water is pumped to an AMD treatment plant, where it is treated with lime, oxygenated, and discharged to the surface.

Pooling of acid mine water occurs in other abandoned areas of the mine. Consolidation needed to pump this water to the central treatment facility, so five injection wells were constructed to accomplish this. Total daily injection volume is about 960,000 gallons.

The report concludes that this procedure, if properly managed, is environmentally prudent and will not adversely affect USDW. Areas of concern are:

1. Construction of wells: Construction requirements are not incorporated into the environmental permit.

2. Hydrostatic head build-up in down dip portions: Injection of acid mine water, if it results in excessive hydrostatic head, could cause outcrop "seeps" or "blowouts".

3. Water quality changes: These have not been quantified, but it is important that all effluent water quality standards addressed in permits are met.

V. In-Depth Investigation Program

Acid Mine Water Transfer Wells

A) Facility Selection Methodology

The facility selected to do an in-depth investigation into Acid Mine Water Transfer Wells was selected using the following criteria:

1) Availability of file information: The facility should have an abundance of file information to reduce the need for extensive field investigation.
2) Number of wells operated by a single facility: The number of wells at a single facility should be high to reduce travel time during the assessment.

Based upon these criteria, the Class V facility chosen to make an assessment on Acid Mine Water Transfer Wells was Consolidation Coal Company, Northern West Virginia Region. Consolidation owns and operates twenty-one injection wells over a three county area (Monongalia, Marion and Harrison). These wells can be broken down into three basic categories:

1) Sludge Disposal: Wells used to dispose of AMD precipitate into the abandoned portions of deep mines. The precipitate originates from settling impoundments associated with treatment facilities. Consolidation operates two sludge disposal wells at this facility.
2) Leachate Transfer Wells: Wells used to inject (gravity feed) leachate which is collected from gob piles into an updip portion of an abandoned deep mine so that the

leachate may flow to a centrally located downdip treatment facility where, as like other acid mine water, it is removed from the mine, treated and finally discharged to the surface. Consolidation operates one well of this type in the Northern West Virginia Region.

3) Acid Mine Water Transfer Wells: Wells used to inject (gravity feed) acid mine water into the updip portions of abandoned deep mines so that it can flow to a downdip, centrally located, treatment facility. The acid mine water is removed from the mine, treated and discharged to the surface. Consolidation operates 19 wells of this type in their Northern West Virginia Region.

B) Investigation Methodology

The objective of this assessment is to determine the impact of Acid Mine Water Transfer (AMWT) wells on underground sources of drinking water (USDW's). The AMWT injection wells to be studied are located over a (two) county area (Monongalia, Harrison) of Northern West Virginia. The Company which owns and operates the injection wells is the Consolidation Coal Company (Consolidation). In the study area, Consolidation is deep mining the Pittsburgh coal seam and the overlying Sewickley coal seam.

West Virginia UIC personnel visited Consolidation Coal Company, Northern West Virginia Region, to gain a better understanding of the Class V activity ongoing at this facility. UIC personnel

were accompanied by Consolidation employees to each of the injection sites. Specifics as to the nature of the injection operation at each site were discussed. Subsequent to the field investigation, extensive file information was gathered from DWR's Coal Section concerning Consolidation's operation in Northern West Virginia. However, the information was not specific to the activity to be assessed. UIC personnel evaluated the information and determined that the best and swiftest method of assessing the activity would be to select a mode "manageable" sub-area within the larger study area which would have transfer value to the entire study area as well as to areas of similar activity throughout the state. One such area was selected.

The sub-area that was selected for the purpose of this assessment lies approximately 2.5 miles west of Morgantown, West Virginia. Within this sub-area the Pittsburgh coal seam is currently being mined. The overlying Sewickley seam has been mined out in this area. The Sewickley seam is dipping to the southwest causing natural ground water flow in the mine to be in that direction. The result is the pooling of water in the most down-dip portion of the abandoned mine in the area of the Sears Impoundment.

Consolidation Coal Company constructed and AMD treatment plant (Sears AMD Treatment Plant) over the most down dip portion of the Sewickley seam in this area. The treatment plant receives mine water which is pumped from the Sewickley mine. This plant was constructed to treat AMD and thus protect the underlying portions of the Pittsburgh coal, which are currently being mined, from the danger of the increasing head in the Sewickley.

The acid mine water is pumped from the Sewickley mine, treated with lime, oxygenated and then discharged to the surface after the precipitant is settled out in the Sears impoundment.

There are portions of the mined Pittsburgh coal seam that underly the Sewickley in this area that also pool ground water. Consolidation has a need to pump acid mine water from the Pittsburgh seam in several locations (down-dip) within the sub-area to protect the working portions (up-dip) of the mines in the Pittsburgh. To avoid the need for constructing an AMD treatment facility at every withdrawal point from the Pittsburgh or transferring the mine water to some other existing treatment facility, Consolidation constructed five injection wells which would inject water from the Pittsburgh into the abandoned Sewickley where the acid mine water flows to the down-dip point of withdrawal at the Sears Treatment Plant. Therefore, in addition to the AMD resulting from natural ground water flow into the Sewickley mine, five additional sources are pumped into the abandoned Sewickley. The following is a list of the injection wells which inject into the Sewickley.

Name	Volume
No. 1 Jere	60,000 GPD
6 Right	150,000 GPD
Loar	200,000 GPD
Vallotto	400,000 GPD
Hess	150,000 GPD

The abandoned mine is simply used as a conduit for the transfer of AMD.

C. Summary of Facility Investigation

Ground water pooling in the down-dip portion of abandoned deep mines is an inevitable consequence of deep mining in general. To reduce the head by dewatering active mines is a common practice and necessitates treating the acid mine water before ultimately discharging it to the surface water. The Class V injection activity associated with Consolidation's operation is also not unique.

The injection of acid mine water into abandoned mines for the purpose of transferring it to a centrally located treatment facility, if properly managed, would seem to be an environmentally prudent practice. When these abandoned mines exist and the configuration of the mine is known, the Acid Mine Water Transfer Method is superior to the transportation of this water along the surface by either truck or pipeline. The use of abandoned mines is relatively inexpensive and eliminates the chance of a surface spill which could ultimately contaminate shallow fresh water aquifers.

Even though this practice seems to be an excellent method to protect shallow USDW's, there are several areas of concern that should be addressed:

1) Construction of the Injection Wells: The construction requirements of these wells are not incorporated into the environmental permit associated with this facility. These wells must be constructed properly to ensure that no water from USDW's penetrated by the well can flow down the borehole and into the mine thus dewatering a potable aquifer. Additionally, proper

construction precludes the introduction of the injectant (AMD) into shallow USDW's. Historically, the adequacy of construction of wells into mines has not been looked at from a ground water protection standpoint. The primary concern was to minimize the volume of water entering the mine. In addition, comprehensive well abandonment plans are not required to assure that the wells are properly plugged and abandoned.

2) Hydrostatic Head Build-up in the Down-dip Portions of Abandoned Mines: If, by the addition of injected acid mine water, the water within the mine is allowed to build excessive hydrostatic head over time, the possibility of outcrop "seeps" and "blowouts" increases. The rate of buildup and withdrawal of water in addition to the barrier thicknesses in the mines must be examined to insure that the possibility of mine "blowouts" and excessive "seeps" are minimized. The problems associated with head buildup in abandoned portions of mines may, at some point in time, need to be a concern of the UIC program, however, these concerns are currently addressed by the Coal Section of the DWR. The Coal Section uses standard formulas to calculate the necessary barrier thickness, given certain other conditions, to prevent seepage or blowouts in outcropping areas and mine-to-mine leakage.

3) Water Quality Changes: It is difficult to predict the change in water quality that acid mine water may undergo as it travels through an abandoned mine. However, this may not be a critical point of concern. The permits under which the AMD treatment plants operate establish effluent standards of water quality. If all other aspects of the injection operation are

functioning properly and all of the injected water is being withdrawn, any changes in water quality within the mine are of no concern.

Diane Smith
West Virginia University
Department of Geology
and Geography
425 White Hall
Morgantown, WV 26505
(304) 293-5603
December 30, 1986

David Long
erground Injection Control Program
ision of Water Resources
0 Greenbrier Street
rleston, WV 25311

r Mr. Long:

Attached is an interim copy of the summary earch report for the U.S. Environmental Protection ncy. Please be advised that we have still not eived analyses from samples sent to the Department Natural Resources laboratories anywhere from one or e months ago. We understand that a person ponsible for atomic absorption metal analyses has fered a heart attack and that we may not expect to eive the analyses soon. If this situation has nged, please advise. The analyses are crucial to us our endeavor to provide a complete final report to . Please note that inventory information is vided at the back of the report for your use in viding EPA with information on the injection wells.

The organization of the report is planned as lows: The introduction to the report includes tions on background and previous research, as well stating the problem and the scope of the research ort. The background and previous research sections tain information on the nature and origin of sludge slurry wastes, their interaction with water, its lacement into mines and any information which was nd concerning the environmental impact of this tice.

The results section of the report will be livided into three sections: the inventory data essment, the assessment of the mine sites studied in ail and an overall assessment. Conclusions alluded n the results section will be listed separately one one at the end of the text of the report. The ntory data assessment subsection of the results

In the conclusions section, a summary of major conclusions and recommendations will be presented. The reference section will include all published and unpublished written information drawn upon in the report. Personal oral and written communication references will also be included in the references.

The appendices section shall include the following:

Appendix A - Tabularized information for each disposal project and separately, additional information on many disposal projects either to clarify tabularized information or to present additional data which did not lend itself to easy tabularization.

Appendix B - Results of Mann-Whitney U Tests used to determine the significance of observed trends in water quality data.

Appendix C - Laboratory analyses of water and waste samples obtained in the field at mines used for detailed study.

Appendix D - The listing of statistics ran on the water quality data submitted by the coal companies that was used for the statistical analyses.

Appendix E - Listing of existing raw water quality data submitted by the coal industry.

Appendix F - Method of statistical testing, including the fortran programs used to generate Mann-Whitney U Values and tied observation values.

Appendix G - Methods of converting tons of solids to million gallons, showing one sample calculation and a listing of the original and converted data from disposal projects where this conversion was necessary.

Appendix H - Tables showing information compiled on mining chemicals commonly used in coal preparation and in acid mine drainage treatment.

Appendix I - Preliminary and detailed questionnaires and memorandums sent to the coal industry to compile information on the disposal of slurry or sludge into underground mines.

Confidential information such as the name and address of the coal companies, mine, source of waste, phone numbers and names of contact persons will be provided separately to the state. Also, files maintained for each disposal project will be presented to the state upon completion of the project.

To give you an update on the current status of the research effort, at the present time the main introductory section, including the objectives, background, previous research, and methods of investigation sections are completed and are in the process of being reviewed.

Data analysis for the results and conclusions sections is completed save the outstanding analyses previously mentioned. Late receipt of water quality information from two mines slowed down this process so that it was only completed in early December. Despite this, approximatey three-quarters of the results and conclusions section has been written. It is estimated that the results and conclusion sections will be completed and ready for review (pending receipt of laboratory analyses) by the fifth of January. If we do not receive the analyses we expect from DNR, the final report will have to be written without them, since the final deadline is imminent.

Sincerely,

Diane Smith

Diane Smith
Geology Graduate Student
West Virginia Univesity

SECTION 5.1.4

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	From Underground Injection Operations in Texas: A Classification and Assessment of Underground Injection Activities; Report 291
AUTHOR: (OR INVESTIGATOR)	Ben F. Knape, Texas Department of Water Resources
DATE:	December 1984
FACILITY NAME AND LOCATION:	Terlingua, Texas, USEPA Region III
NATURE OF BUSINESS:	Not applicable

BRIEF SUMMARY/NOTES: These wells are typically defined as those that are drilled into mined-out portions of subsurface mines for the purpose of filling them by injection of a slurry of sand, mill tailings, or other solids. This definition does not apply "strictly" to mine backfilling in Texas.

The first mine backfill "wells" are part of a recent project involving the sealing off or filling of some abandoned Terlingua mercury mines in Brewster County. The plans provide that shafts deeper than 100 feet will be sealed off by emplacement of steel grates in concrete collars. Shallower shafts will be filled with local soils and mine spoil removed in digging original shafts and mine workings. These are referred to as mine backfill wells because of their dimensions.

The project area is dominantly characterized by Cretaceous marine limestones and shales intruded by numerous Tertiary dikes, loccoliths and plugs. The lowermost unit that has yielded commercial quantities of mercury is the Santa Elena limestone, which locally yields potable water and is the most important aquifer in the area. Typical depths of this aquifer range from 700 to 800 feet, and very little groundwater occurs above these depths. Consequently, the backfill project will be essentially dry, occurring several hundred feet above groundwater.

Rainfall or runoff may constitute a source of recharge, but this is believed to be minor in that the project area is within the Chihuahuan desert, an area characterized by less than 12 inches of rainfall annually. Traces of mercury in the mine backfill material are considered an insignificant source of groundwater contamination relative to pre-existing contamination by in-place mercury.

MINE BACKFILL WELLS

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MINE BACKFILL WELLS

Introduction

Mine backfill wells are usually defined as wells drilled into mined-out portions of subsurface mines for the purpose of filling them by injection of a slurry of sand, mill tailings, or other solids. The term "mine backfill wells" has also been used in a different sense in reference to water wells or monitor wells drilled into backfill of surface mines. This use of the term will not be considered further in this chapter.

Only four underground mines are believed to be active in Texas: two salt mines, a limestone mine, and an abandoned silver mine being reactivated. None of these mines are believed ever to have utilized mine backfill wells in their operations. As far as can be determined, this technique of backfilling underground mines has never before been utilized in the State.

The largest, and at one time the most important, underground mines in Texas are those of the Terlingua mercury district and smaller genetically related districts in the Trans-Pecos region. Now completely abandoned, the very extensive Terlingua district workings yielded over 150,000 76-pound flasks of mercury from a number of mines during the first half of the present century. The Chisos Mine alone has over 23 miles of underground workings.

A recent project involved sealing off or filling some of the abandoned Terlingua mercury mines and prospect workings. This project included the first use of mine backfill wells in Texas.

The Terlingua mercury district, which includes the mine backfill project area, is in southern Brewster County about 80 miles south of the City of Alpine and consists of a rather narrow band extending westerly from the town of Study Butte for about 20 miles. The mining district lies just north of the western portion of Big Bend National Park as shown in Figure 12-1. The Terlingua Abandoned Mine Land Project encompasses an area within the Terlingua mercury district extending westerly from Study Butte along Farm to Market Road 170 (FM 170) about 16 miles to near Lajitas Mesa.

The major industry in this sparsely populated area is tourism. During the tourist season accomodations in and near Big Bend National Park are in short supply. Many tourists travel FM 170 enroute to and from facilities in Lajitas. Adobe and stone ruins associated with the former mine activity are clearly visible from FM 170. The land is almost entirely unfenced, and tourists attracted by the ruins can unknowingly enter areas rendered extremely dangerous by the presence of open and unmarked shafts. In 1982, a boy fell almost 300 feet to his death in one of the shafts, and in mid-1983 another person was reported missing in the area. Probably hundreds of shafts and prospect workings exist within the mercury district. Only a limited number, all easily accessible from FM 170, are included in the project.

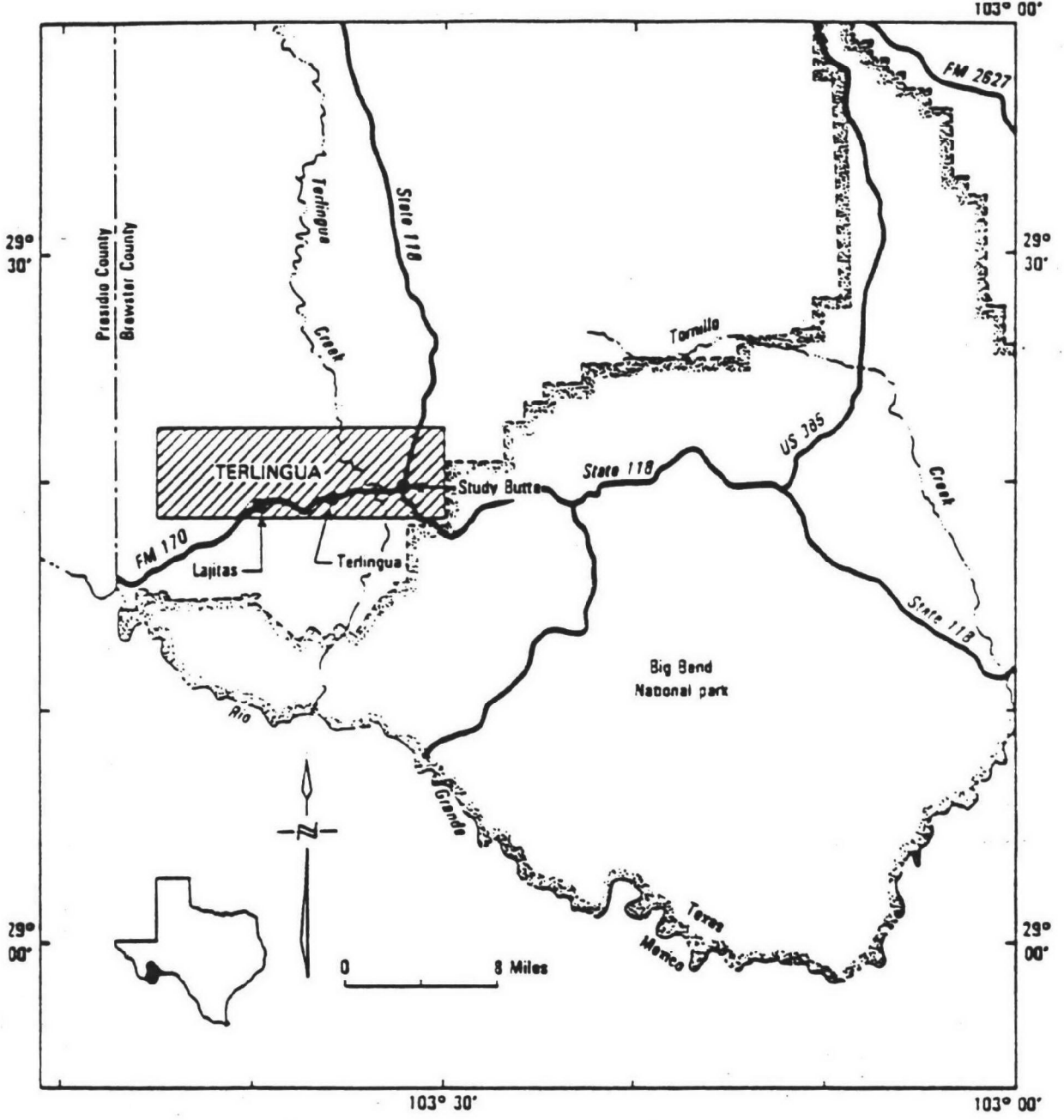

Figure 12-1.—Location of the Terlingua Mercury District in Trans-Pecos Texas (Modified after Sharpe, 1980)

Geohydrology

The Terlingua area is part of the Chihuahuan desert, which is characterized by an arid subtropical climate. Annual rainfall averages less than 12 inches, most of which occurs during the late summer months. Summer rains are often torrential and are usually highly localized. Vegetation is sparse to moderate in density, consisting mainly of desert forms such as yucca, cacti, and agave. Creosote bush, mesquite, and catclaw occur mainly along usually dry watercourses. The few trees in the area are cottonwoods which grow along the major arroyos. The abandoned mine area is located in a heavily dissected terrane of rocky slopes and ravines. Its elevation ranges from about 2,500 to 3,300 feet.

Stratigraphy and Structure

The rock strata of concern in the Terlingua area are Cretaceous sediments, dominantly limestone and shale. These are intruded by Tertiary sills, dikes, laccoliths, and plugs of variable igneous composition. Faults and tectonic fractures are abundant. The stratigraphic nomenclature utilized herein is that of the Emory Peak-Presidio Sheet of the Geologic Atlas of Texas (Bureau of Economic Geology, 1979).

The oldest stratigraphic unit entered by the deeper mine shafts of concern is the Santa Elena Limestone of late Lower Cretaceous age Mercury is not known to occur in significant quantities below the upper part of the Santa Elena. The Santa Elena Limestone is white to light gray, fine grained, and massive in character. Its thickness is unknown in the project area, but elsewhere in the Big Bend region it is known to range from about 500 feet to more than 900 feet. The Santa Elena is the primary aquifer in the Terlingua district.

Overlying the Santa Elena is the Del Rio Clay, which ranges up to about 180 feet in thickness. The Del Rio is dominantly bluish to gray structureless clay with some interbedded flaggy limestone

Less than 100 feet of Buda Limestone overlies the Del Rio The Buda is a grayish white limestone containing a middle member which is argillaceous and marly

The Boquillas Formation, the basal unit of the Upper Cretaceous, is the most prominently exposed unit in the project area. The lower Ernst Member is a bluish gray, flaggy, silty limestone grading to siltstone; the overlying San Vicente Member consists of thin to medium bedded, chalky, argillaceous limestone flags interbedded with gray marl.

The Pen Formation overlies the Boquillas. The Pen, the youngest formation of pertinence to the Terlingua mining project, is about 1,000 feet thick in the area and consists dominantly of clay, which is calcareous with thin chalk beds in the lower part and sandy with some sandstone beds in the upper part.

With one notable exception, to be discussed, the Tertiary igneous intrusions in the region have no direct relationship with the hydrology of the project area and need not be considered here These intrusions also lack a direct relationship with the mercury mineralization, which took place later, although there is probably an indirect genetic relation in that the intrusions may have differentiated at depth from the same parent magma that was the later source of mercury-bearing hydrothermal solutions.

Aquifers

Because of complex faulting of the rock formations and extreme paucity of well data in the area, few generalized statements can be made regarding the hydrology of the Terlingua area other than to say that the Santa Elena often yields potable water and is the most important aquifer known in the area. Ragsdale (1976) records that when the Chisos Mine shafts penetrated below the 700-foot level, a large quantity of water unsuitable for household use was encountered and sealed off Usable water was later discovered near the 800-foot level. The usable water undoubtedly came from the Santa Elena, but the source beds of the unusable water must be considered

any report of water being encountered. It is probably safe to state that in most of the project area there is no ground water above a depth of several hundred feet.

A major exception to the preceding statement occurs in the vicinity of Study Butte at the eastern extremity of the project area. The Study Butte intrusion, of fine-grained quartz soda syenite, forms the hill of the same name. It is intruded into clays of the Pen Formation. The intrusion is cut by abundant joints and fractures, enabling it to function as a local aquifer. This intrusion is mentioned here because a mine shaft located near the road at Study Butte is part of the abandoned mine project. The shaft will be covered by a steel grating and is not one of the proposed mine backfill wells. The water level in the shaft is about 20 feet below land surface, approximately where water was encountered when the shaft was first opened.

Abandoned Mine Project Ground-Water Impact

The Terlingua Project plans provide that the mine shafts deeper than about 100 feet will be sealed off by emplacement of steel grates in concrete collars at the shaft openings at ground surface. These deep mine shafts, at least near the surface, are roughly square to rectangular in horizontal section. In contrast, the shafts and various prospect workings shallower than this arbitrary depth are to be filled with available solids which will include local soils and mine spoil. Shafts and workings of the shallower category will be regarded as mine backfill "wells," being generally deeper than they are wide. The backfill wells are highly variable in shape and size. While the deeper of these backfill wells resemble the deepest mine shafts in cross-sectional size and geometry, some of the shallower ones may be little more than infillings of irregularly oblong pits barely large enough for one man to have worked with hand tools.

Unlike more conventional mine backfill wells, the injected materials for the Terlingua project, usually consisting mainly of spoil removed in digging the original shafts and prospect workings, will be essentially dry, as will the wells themselves. As mentioned earlier, ground water is not known to occur above a depth of several hundred feet in the project area, except in the local Study Butte aquifer. The ground-water contamination potential of the project is apparently nil.

It is of course recognized that any open shaft into permeable sediments or any shaft backfilled with permeable material which is allowed to collect rainfall or runoff may constitute a minor source of water recharge to the unsaturated zone overlying the local aquifers. The possibility of mobilization of toxic mercury compounds from mine tailings used as backfill should be insignificant, considering that the possible effect of the mercury ore minerals on the water quality of the local aquifers has been a natural and pre-existing condition in the Terlingua mine district.

The only practicable alternative to the methods proposed (i.e., steel gratings at shaft openings, and use of mine backfill wells) is the erection of fences around the shafts. This option would be more expensive, and as demonstrated by fenced shafts in Big Bend National Park, would involve heavy maintenance expense. Some tourists have already tried to climb or burrow under fences around shafts in the park.

Legal and Jurisdictional Considerations

To eliminate the dangers of open mine shafts, the Governor declared a state of emergency on December 3, 1982, and requested federal assistance for the Terlingua Abandoned Mine Land Project. As a result, the Railroad Commission of Texas received an Administrative Grant for funds under Section 409 of Public Law 95-87 (Abandoned Mine Land Program) to remedy the hazardous situation. Railroad Commission personnel have identified 88 mine shafts or prospect workings within the mercury district which are easily accessible from FM 170 and, therefore, constitute public hazards.

The Department's authority under Chapter 27 of the Texas Water Code extends to regulation of injection wells. It has been determined that, for regulatory purposes, the shallower group of shafts and workings which are to be filled with solids are mine backfill wells, a category of Class V injection wells.

Concluding Statement

It has been shown that the Terlingua mine backfill project should have no impact upon ground-water resources. If other mine backfill wells should be proposed in the future, their potential effect upon ground-water quality should be evaluated on a case by case basis

Bureau of Economic Geology, 1979, Geologic atlas of Texas, Emory Peak-Presidio sheet: Univ. Texas, Bur. Econ. Geol. map.

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Ragsdale, K. B., 1976, Quicksilver, Terlingua and the Chisos Mining Company: Texas A&M University Press, College Station, Texas.

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_____1983b, Supplement for environmental assessment of the Terlingua abandoned mine project, Brewster County, Texas: File report, Austin, Texas.

Sharpe, R. D., 1980, Development of the mercury mining industry: Trans-Pecos Texas: Univ Texas, Bur Econ Geology, Mineral Resources Circular 64

Yates, R. D., and Thompson, G. A., 1959, Geology and quicksilver deposits of the Terlingua district, Texas U S. Geological Survey Professional Paper 312.

SECTION 5.1.5

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	From Missouri Underground Injection Control Program Class V Assessment
AUTHOR: (OR INVESTIGATOR)	Not available
DATE:	December 1986
FACILITY NAME AND LOCATION:	Missouri, USEPA Region VII
NATURE OF BUSINESS:	Not applicable

BRIEF SUMMARY/NOTES: This portion of the Missouri study addresses the Tri-State Mining District, where numerous shafts communicating surface water and groundwater still exist. Zinc and lead mining was conducted in a four-quadrangle area around Joplin, and 500 million metric rock tons were mined from 1848 to 1970. After the mines were closed, the abandoned workings were allowed to flood, causing such environmental and safety hazards as subsidence, numerous open shafts and water-filled pits, and local influence on surface water due to seepage from tailings piles and artesian flow from mine workings.

Zinc and lead ore deposits were recovered from Mississippian cherty limestones (>400' thick) which are also considered to compose a shallow aquifer in the area. Recharge to this aquifer is local and often direct, and some of the open pit lakes are probably hydrostatically connected. A deeper aquifer is made up of Cambrian-Ordovician strata and is the major drinking water supply for the area. Recharge areas to this aquifer lie outside the region of interest.

Groundwater sampled from the abandoned mine workings generally exceeds level for cadmium, copper, lead, and zinc set forth by the Public Health Department in 1962. Sodium and iron levels are often noted to be adversely high. It is recommended that water wells should be effectively cased across this shallower aquifer so that production is from the deep aquifer only.

The use of concrete on metal inverted pyramids, covered with mine tailings, has been proposed for backfilling. This would permit economical mine re-entry in the future if ore prices increase.

7. MINE BACK-FILLED WELLS

7.1. Introduction

Mine back-filled wells are usually defined as wells drilled into mined-out portions of subsurface mines for the purpose of filling them by injection of a slurry of sand, mill tailings, or other solids. The UIC Program in the State of Missouri would like to see the term redefined to include shafted mine entrances as these constitute a connection between subsurface aquifers and surface waters.

The State of Missouri has a long history of mining, both surface and underground workings, and consequently has numerous shafts that communicate surface water and groundwater. These shafts pose numerous problems in the area of groundwater protection. For the purpose of this study, we will look at four quadrangles in the vicinity of Joplin, Missouri (Figure 7-1). These quadrangles are located in the Missouri portion of the Tri-State Mining District and constitute the largest area of mining in the State this area also includes most of the large mining subdistricts.

From 1848 to 1970 the Tri-State Mining District of Missouri, Kansas and Oklahoma produced zinc and lead concentrates worth over 2 billion dollars. The ore production from this district, which ranks as the world's largest, exceeds 500 million metric rock tons. Within the District zinc ores were about six times as abundant as those of lead. The removal of

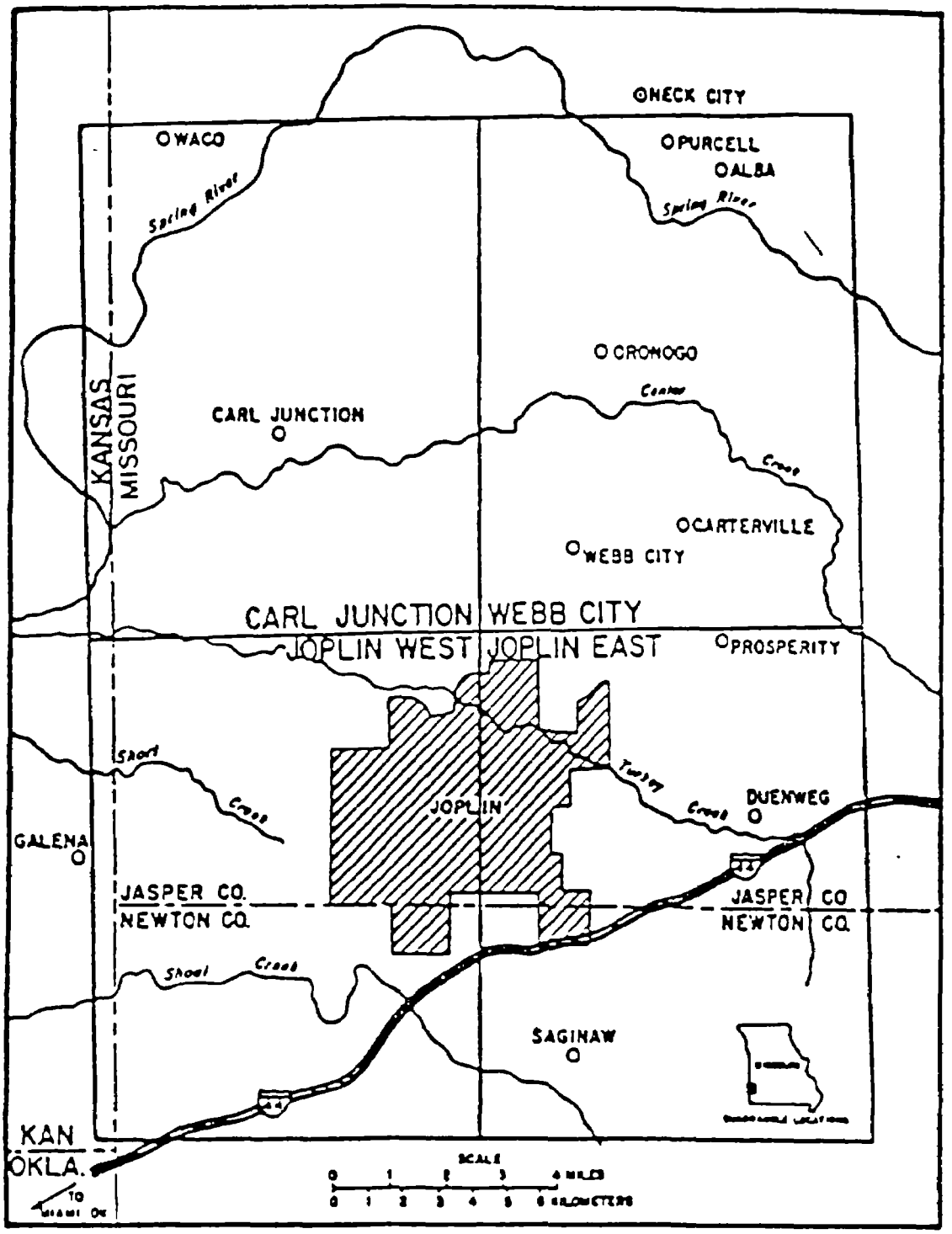


FIGURE 7-1

LOCATION MAP SHOWING STUDY AREA

the mineralized beds created large underground voids, some with very thin weak ceilings. The stripping of the ore bearing support pillars at the end of the mining activity lead to increased roof instability. Following shut-down of the mining operations, the underground workings were allowed to flood. The abandoned mines now pose several types of safety and environmental hazards to area residents. Subsidence or sinking of the ground surface has resulted from roof collapse above the mine workings. There are numerous open shafts and water-filled pits throughout the region. Local surface water quality has also been effected by rain water runoff and seepage from mine waste piles and by artisan flow of polluted mine water from open shafts. These problems have been recognized for some time, but there has been no concentrated effort to correct them.

7.2. Geohydrology

7.2.1. Geology Stratigraphy and Structure

The zinc lead ore deposits of the Tri-State region are in cherty Mississippian limestones. The chert occurs as nodules in limestones and as inter-bedded layers. From oldest to youngest, the Pierson, Fernglen, Reeds Spring, Elsey, Grand Falls, Burlington, Keokuk, Warsaw, and Carterville Formations were host rocks for most of the zinc/lead mineralization. Their total thickness in area exceeds 400 feet. Small outliers of Pennsylvanian Cherokee formation shales and sandstones lie unconformably on top of the Mississippian rocks in some localities. Rich ore bodies are associated with these Pennsylvanian sediments where they

have filled dissolution structures, sinkholes, and collapses in the Mississippian strata.

Throughout the Tri-State district extensive chemical dissolution of carbonate rock produced horizontal and vertical channels, porous breccia zones, insoluble cherts, and other subsurface cavities. These voids proved excellent repositories for ore precipitation and concentration of mineralized fluids.

The structure in the area is limited to gentle folding, the axis generally plunging northwest. The regional 1^{o} dip of the sedimentary formations is also northwestward away from the Ozark uplift. The Joplin anticline and adjacent Webb City syncline are believed to have influenced the localization of rich trends of mineralization around Joplin in Webb City. Minor faulting and fracturing provided increased zones of rock dissolutions and eventually channels for ore bearing fluids.

7.2.2. Aquifers

Two major aquifers are available for water production in the area. The Mississippian strata act as one unit, the Cambrian Ordovician strata is a second. The first unit will be called the shallow aquifer in this report and the second unit is referred to as the deep aquifer. These two units are hydrostatically separated with the piezeometric surface of the shallow aquifer higher than that of the deeper aquifer. The recharge areas for the deep aquifers lie outside of the area except for local

seepage through the Northview and the Chattoonaga formations. Recharge of the shallow aquifer is local and is quite often direct. Local drainage in some areas discharges directly into abandoned mine workings during periods of rainfall. Some of the open pit lakes are probably hydrostatically connected to the shallow aquifer system. Springs, the majority of which are located along Shoal Creek, all discharge from this shallow or Mississippian strata.

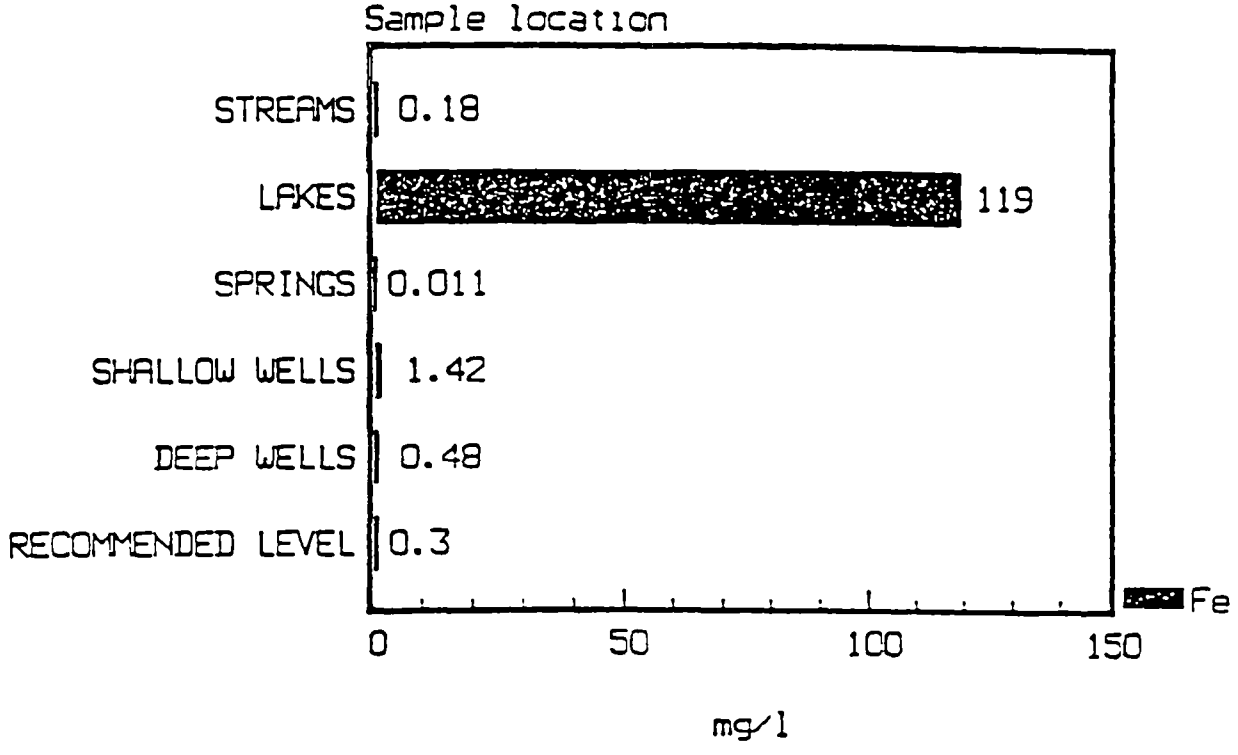
Mine related water quality problems exist throughout the study. Many open shafts were found to have wet weather or perennial artisan flow of mine waters to the surface. Rain water runoff and seepage from the waste piles is also common. The effects of these processes have been examined and some possible solutions proposed (Barks 1977, Warner 1977, and Stewart 1980). Stability problems arise as the downward movement of surface waters accelerates, causing the deterioration of ground adjacent to open shafts thus promoting further collapse. In addition, subsided areas experience increased widening of their parameters as well as further steepening and other undercutting of other slopes. Back filling or sealing of hazardous sites would greatly reduce the damaging affect of such waters as well as help to alleviate some of the ground water problems caused from the introduction of surface water into the aquifer(s).

7.2.3. Abandoned Mine Groundwater Impact

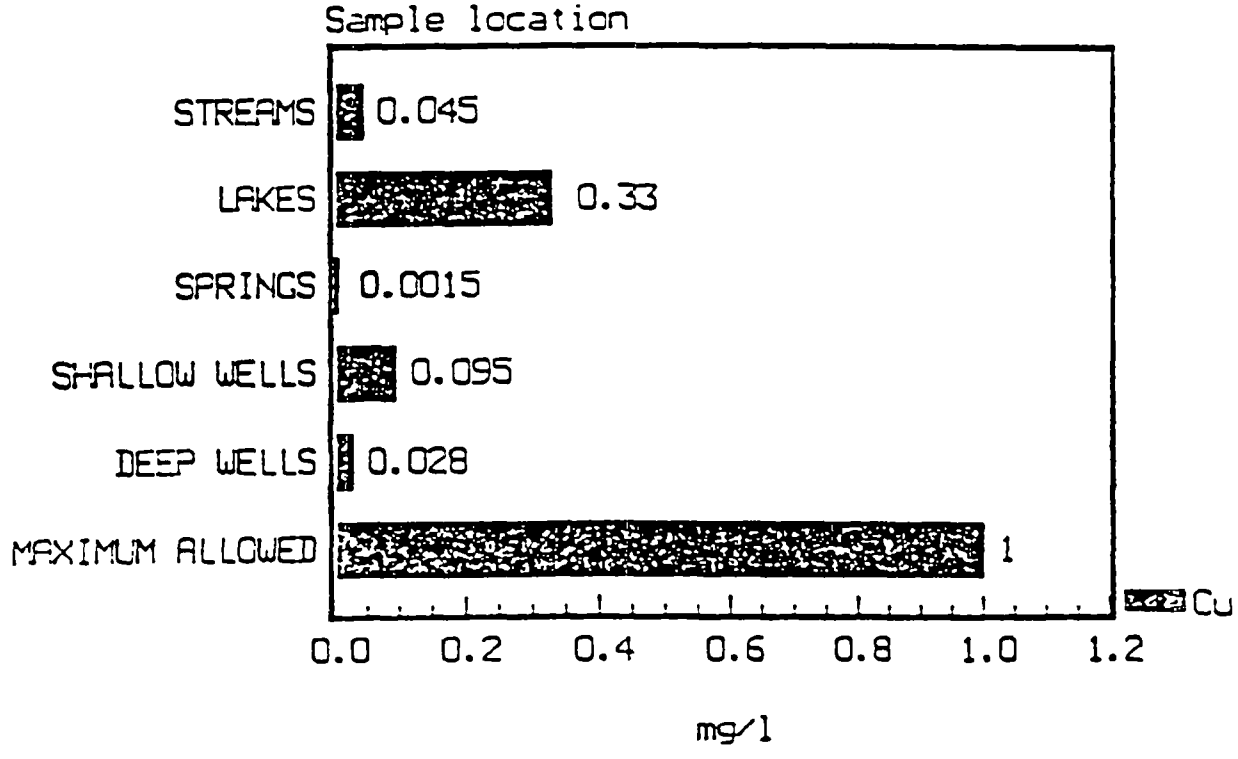
The purity of the majority of the water samples generally exceeded the recommended limits for cadmium, copper, iron, lead, and zinc set by the

Public Health Service in 1962 for drinking water (Figure 7-2). However, a few samples with values for one or more metals in excess of these limits would indicate a need for some care in selection of water supplies for human consumption. Cadmium may represent the major hazard in this regard. Lead apparently presents no problem in this regard even though lead mineralization occurs in the district. Iron reached objectionable levels for normal household use in a number of samples though it does not normally present a health hazard. Sufficient copper and zinc are present in a number of samples to endanger some forms of aquatic life including some species of fish. It should be noted that long and continued use of some polluted waters may contribute to health problems in ways not presently understood even though the heavy metal contents are below the recommended limits. The sodium content of some samples, especially those treated by some types of water softeners, may pose a problem to people requiring a low sodium diet. It would be wise for people with this problem to have a check made on the sodium content of their drinking water supplies. Water supplies having a known or suspected close connection to mining activities, i.e. open pit lakes, underground workings, or wells in mined areas should be tested prior to use to insure against contamination from such sources. Properly cased deep wells where the shallow aquifers are sealed out are probably the safest source of water since they are not connected to mineralized ground at shallower depths. Due to the calcium magnesium contents all groundwater in the area is relatively hard and would be found objectionable for some special purpose uses.

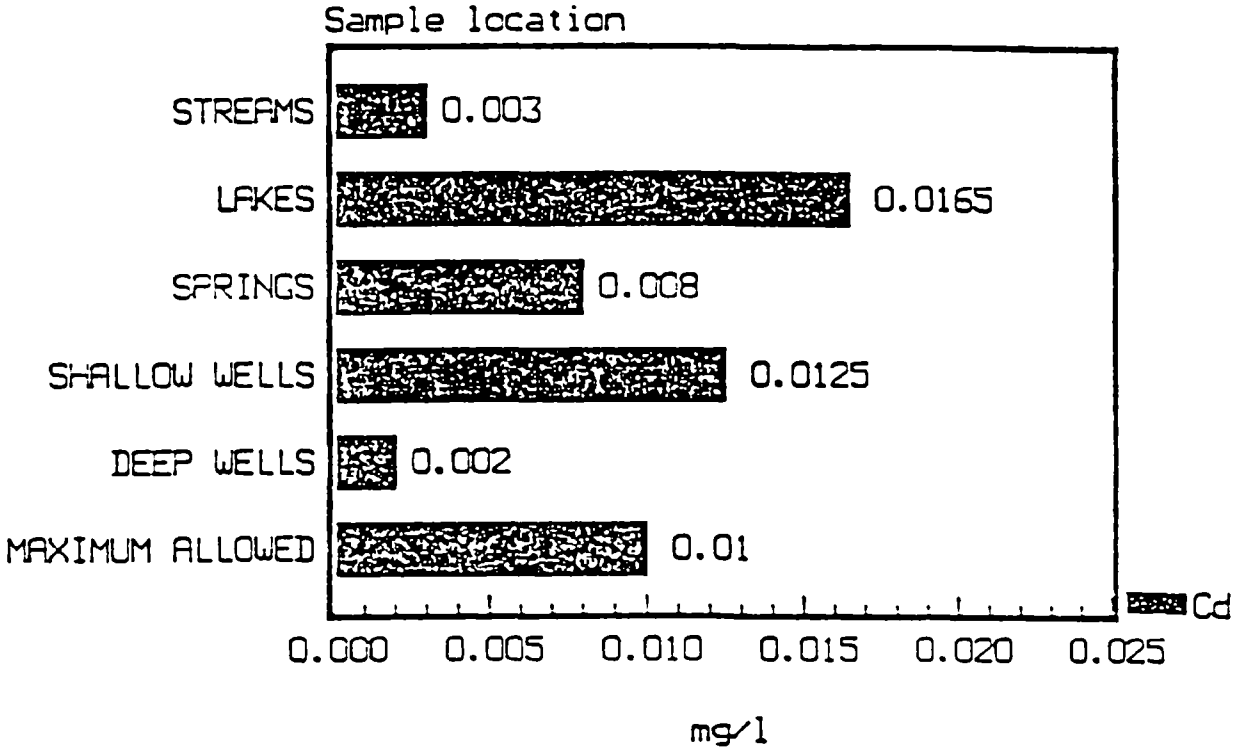
OBSERVED MAXIMUM CONCENTRATIONS OF METALS FOUND IN SURFACE AND GROUNDWATER SAMPLES FROM THE JOPLIN, MISSOURI AREA



OBSERVED MAXIMUM CONCENTRATIONS OF METALS FOUND IN SURFACE AND GROUNDWATER SAMPLES FROM THE JOPLIN, MISSOURI AREA

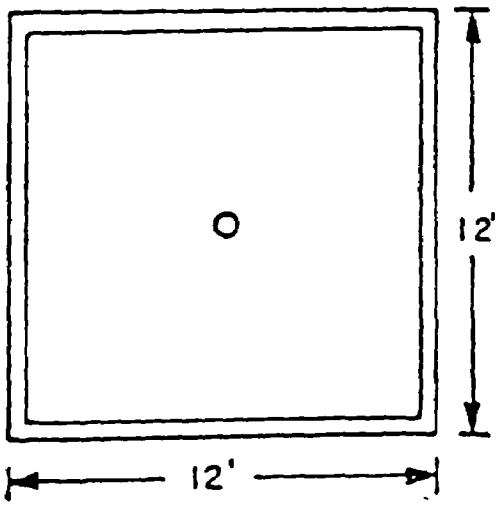


OBSERVED MAXIMUM CONCENTRATIONS OF METALS FOUND IN SURFACE AND GROUNDWATER SAMPLES FROM THE JOPLIN, MISSOURI AREA



The use of concrete or metal inverted pyramids as a closure method for these shafts has proven effective in a case study done in Galena, Kansas (Figure 7-3) (Dressel 1985). Considering the amount of back-fill material that is still present in the Joplin area, and the number of open shafts that occur within the study area (approximately 478 shafts) it would probably be of a more economic nature to put these inverted pyramids into the shaft openings and use the tailings piles as a cover after the emplacement of the pyramids. This procedure also allows for economical reentry of the mine should future prices warrant.

It has been shown that the Joplin Tri-State District constitutes a major problem for groundwater in the area and that other areas, notably the Old Lead District and the new Virburnum Trend District, should be monitored. Back-filling of these mine shafts or the emplacement of pyramids in the shafts will probably be proposed in the future. Regardless of what decision that is reached on these mines the potential effects from any mine on the groundwater quality should be evaluated on a case by case basis.



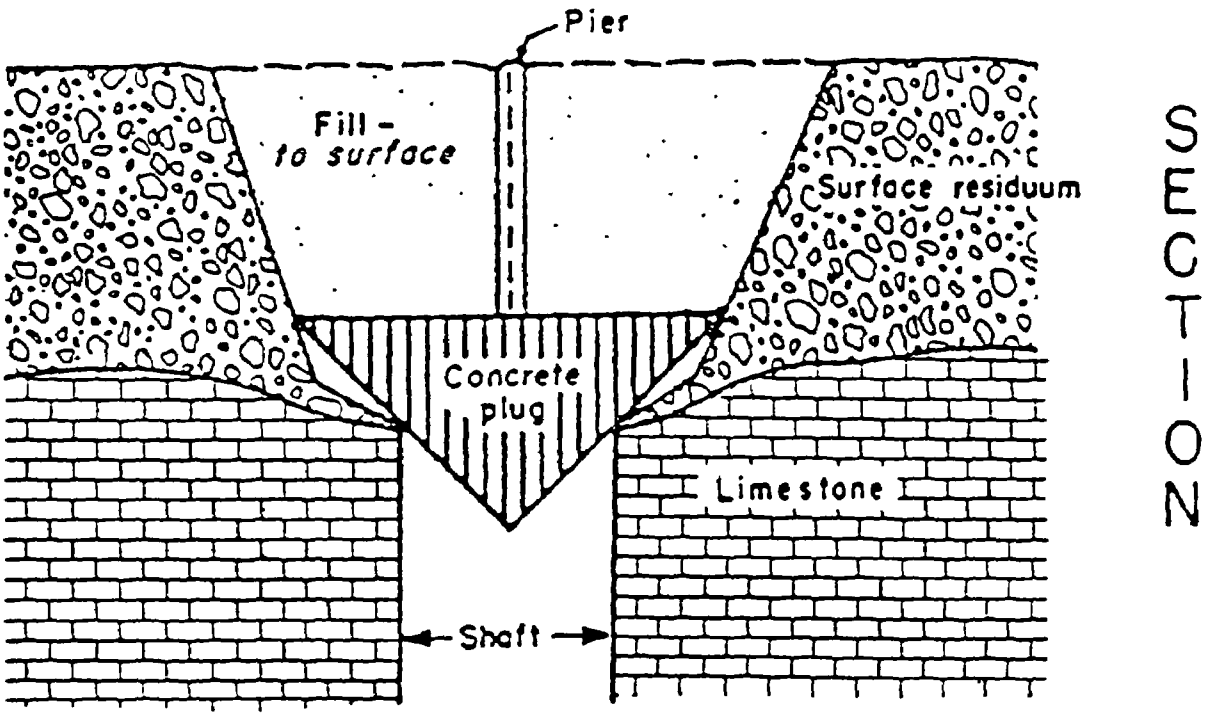


FIGURE 7-3
INSTALLED PLUG

SECTION 5.1.6

TITLE OF STUDY: Backfill Monitoring Methods
(OR SOURCE OF INFORMATION)

AUTHOR: March A. Hulbert
(OR INVESTIGATOR)

DATE: Winter 1983

FACILITY NAME AND LOCATION: Not Applicable

NATURE OF BUSINESS: Not Applicable

BRIEF SUMMARY/NOTES: This study examines the most critical assumption in the prediction of post-mining hydrologic conditions: characterization of the replaced spoil material. Recommended approaches are intended to allow early definition of backfill properties and enhance understanding of spoil aquifer systems prior to full post-mining saturation and equilibration of the hydrologic system.

The Surface Mine Control and Reclamation Act requirements necessitate the ability to predict and control re-establishment of the hydrologic system within backfill materials. This level of prediction and control has not yet been achieved. However, many tools are presently available to begin to study and understand the characteristics of these new systems. These tools include geophysical logs if water can be retained in the wellbore, and pump, bail or slug tests to determine permeabilities of backfill aquifers as a whole.

BACKFILL MONITORING METHODS

Predicting and controlling the reestablishment of the hydrologic system within backfill materials is discussed

by Margery A Hulburt

The 1977 Federal Surface Mine Control and Reclamation Act regulates surface mining operations with respect to environmental impact In the area of ground-water hydrology the Act includes three major requirements The surface mining operation must be designed to 1) preserve the hydrologic balance of the area 2) prevent material damage to the hydrologic system off-site and 3) minimize degradation of groundwater quality and quantity

These requirements, when applied to the long-term, post-mining hydrologic system, become very difficult if not impossible to meet They imply not only the ability to accurately predict post-mining hydrologic conditions, but also the ability to control development of the post-mining system through manipulation of mine operations design Both of these abilities are beyond the industry's current state of knowledge

This article examines the single most critical assumption in the prediction of post-mining hydrologic conditions the character of the replaced spoil material Early studies of backfilled spoil in Montana and northern Wyoming are briefly discussed and recent findings in the Wyoming Powder River Basin are presented Based on these findings several alternative approaches to backfill testing and characterization are recommended These approaches are intended to allow early definition of backfill properties and enhance understanding of spoil aquifer systems prior to full post-mining saturation and equilibrium of the hydrologic system

Wyoming Powder River Basin

One of the largest surface minable coal reserves in the United States is found in the Powder River Basin of Wyoming There are currently 15 surface mines operating or under construction in the basin the oldest of which has been active since 1922 Several of these operations now contain pit areas which have been mined out and backfilled with spoil material Wells have been completed in backfill material at several sites and information about the properties of this material is slowly being developed

Most testing of backfill material in the Powder River Basin has been done within the last two years, while hydrologic requirements of the Surface Mine Control and Reclamation Act have been in effect since 1977 In order to predict post-mining hydrologic conditions as required by the Act assumptions about the characteristics of backfill aquifers have been made based on early studies conducted in northern Wyoming and Montana.

The Work of Rahn and Van Voast

Two researchers Perry Rahn and Wayne Van Voast studied backfilled spoil materials at six western surface coal mines in the mid-1970s Rahn investigated spoils at the Hidden Water Creek and Bighorn Mines both near Sheridan, Wyoming The Hidden Water Creek Mine is a dragline operation while the Bighorn Mine employs bulldozers and scrapers for spoil handling Rahn found the backfilled spoil to be saturated at both mines Through the use of multi-well pump testing he obtained transmissivity and storage values of 11 050 gpd/ft and 0 17 respectively for the Hidden Water Creek Mine, and 172 gpd/ft and 0 233 respectively for the Bighorn Mine These data indicate that spoils at the Bighorn Mine have a post mining transmissivity comparable to that of the unmined formation while spoils at the Hidden Water Creek Mine have a transmissivity much higher than pre-mining conditions These differences were attributed to the method of spoil placement and resulting differences in compaction of the backfilled material Generalizing from these findings scraper-emplaced spoils can be expected to have post-mining transmissivities similar to pre-mining conditions Dragline-emplaced spoils can be expected to exhibit transmissivities much higher than in the pre-mining state (Rahn 1976)

Van Voast investigated spoils at the Absaloka Rosebud Big Sky and Decker Mines in southeastern Montana Spoil saturation was found at all four sites Aquifer testing at these sites indicated that on the average, spoil transmissivity is comparable to that of the unmined coal (Van Voast et al 1978)

Based on these early findings, three assumptions regarding the development of backfill aquifers have been made almost universally among operators in the Powder River Basin of Wyoming They are: 1) backfilled spoil materials will resaturate 2) a single backfill aquifer will form within the spoils with a water level approaching pre-mining

nditions, and 3) backfill aquifer nsmissivity will be comparable to hat of the unmined coal These ssumptions have, in general, been ised as the basis for predicting on- and off-site post-mining hydrologic conditions

Recent Findings

Backfill wells have been established in recent years at the AMAX Belle Ayr Mine, the Wyodak Resources Development Corp Mine the Kerr-McGee Clovis Point and Jacobs Ranch Mines, and the ARCO Black Thunder Mine, among others Of these sites, only Wyodak has shown water in the backfill wells

A bail test was performed on each of two wells at the Wyodak operation. Pump testing was attempted, however the permeability was insufficient to allow sustained operation of a pump The test results indicated very low transmissivities in the order of 5 gpd/ft Unfortunately, baseline data are not available for the site for either the coal or overburden aquifer Tests performed in the area after mining began indicate an average coal transmissivity of 500 gpd/ft and a range of overburden transmissivities from 1 to 38 gpd/ft (Wyodak 1981)

Slug tests were performed in backfill wells at the Kerr-McGee Clovis Point and Jacobs Ranch operations In both cases it was found that the wells could not be filled with water Evidently a highly permeable zone exists which is able to accept water as fast as it is injected preventing the well from filling to the top Transmissivities were calculated for these permeable zones as 81 gpd/ft at the Clovis Point site and 911 gpd/ft at the Jacobs Ranch site The zones above the permeable layers could not be characterized Lower 1982)

Initially, water was present in backfill wells constructed at the AMAX Belle Ayr Mine however once this water was removed, the wells remained dry (AMAX 1981) Backfill wells have been constructed only recently at the ARCO Black Thunder Mine and have been dry since emplacement (Glaze 1982)

Comparison With Early Studies

The results of backfill monitoring in the Wyoming Powder River Basin to date show that at the majority of the sites tested, the replaced spoil materials have not yet recharged At one site, saturation has been found but with very low permeability Several conclusions have been drawn from the results of testing done so far and indeed backfill conditions may vary between mine sites

Contrary to the Montana findings the Wodak testing indicates that the backfill will saturate but that the permeability of the backfill aquifer will be much lower than the permeability of the unmined coal Instead backfill permeabilities appear to approximate pre-mining overburden values

Kerr McGee Clovis Point and Jacobs Ranch test data indicate that although the spoil materials are currently dry, there is a high potential for development of a viable aquifer upon resaturation of the backfill There is strong evidence for development of a "base-of-lift aquifer near the bottom of the replaced spoil Whether additional aquifers will form at the base of higher lifts is unknown

Evidence from the AMAX Belle Ayr Mine indicates that the spoils may never resaturate to a viable backfill aquifer at this site Laboratory analysis of the backfill material shows that it is predominantly clay and consists of a high proportion of swelling clays AMAX has postulated that upon contact with water, clays within the backfill will swell and reduce spoil permeability to practically nothing Based on this theory AMAX has initiated a sophisticated special handling program to segregate sandy overburden materials from the bulk of the spoil These sandy materials are then selectively replaced in the backfill to recreate permeable sand channel aquifers within the low permeability spoils (AMAX 1981)

Post-Mining Hydrologic Systems

Three post-mining hydrologic conditions can be postulated in the Wyoming Powder River Basin 1) backfill aquifers will form with very low permeabilities 2) viable aquifers will form at the base of one or more lifts within the backfill, and 3) backfill aquifers will not form Further testing may give rise to additional scenarios Each of these possible backfill conditions affects the overall post-mining hydrologic regime in a different way and requires its own level of mitigation to meet the requirements of the Surface Mine Control and Reclamation Act Clearly time is required to prove the validity of these postulates However early monitoring and testing of backfill materials can indicate potential problems before the mining operation is too far underway

The preliminary findings from the Wyoming Powder River Basin raise as many questions as they answer concerning the hydrologic nature of backfill materials In the case of a low permeability backfill aquifer the immediate question is why the permeability is not greater than it is Low permeability could be due to the lithology of the spoil materials the method of spoil placement or possibly the difficulty in developing backfill wells adequately The uniformity of the spoils both vertically and laterally is also of interest, as is the question of changes in spoil permeability over time

In the case of backfill wells containing no water the overriding concern is the potential for recharge of the spoils at some time in the future Saturation of the backfill material may simply be a matter of time or there may be evidence that recharge will not occur Such evidence may come from the lithology of the replaced spoil the method of emplacement vertical and lateral uniformity of the spoils or the presence of identifiable permeable zones within the backfill

Where a permeable basal layer is indicated in the backfill the question arises as to the continuity of that layer and its relationship to the overlying materials The character of these overlying materials is also of interest particularly whether or not they contain additional high permeability zones Finally, the cause of the permeable layer is of interest

Testing of Backfill Materials

New approaches to backfill testing can provide additional hydrologic information and predictive data before saturation occurs allowing early modification of mining and reclamation techniques if necessary It is recommended that five areas be investigated in existing backfilled spoil 1) geologic characterization of the backfill material 2) hydrologic characterization of backfill permeability 3) vertical uniformity of the spoils 4) lateral uniformity of the spoils and 5) the relationship of backfill properties to the method of spoil placement The approach and intensity with which each of these areas is investigated will be determined by the particular conditions found at each mine site

Geologic Characterization

Geologic characterization of backfilled spoil has been sparse to date Geologic logs of drill cuttings

have been kept during drilling of backfill wells at some sites These have not been particularly useful General homogeneity of the spoils has been seen, with no indication of discrete permeable zones This was found to be the case even at the Kerr-McGee sites where hydrologic testing indicated high base-of-lift permeability Cuttings samples may provide lithologic information such as the presence of swelling clays which reduce permeability however little information is gained regarding particle size of the spoils

Core samples may provide particle size data, however the information is still limited by the diameter of the hole Examination of cores may yield insight into vertical variation or segregation of spoils by lithology If water can be retained in the hole, geophysical logs may be the best indicator of permeability changes

Hydrologic Characterization

Permeability of the backfill aquifer as a whole, or of a basal aquifer zone if present can be determined through the use of pump bail or slug tests This has already been done at three of the sites in the Wyoming Powder River Basin A valuable tool which has not yet been employed is repeat testing of these wells If the wells are drilled with air then repeated aquifer testing over a period of several years may indicate changes in permeability over time within the backfill aquifer If the wells are drilled with water or mud, repeated testing over a period of weeks or months may aid in well development and reflect changes in permeability for this reason

Vertical Continuity

To date, backfill wells in the Wyoming Powder River Basin have been completed throughout the anticipated zone of saturation If geologic or hydrologic evidence indicates that the spoils are not vertically homogeneous, it might be of interest to complete several wells at various depths within the spoil In this way, permeable zones above the floor of the pit can be investigated Well clusters also allow study of the extent of vertical interconnection between permeable zones This relationship may affect the potential for recharge to the lower zone

Lateral Continuity

The lateral uniformity of spoils is also critical to a recharge analysis If a permeable zone is continuous laterally across the backfilled area then fairly rapid recharge from the unmined coal or overburden would be expected If, on the other hand the zone is limited in extent little or no recharge may occur despite the high permeability of the zone The lateral uniformity of spoils can be best examined by completing several wells in the spoil and comparing their geologic and hydrologic characteristics

Mining Method

Finally, a comparison of spoil characteristics with overburden lithology and mining method may be instrumental in predicting future backfill aquifer properties and learning to control the development of backfill aquifers This type of comparison will require study of many backfill sites and mining operations to detect basin-wide trends

Conclusion

The Surface Mine Control and Reclamation Act requirements necessitate the ability to accurately predict and control the reestablishment of the hydrologic system within backfill materials This level of prediction and control has not yet been achieved Although definitive answers will not be attained for many years through observation of the actual development of backfill aquifers many tools are available now to begin to study and understand the characteristics of these new systems

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Biographical Sketch

Margery Hulburt holds degrees in geology from Carleton College, Northfield, Minnesota, and hydrology from the University of Arizona, Tucson. She has been employed as a hydrologist with GE-TEMPO and as a hydrologist and field manager with the University of Arizona Water Resources Research Center. She has recently spent three years as a hydrologist and chief hydrologist for the Land Quality Division of the Wyoming Department of Environmental Quality She is currently employed as an independent geohydrology consultant in Cheyenne, Wyoming

[5-110]

Section 5.2

Solution Mining Wells Supporting Data

SECTION 5.2.1

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Letter to Mr. Mark Bell of the Colorado Department of Health, Denver, RE Underground Injection Control permit requirements
AUTHOR: (OR INVESTIGATOR)	Edward C. Rosar, President, Industrial Resources, Inc.
DATE:	April 14, 1983
FACILITY NAME AND LOCATION:	A single well bulk sampling test in NE-1/4 of Section 27, T1S, R98W, Rio Blanco County, Colorado, USEPA Region VIII
NATURE OF BUSINESS:	Nahcolite Solution Mining

BRIEF SUMMARY/NOTES: The proposed mining plan involves a "Class III" well to: 1) demonstrate the feasibility of solution mining techniques for extraction of nahcolite; 2) optimize the mining process; and 3) evaluate product characteristics. The project will occur over a 6-month period in late 1983 and produce about 250 tons of nahcolite. The solution mining technique will involve the injection of hot water into a saline zone (1795 to 1826 feet below the surface) and dissolved nahcolite will be pumped to the surface. Processing will include dewatering, drying, and crystallizing.

The site is near the center of the Piceance Basin which is an asymmetrical trough filled with Eocene sediments. The Parachute Creek member of the Green River Formation has an upper and lower aquifer, which are the only potential USDW beneath the site. The lower aquifer has been extensively leached where nahcolite has been dissolved from the formation. The injection zone lies about 30 feet below the lower aquifer, and is separated from the aquifer by a zone of relatively competent, unleached marlstones. Within these marlstones are three highly plastic, impermeable kerogen zones.

The proposed monitoring program encompasses three elements: 1) well construction that ensures no migration of injection fluid through the well-bore; 2) calculation of fluid balance during injection and recovery; and 3) installation and sampling of a monitoring well. Water samples will be analyzed for TDS, sodium, potassium, calcium, magnesium, carbonate, bicarbonate, chloride, and sulfate. After completion of the monitoring program, each well will be equipped with a locking steel surface cap. No plugging and sealing is planned so that wells can be used for future monitoring if necessary.

INDUSTRIAL RESOURCES, INC.
SUITE 320
300 UNION BOULEVARD
LAKEWOOD COLORADO 80228
TELEPHONE (303) 980-4507

14 April 1983

Mr. Mark Bell
Colorado Water Quality Control Division
Colorado Department of Health
4210 East 11th Avenue
Denver, CO 80220

RE: Underground Injection Control (UIC) permit requirements.

Dear Mr. Bell:

Industrial Resources Inc. (IRI) is proposing to develop a single well bulk sampling test to solution mine nahcolite in the NE 1/4 of Section 27, T1S, R98W in Rio Blanco County, Colorado. From discussions with you (14 March 1983) through our environmental consultant, Camp Dresser and McKee (CDM), it is my understanding that the UIC program is not currently in place but that your agency requests an informational letter describing our process in relation to UIC requirements. This letter, therefore, serves to delineate critical components of the proposed injection program in terms of specific regulatory requirements. Information provided herein is designed to meet the requirements of 40 CFR 122 and 40 CFR 146, as amended. The proposed program is presented below in terms of the plan of operation, the existing hydrogeologic environment, and proposed monitoring plans.

Plan of Operation

The proposed mining plan involves a Class III well for the solution mining of salts. It consists of a single well test to (1) demonstrate the feasibility of solution mining techniques for the extraction of nahcolite, (2) optimize the mining process, and (3) evaluate product characteristics. The single well test will be conducted over approximately a six-month period during the summer and fall of 1983, with a total production of approximately 250 tons of nahcolite.

Drilling of the production well is scheduled to commence in mid-May 1983. The well will be drilled to an initial depth of approximately 1,795 feet. (Geologic and geophysical logging will be accomplished following drilling activities.) This section will be fully cased with a nominal 6-inch diameter steel casing. Surface casing of approximately a 10-inch diameter will also be installed. The annular space between the well bore and casing will be sealed to adequately isolate the injection zone from the lower aquifer, and the lower aquifer from the upper aquifer, (reference geologic description below) with a cement or grout/bentonite slurry. Additionally, 150 feet of steel surface casing will be sealed in place to preclude introduction of surface runoff. Once the annular seal has been established

and verified by bond logging, an open hole injection zone will be drilled to a depth of 1,826 feet. Total surficial disturbance associated with production drilling activities will consist of an area approximately 50 feet by 75 feet in size.

Nahcolite will be extracted using solution mining techniques. Hot water will be injected into the saline zone (1,795 to 1,826 feet below ground) and the dissolved nahcolite will be pumped to the surface. The pregnant solution will be pumped from the injection well through pipes to a surface bulk sampling plant. Processing includes dewatering, drying, and crystallizing.

Additional ancillary surface facilities will include a portable power generator, topsoil stockpile, a pit (plastic-lined) to hold water for drilling purposes, and access road(s). Details of the surface facilities and associated activities are provided in the Limited Impact Permit, on file with the Colorado Mined Land Reclamation Division (CMLRD).

Existing Hydrogeologic Environment

The site is situated near the center of the Piceance Basin, an asymetrical trough filled with thick sequences of Eocene age deposits (see attached Figures 1 and 2). The dominant geologic units are the Uinta and Green River Formations. The younger Uinta Formation comprises the exposed surficial strata, largely silty sandstone and siltstone, with interbedded marlstone. The unit is approximately 1,000 feet thick on this site. The Green River Formation underlies the Unita Formation, and has a total thickness of greater than 3,000 feet. The Green River Formation is divided into three principal sub-units. In descending order, these are the Parachute Creek, Garden Gulch, and Douglas Creek members. The latter two members are characterized by largely impermeable shales and clayey siltstone, and generally comprise the lower confining zone for the ore body.

The Parachute Creek member is typically divided into upper and lower zones, with the kerogen-rich Mahogany Zone comprising a semi-permeable to impermeable intervening layer. Similarly, the occurrence of ground water within the Parachute Creek member is divided into upper and lower aquifers. The upper aquifer includes fractured marlstones of the upper Parachute Creek member as well as fractured sandstones of the overlying Uinta Formation. The lower aquifer consists of marlstones which have been extensively leached, where nahcolite has been dissolved from the formation. This is consequently referred to as the leach zone. These aquifers are the only potential Underground Sources of Drinking Water (USDW) beneath the site.

The zone of injection, regionally referred to as the saline zone, underlies the lower aquifer. The saline zone itself is uniformally a nahcolite-bearing marlstone and is relatively impermeable. It is not, and cannot be, considered a USDW. This mineralized zone occurs at a depth of approximately 1,792 feet, and is separated from the lower aquifer by nearly 30 feet of relatively competent, unleached marlstones. Within these marlstones are

three highly plastic kerogen zones referred to as the "rubber beds" whereas Garden Gulch and Douglas Creek strata form an impermeable lower boundary to the saline zone. The rubber beds provide hydraulic isolation above the saline zone to the lower aquifer.

IRI is utilizing a 1/4-mile radius to encompass the area of review. However, data available from both inside and outside this area have been utilized for the characterization of the existing environment. A ground water use inventory indicates that no ground water wells have been installed within a one-mile radius of the proposed injection site. Additionally, ground water use from the lower aquifer is sparse, owing largely to high levels of Total Dissolved Solids (TDS) in the aquifer. TDS concentrations are uniformly in excess of 1000 mg/l, and often range as high as 40,000 mg/l as reported in the Final Supplemental Environmental Impact Statement for the Prototype Oil Shale Leasing Program (Bureau of Land Management 1983.)

Proposed Monitoring Plans

IRI proposes a monitoring plan that encompasses three components:

(1) Well construction that ensures no migration of injection fluid through the well bore,

(2) Calculation of a fluid balance during injection and recovery, and

(3) Installation and sampling of a monitoring well.

The production well will be fully cased through the lower aquifer and through the intervening impermeable kerogen beds. Therefore, no loss of fluid is anticipated through the well itself. Furthermore, the annulus will be sealed to prevent upward migration from the injection zone into the lower aquifer in the well bore.

Any potential excursion of injection water or saline-pregnant recovery fluid will be detected from deficits in the water balance. As noted previously, no migration is anticipated due to the impermeable character of the injection zone and overlying strata.

IRI will install a monitor well to provide an extra measure of security. Data from existing wells in the area have been utilized to calculate the flow direction (N 34° E) and approximate natural flow velocity (0.01 ft/day) of the lower aquifer. These data allow selection of an optimal location (down-gradient) for installation of the monitoring well.

The monitor well will be initially drilled to a depth of 1,300 feet at the top of the lower aquifer. This section will be cased for the full length with 4-inch diameter steel casing, and the annular space sealed across the Mahogany Zone as with the production well. An open hole completion interval

will then be drilled to a total depth of 1,765 feet below ground surface. The monitor well will be situated approximately 50 feet from the production well and will disturb an area of approximately 50 feet by 75 feet.

Water samples will be collected three times from the monitor well. These are prior at operation, during operation, and approximately one month after operation. Samples will be analyzed for the following consituents:

Total Dissolved Solids (TDS)	
Sodium	Carbonate
Potassuim	Bicarbonate
Calcium	Chloride
Magnesium	Sulfate

These parameters were selected to provide both an adequate representation of existing conditions and an indication if any fluid migration is occurring.

Well Abandonment

Subsequent to completion of the monitoring program, each well will be equipped with a locking steel surface cap. The cap will insure that foreign material (including surface runoff) will not be introduced into the cased or completion interval. No plugging or sealing of the wells is currently planned so that the wells can be used for future monitoring purposes if necessary.

I trust that the information provided in this letter will serve the needs of your agency. IRI will be happy to work with the Water Quality Control Division on this test program as with any future injection programs.

If you have any questions, please call.

Sincerely,

Edward C. Rosar
President

ER/db

cc: Paul Osborn, EPA-Denver
M. Jones, Cliffs Engineering
E. Hinzel, CDM

SECTION 5.2.2

TITLE OF STUDY: Assessment of Class V Injection Wells in the State of Wyoming
(OR SOURCE OF INFORMATION)

AUTHOR: Western Water Companies
(OR INVESTIGATOR)

DATE: September 1986

FACILITY NAME AND LOCATION: Wyoming, USEPA Region VIII

NATURE OF BUSINESS: NA

BRIEF SUMMARY/NOTES: Solution mining wells in Wyoming are associated with stopes leaching of conventional uranium mines at two facilities in Converse County. Available inventory indicates there are 14 active wells of this type. Wells are completed into mined areas and total depths vary. PVC or steel casing is used and perforated opposite stopes. The annulus is generally cemented from the packer above the stop to land surface. Lixiviants used include acids (hydrochloric, sulfuric, acetic), oxidizers (hydrogen peroxide, ozone, chlorine, oxygen), bases (sodium carbonate), and ion exchange agents (ammonia, ammonium chloride, alkalai metal salts). Hazards to groundwater from such activity include increases in TDS, sulfates, and nitrates or extreme pH fluctuations. Other contaminants are radium, vanadium, thorium, and uranium. Experimental technology wells are found in areas where uranium ore is found in saturated aquifers at shallow to moderate depths. Sixteen facilities, operating more than 119 wells, have been inventoried. PVC or steel casing, perforated opposite the ore body and cemented from the packer (set in clay or shale above the ore body) to land surface is common. Lixiviants used are generally identical to those used in conventional solution mining. Hazards to groundwater are also generally the same.

Experimental technology wells used for in situ Trona recovery are found in the Central Green River Basin (Sweetwater County), and three facilities, using 16 wells, have been inventoried. Total depths range from 1500 to 2000 feet in this area, a steel casing is extended into or through trona beds. Perforation in the casing are opposite the trona beds, and casing is usually cemented from the top of the highest minable trona bed to the land surface. Occasionally the casing is cemented between trona beds. Lixiviants are of proprietary composition, and mobilize sodium, chloride, and carbonate species. Hazard potential to groundwater is deemed minimal with proper well construction in that trona deposits are vertically and hydraulically isolated from drinking water aquifers.

Solution Mining Wells

Class V injection wells in Wyoming that fall into this category are associated with stopes leaching of conventional uranium mines at two facilities in Converse County. Potential application of this type of well would probably be limited to areas having either uranium or trona resources, as outlined on Figure 3-1, with the unlikely addition of certain metal-bearing mineralized areas in the Precambrian cores of Wyoming's mountain ranges. At present, only 14 stopes leaching wells exist in Wyoming according to available inventory data (WDEQ, 1985a).

Construction techniques for the existing solution mining wells are very similar to those used for uranium in situ leaching wells, as are the injected fluids and injection horizons. Consequently, solution mining wells received a hazard ranking that was the second highest of the ranked well types.

SOLUTION MINING WELLS - STOPES LEACHING IN CONVENTIONAL URANIUM MINES

Number of Facilities: 2
Number of Wells: 14

Locations:	Limited to existing underground uranium or other mineral mines; Converse and Fremont Counties (see Figure 3-1)
Well Construction:	Wells are completed into mined areas; total depths are variable; PVC or steel casing generally installed to total depth and perforated opposite stopes; annulus cemented from packer above stope to land surface
Injection Horizon:	Into, above or below sensitive aquifers
Injected Materials:	Lixiviants: acids such as hydrochloric, sulfuric, or acetic; oxidizers such as hydrogen peroxide, ozone, chlorine, or oxygen; bases such as sodium carbonate; ion exchange agents such as ammonia, ammonium chloride, or alkali metal salts
Hazards:	Water can become unfit for use due to increased concentrations of TDS, sulfates, nitrates, or extreme pH. Restoration of aquifer to background water quality often difficult. Contaminants such as radium thorium, vanadium and uranium may be released into strata above or below ore body

EXPERIMENTAL TECHNOLOGY WELLS - URANIUM IN SITU LEACHING

Number of Facilities: 16
Number of Wells: more than 119

Locations:	Areas of the State where uranium ore is found in saturated aquifers at shallow to moderate depths (see Figure 3-1)
Well Construction:	Shallow to moderate total depth; PVC or steel casing perforated opposite ore body in permeable sandstone; packer set opposite clay or shale above ore body; annulus cemented from packer to land surface
Injection Horizon:	Below, into or above sensitive aquifers
Injected Materials:	Lixiviants: commonly acids such as hydrochloric, sulfuric, or acetic; oxiders such as hydrogen peroxide, ozone, chlorine, or oxygen; bases such as sodium carbonate; ion exchange agents such as ammonia, ammonium chloride, or alkali metal salts. Leaching also mobilizes toxic contaminants such as uranium, thorium, radium, vanadium, arsenic, and selenium
Hazards:	Water can become unfit for use due to increased concentrations of TDS, sulfates, nitrates, or extreme pH. Restoration of aquifer to background water quality often difficult. Contaminants are often released into strata above or below ore body

EXPERIMENTAL TECHNOLOGY WELLS - IN SITU TRONA RECOVERY

Number of Facilities: 3
Number of Wells: 16

Locations:	Central Green River Basin, Sweetwater County (see Figure 3-1)
Well Construction:	Total depths (in Wyoming) 1,500 ft to 2,000 ft; steel casing extending into or through trona beds to be mined; perforations opposite trona beds; annulus cemented from top of highest minable trona bed to surface and occasionally between minable beds also
Injection Horizon:	Below sensitive aquifers
Injected Materials:	Lixiviants of proprietary composition, water. Solution mobilizes sodium, chloride, and carbonate species (trona and associated minerals)
Hazards:	Water might become unfit for use due to increased concentrations of TDS, sodium or chloride, or extreme pH. Small hazard potential with proper well completion because trona deposits are vertically and hydraulically isolated from aquifers with Class I-III water

SECTION 5.2.3

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	"Chapter 7: In Situ Uranium Leaching," Assessment of Class V Injection Wells in the State of Wyoming
AUTHOR: (OR INVESTIGATOR)	Western Water Companies
DATE:	September 1986
FACILITY NAME AND LOCATION:	Wyoming, USEPA Region VIII
NATURE OF BUSINESS:	NA

BRIEF SUMMARY/NOTES: This technology has been used in Wyoming since the early 1970's. The in situ method involves: 1) injection of a lixiviant (barren solution) into a uranium-bearing ore body via injection wells; 2) mobilization of uranium by the creation of a soluble complex salt; 3) recovery of the uranium-bearing lixiviant (pregnant solution); 4) recovery of uranium from the pregnant solution using ion exchange techniques; and 5) restoration of the groundwater to a prescribed post-mining quality.

In situ projects fall into two categories: 1) Those using production wells to recover pregnant solution from a subsurface ore body which has not been previously mined; and 2) those which recover pregnant solution from ore bodies via pre-existing underground mine workings. Selection of lixiviants is based on several factors, including geologic setting, mineral and chemical constituency of the host rock, hydrology, previous experience with and knowledge of lixiviants, and the potential profitability of various leaching systems. The three principal types of lixiviants are sulfuric acid, ammonium carbonate, and sodium carbonate/bicarbonate. The use of sulfuric acid and ammonium solutions is no longer permitted by the Wyoming DEQ because they have created complex problems with groundwater restoration.

The following projects, located in the Powder River Basin, are assessed in this report:

1. Collins Draw Project (Cleveland Cliffs Iron Co.) which utilized ammonium carbonate lixiviant;

2. Reno Ranch Project (Rocky Mounting Energy Co.) where sulfuric acid and sodium carbonate lixiviants were used; and

3. Bill Smith Stopes Leaching Project (Kerr-McGee Nuclear Corp.) in which sodium bicarbonate lixiviant was injected into ore above underground mine workings.

CHAPTER 7

IN SITU URANIUM LEACHING

Introduction

The goal of this chapter is to evaluate the degree of hazard and the severity of existing and potential impacts to the ground water caused by experimental in situ uranium mining in Wyoming. The assessments will be based upon available site-specific data.

In situ mining, also called in situ leaching or solution mining, is a relatively new addition to the list of mining methods currently used to extract uranium in Wyoming. The technology has been in use to recover uranium in Wyoming for 14 years. Basically, the in situ method involves: 1) the injection of a lixiviant (an acidic or basic oxidizing solution, the so-called barren solution) into a uranium-bearing ore body via injection wells; 2) mobilization of the uranium from the host material by the lixiviant via creation of a soluble complex salt; 3) recovery of the uranium-bearing lixiviant (called pregnant solution); 4) recovery of uranium from the pregnant solution using ion exchange techniques (Vandell, undated); and 5) restoration of the ground water to a prescribed post-mining quality.

In situ uranium leaching projects fall into two categories: 1) those which use production wells to recover lixiviants from a subsurface ore body which has not previously been mined; and 2) those which recover lixiviants from ore bodies via pre-existing underground mine workings. In the latter case, the pregnant solution drains into the mine workings

through longholes or directly through the formation, and is then pumped to the surface for uranium recovery. A variety of lixiviants may be employed to leach uranium and some experiments may use more than one kind of lixiviant. In Wyoming, the selection of lixiviants has been made by the industrial company responsible for conducting an experiment. Selections have been based on factors including geologic setting, mineral and chemical constituency of the host rock, hydrology, previous experience with and knowledge of lixiviants, and the potential profitability of various leaching systems.

The three principal lixiviant types used in subsurface in situ uranium mining have been: 1) sulfuric acid, 2) ammonium carbonate, and 3) sodium carbonate/bicarbonate. With each type, an oxidizing chemical such as hydrogen peroxide or oxygen may be added to the lixiviant in addition to the principal chemical. The use of sulfuric acid or ammonium solutions as lixiviants is no longer permitted by WDEQ because these lixiviants have created complex problems with ground-water restoration in Wyoming.

The following projects are assessed in this report:

1. The Collins Draw Project, operated by Cleveland Cliffs Iron Company, which utilized ammonium carbonate lixiviant; and
2. The Reno Ranch project, operated by Rocky Mountain Energy Company, where sulfuric acid and sodium carbonate lixiviants were used;
3. The Bill Smith Stopes Leaching Project, operated by the Kerr-McGee Nuclear Corporation, in which sodium bicarbonate lixiviant was injected into ore above underground mine workings.

All of these projects were located in the Powder River Basin of Wyoming.

Regional Hydrogeology

The Collins Draw, Reno Ranch, and Bill Smith Projects were located in the southern half of the Powder River Basin (see Figure 7-1). The Powder River Basin covers approximately 12,000 square miles and is a structural and topographic basin bounded on the east by the Black Hills and on the west by the Big Horn Mountains. As much as 18,000 ft of sedimentary rock are present in the deepest part of the basin (Hodson and others, 1973). The Eocene Wasatch and Fort Union Formations crop out in the basin and both contain mineable uranium deposits.

The Wasatch Formation is approximately 1,600 ft thick in the Pumpkin Buttes area (NRC, 1978); it consists of alternating sandstones, siltstones, claystones and coal beds.

Approximately 3,500 ft of the Paleocene Fort Union Formation underlie the Wasatch Formation. The Fort Union Formation is composed of interbedded fine- to coarse-grained sandstone, siltstone, claystone, lignite, and coal. The portion of the Fort Union Formation which is the host unit for the uranium ores is locally referred to as the Highland Sandstone. The Highland Sandstone is relatively consistent laterally and underlies a large area in the southern portion of the basin.

The uranium ore deposits in the Powder River basin which have been solution mined are generally at depths ranging from 100 to 500 feet. A plan view and cross sections of typical uranium roll front and uranium

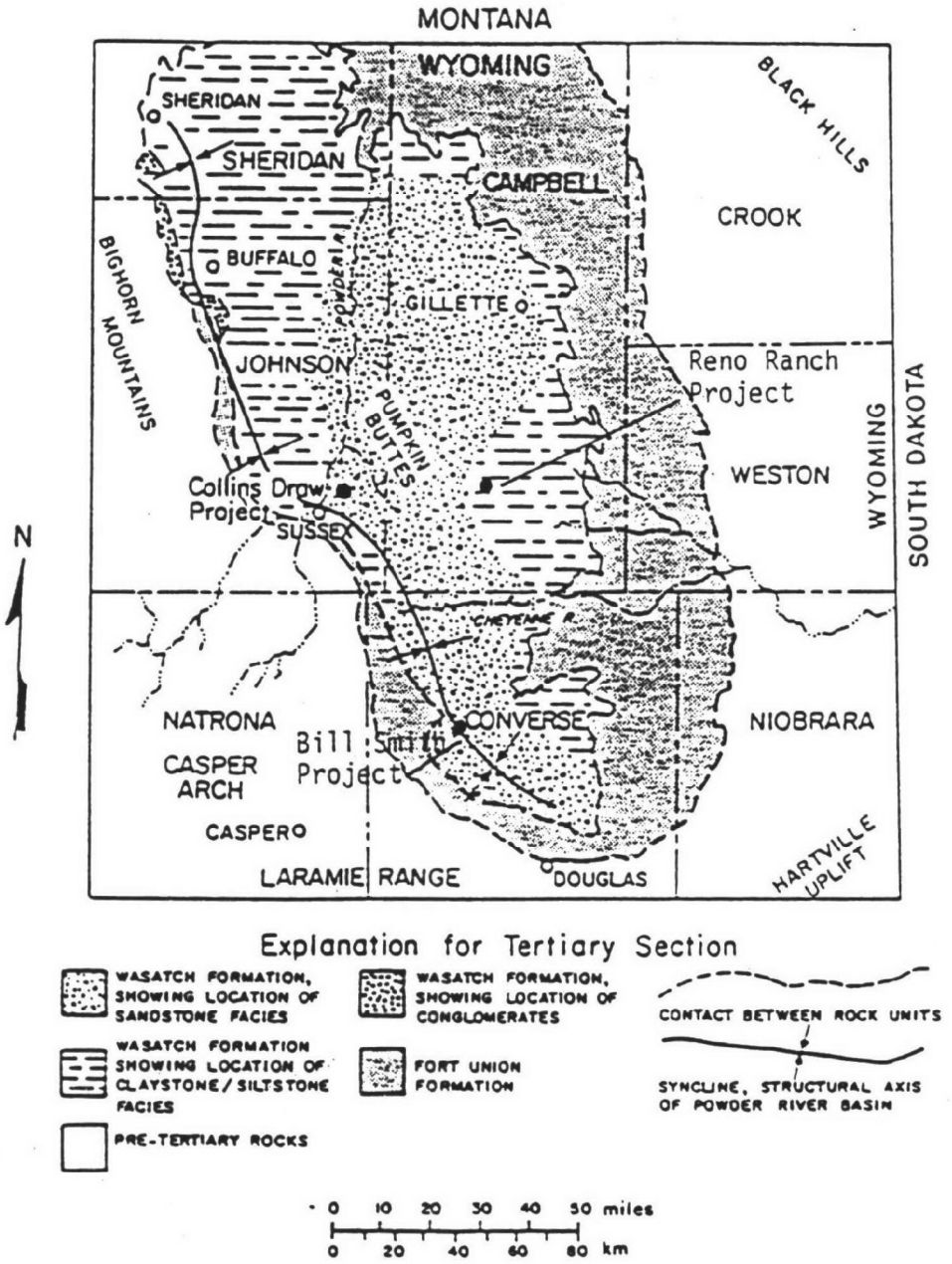


Figure 7-1. Regional Geology of the Powder River Basin, Wyoming, Showing Locations of Assessed Uranium In Situ Leaching Projects (modified after Sharp and Gibbon, 1954).

[5-126]

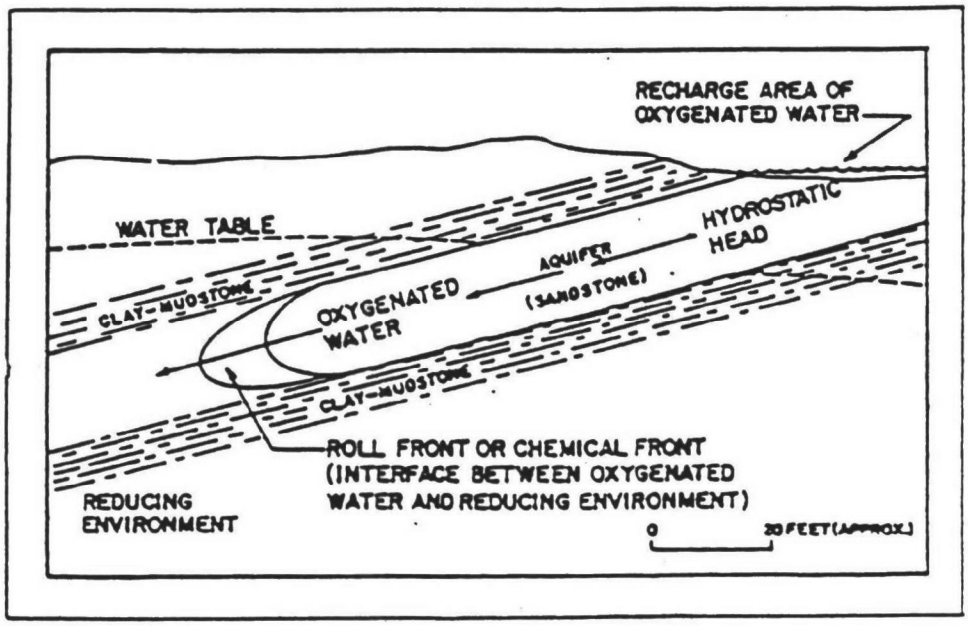
ore deposits are shown in Figure 7-2. Cross Section B of Figure 7-2 illustrates a typical injection-recovery well system and the generalized ground-water flow directions during mining.

Hodson and others (1973) present a description of the hydrostratigraphic units of the Powder River Basin. The following discussion is derived from that description.

Generally, the hydrostratigraphy of the Wasatch Formation consists of sandstone aquifers confined by siltstone and claystone aquitards. Shallow water-table (unconfined) aquifers may also be present; they are of limited areal extent and occur mainly along the more prominent water-courses. Wells in the confined sandstone aquifers may yield several hundred gallons per minute. Jointed coal beds also produce water in some areas, but they yield much less water than the sandstone aquifers. Total dissolved solids range from less than 200 to more than 8,000 mg/L but are commonly 500 to 1,500 mg/L (NRC, 1978). The water generally ranges from a sodium bicarbonate to a sodium sulfate type.

Ground-water movement in the Wasatch Formation generally is to the north toward the Powder River and its tributaries. In shallow aquifers, ground water movement may be influenced locally by other drainages that act as discharge areas. The regional hydraulic gradient, derived from water-level data from 91 wells, was reported as .006 and the ground-water flow rate was estimated to be about 6.3 ft/yr in the central part of the basin (In Situ Consulting, Inc., 1978).

Ground water in the Powder River Basin is primarily used for livestock watering and domestic water supply. Some shallow alluvial wells, yielding between a few gpm and 1,000 gpm, are located on the



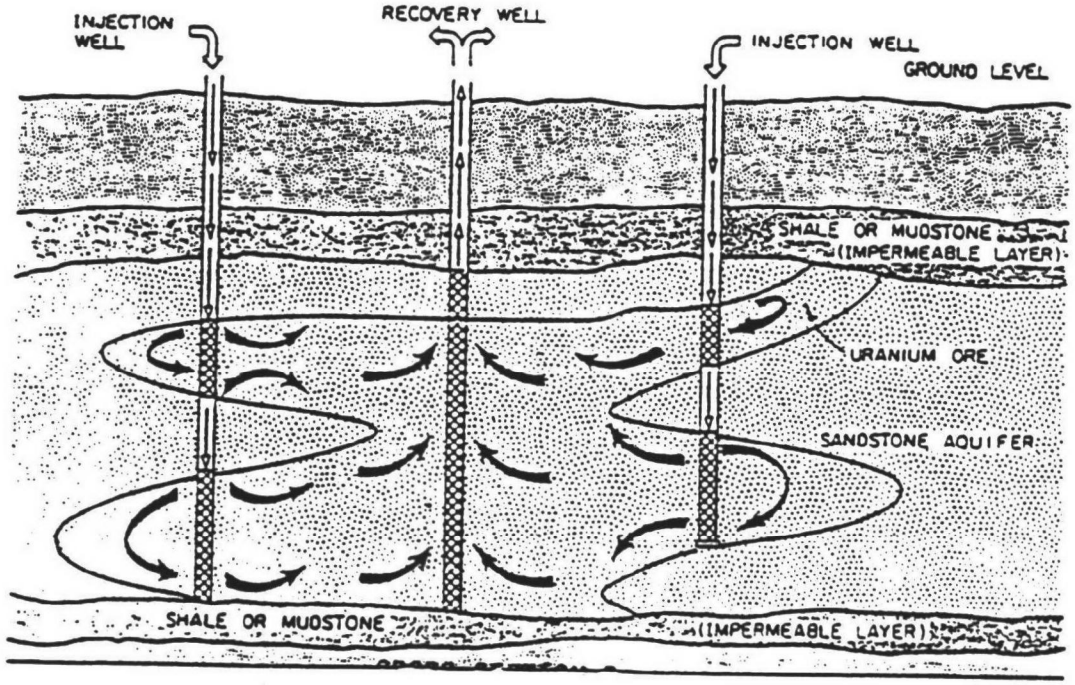


Figure 7-2. Cross Sections of a Typical Uranium Roll Front Deposit and the Solution Mining Unit (from Vandell, undated).

floodplain of the Powder River. However, ground water from the alluvial aquifers is generally of poorer quality than ground water from deeper aquifers in the Wasatch and Fort Union Formations. Ground waters from these two formations have generally good quality, although they may be high in TDS, and are frequently defined as calcium or sodium bicarbonate, or sodium sulfate types. Ground water in the uranium ore zone of the Wasatch Formation may be as high as 8,000 mg/L TDS and ground water in the ore zone of the Fort Union Formation may be as high as 2,000 mg/L TDS. Wells in the Wasatch Formation yield from 10 to 500 gpm and wells in the Fort Union Formation yield a maximum of around 150 gpm.

Ground Water Impacts at Uranium Solution Mines

Two general types of ground-water pollution problems can occur during and following uranium solution mining activities. These problems are lixiviant excursions and failure of ground-water restoration.

An excursion is the movement of lixiviant, either vertically or horizontally, away from the intended mining zone. An excursion can affect water quality in the ore zone outside the mining area and in aquifers above or below the ore zone, either within or adjacent to the mining area. Excursions are initially characterized by increased concentrations of dissolved solids or conductivity in ground-water. If the excursion is not controlled, elevated uranium and other trace element concentrations will also ultimately be detectable in the excursion zone.

Lateral and vertical excursions have occurred at uranium in situ leach sites in Wyoming Powder River Basin as a result of uncontrolled movement of lixiviant out of damaged well casings, through improperly plugged exploration drill holes, and through leaky aquitards. Excursions have also resulted from inadequate balancing of the rates of lixiviant injection and withdrawal at a multiple-well installation (commonly called a well field or cell). Properly balancing injection and withdrawal becomes more difficult as an ore body becomes more hetereogeneous.

Cracked well casings are generally the result of faulty well construction and development. Faulty well construction practices include the use of improper underreaming tools; improper sealing above and below screened, perforated, or open casing intervals; and flaws in casing joints or the use of improper casing materials (i.e., using PVC when fiberglass or steel casing should be used).

Improperly abandoned drill holes can serve as major channels for lixiviant migration into surrounding aquifers. If excursions result in contamination of aquifers of good water quality, costly clean-up programs must be implemented to return the affected ground waters to their potential or existing pre-mining water uses.

If confining units which surround an ore zone are vertically or laterally discontinuous, or are not thick enough, or [illegible] permeability (especially vertical permeability) is not uniformly low enough to prevent excursions, then in situ mining at a site should not be considered.

Following solution mining of an ore body, the remaining ground water must be restored to its pre-mining quality and/or use classification. This may be accomplished by a variety of techniques, some of which are similar to the mining process. The techniques include 1) withdrawal, treatment at the surface to remove contaminants, and reinjection of the treated ground water into the contaminated area to flush the aquifer; 2) ground-water sweeping using native ground water to flush the contaminated area through the existing leaching injection and recovery wells; 3) chemical precipitation; 4) biological nitrification; and 5) natural restoration. Natural restoration combined with surface treatment and reinjection of in situ ground waters generally results in effective restoration. The number of pore volumes of water required for restoration has been reported by Kohler (1984) as between 3 and 30, with the high degree of variability resulting from varied site conditions.

Failure of restoration, when it has occurred, has generally resulted from incompatibilities between the mining process and the aquifer being mined; inadequate efforts on the part of the mine operator; or a combination of these factors. Specific examples are presented in the following chapters.

The impact of restoration failure or uncontrolled excursions is the degradation of ground-water quality from baseline levels. This degradation can affect the ore zone and aquifers above or below the ore zone, within the mining area as well as adjacent to it. Following abandonment of restoration efforts, contaminated ground water will migrate away from the mining area under the influence of natural

hydraulic gradients, carrying the contaminants varying distances from the mining area. Increased concentrations of uranium, radium, selenium, arsenic, or vanadium could preclude the use of affected ground water for domestic, stock, irrigation, municipal, or industrial purposes. High concentrations of these constituents in drinking water are hazardous to the health of animals and humans.

The potential for severe contamination of ground waters at uranium in situ leach mine sites can be minimized by:

1. Obtaining a thorough understanding of the hydrogeology at the site, especially with respect to the proposed mine plan and lixiviant movement in the ore zone aquifer and potentially to the surrounding aquifers and confining beds;
2. Properly plugging all abandoned exploration drill holes or abandoned wells within the hydrogeologic area that will be affected by mining; and
3. Testing well casing integrity before injection and recovery wells are placed into operation. If flaws cannot be located or corrected, then inadequate wells must be properly abandoned, and replaced as necessary.

CHAPTER 7A

COLLINS DRAW PROJECT - CLEVELAND CLIFFS IRON COMPANY

Introduction

The Cleveland Cliffs Iron Company's (CCIC) Collins Draw Project was selected for one of three in situ uranium leaching assessments because: 1) it made use of ammonium carbonate/bicarbonate as lixiviant; and 2) the quality and quantity of data available were adequate for the assessment.

The Collins Draw Project site is located southwest of the Pumpkin Buttes in the central Powder River Basin, in parts of sections 35 and 36, T.43N., R.76W., Campbell County, about 60 miles southwest of Gillette, Wyoming.

Site Hydrogeology

Uranium mineralization at the Collins Draw site occurs as roll-front deposits in a sandstone bed of the Wasatch Formation. The ore sandstone is designated the 1-Sand by CCIC. The 1-Sand is present at a depth of about 425 ft; it has an average thickness of about 50 to 55 ft (CCIC, 1981). Figure 7A-1 presents a generalized stratigraphic section for the mine site. The sandstone units at Collins Draw are separated by silty claystone units. The units identified by CCIC are depicted in cross section on Figure 7A-1.

The 1-Sand was divided into three different layers in a hydrologic evaluation of the site conducted by In Situ Consulting, Inc. (1978).

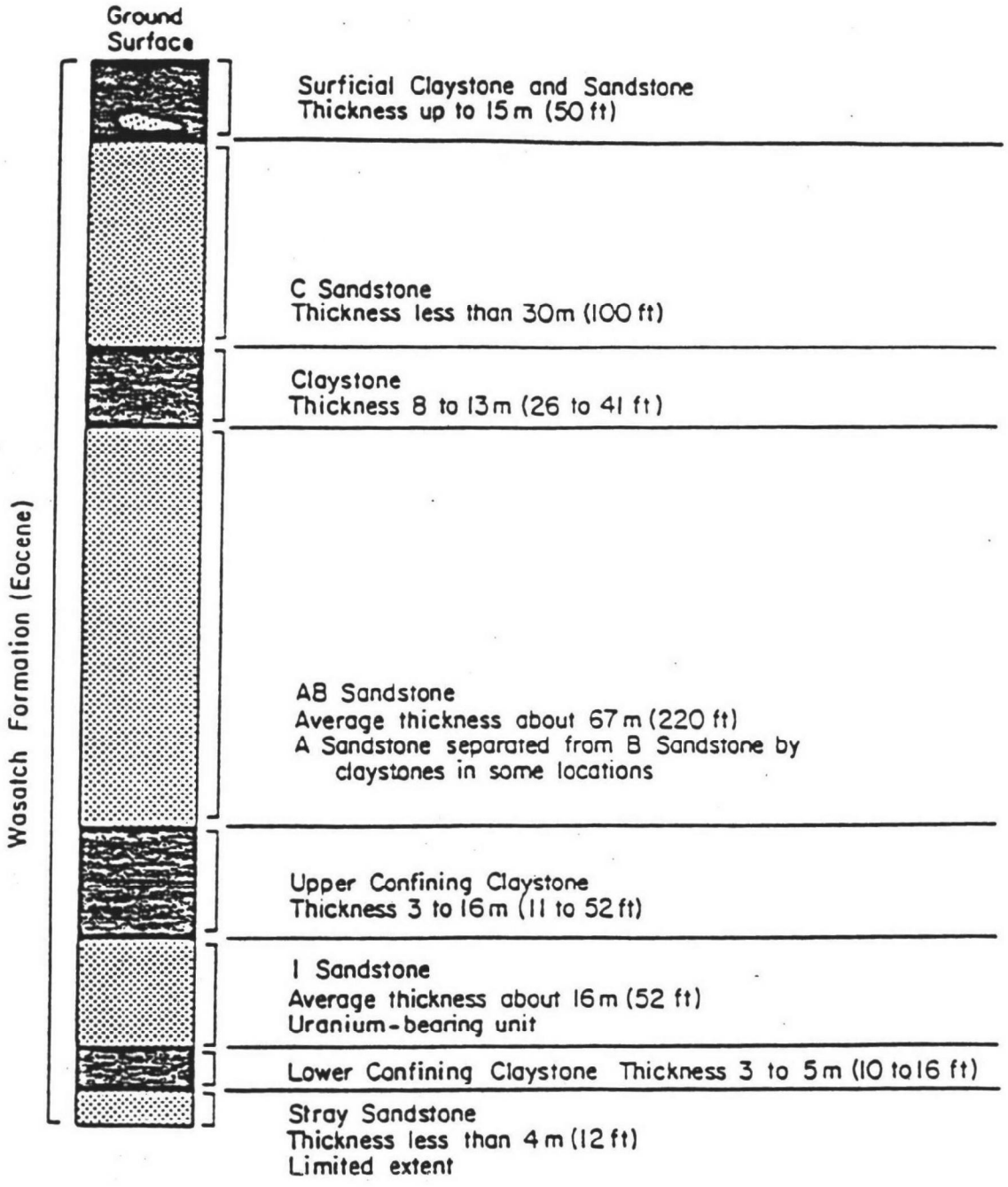


Figure 7A-1. Generalized Stratigraphic Section for the Collins Draw Project Area (after Cleveland Cliffs Iron Company, 1981a).

The upper 15 ft and lower 15 ft of the sand unit were observed to be less clayey than the 20 to 25 ft interior portion; the interior portion has lower porosity and hydraulic conductivity than the upper and lower portions of the unit.

Three major-water bearing sandstone units (the 1, AB, and C sands) are present at the Collins Draw mine site; however, available information pertains only to local ground water conditions in the 1-Sand. The 1-Sand is a confined aquifer; the unit is present between elevations 4,400 and 4,470 feet, and its potentiometric surface lies between 4,790 and 4,815 feet above sea level. (Figures 7A-2 and 7A-3). The direction of ground-water flow direction is 19° west of north under a local gradient of about .008 (In Situ Consulting, Inc., 1978). Water-level fluctuations observed over a one and one-half year period were on the order of a few inches.

In Situ Consulting, Inc. reported that the 1-Sand aquifer averages 52 ft in thickness with a porosity of .28, average storage coefficient of 1.7×10^{-4} and average transmissivity of about 26 ft^2/day. Horizontal hydraulic conductivity of this aquifer was estimated to be on the order of 0.3 to 0.6 ft/day. Standard hydraulic conductivity is 0.48 ft/day. The direction of major transmissivity was determined to be E31°S (In Situ Consulting Inc., 1978).

Ground Water Quality

CCIC conducted a baseline water-quality sampling program in 1978. Thirteen wells were sampled an average of four times each; 11 of these wells were completed in the ore-bearing sandstone aquifer. Wells were

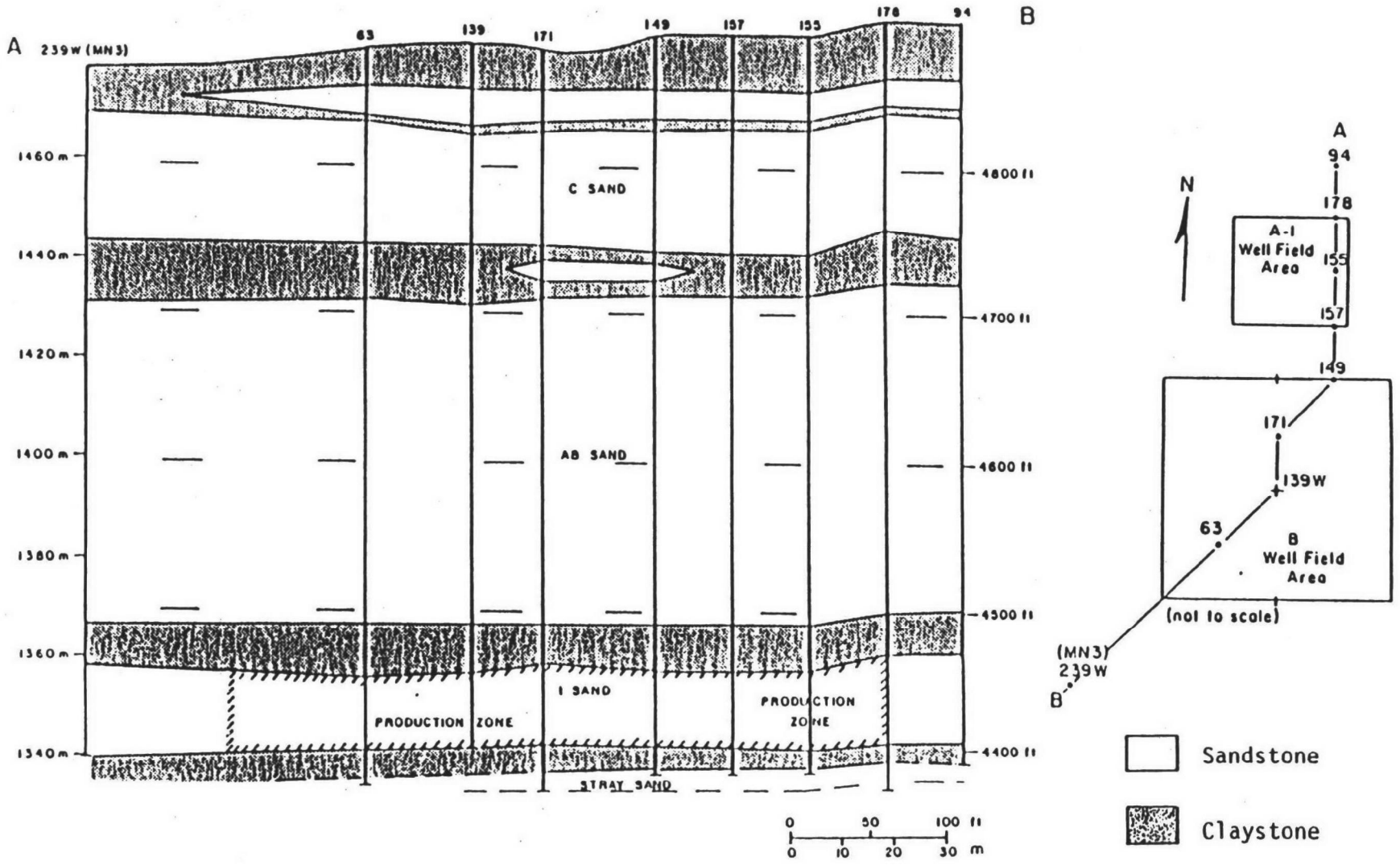


Figure 7A-2. Cross section through the Collins Draw mine area (after Cleveland Cliffs Iron Company, 1981).

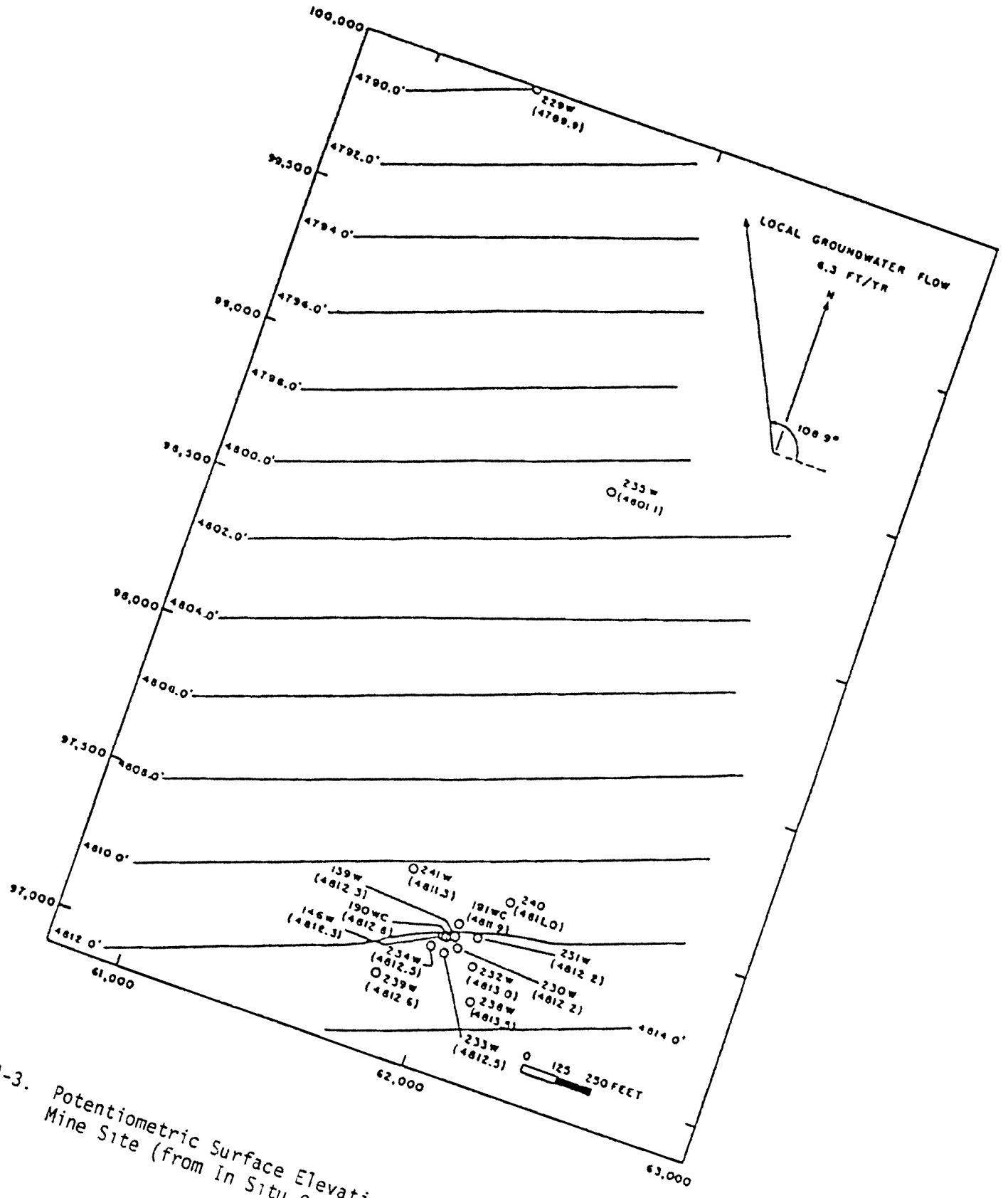


Figure 7A-3. Potentiometric Surface Elevation at the Collins Draw Mine Site (from In Situ Consulting, 1978).

also completed in the overlying and underlying aquifers. Table 7A-1 presents the average concentrations of various dissolved constituents for each aquifer. Total dissolved solids concentrations averaged about 400 mg/L and ammonia (as N) averaged 0.11 in the ore-bearing sandstone aquifer. Water in all three aquifers meets the WDEQ/WQD Class I (domestic use) standard, with the exception of the Radium-226 concentration in the ore-bearing sand, which averaged 16.2 pCi/L.

Ground-Water Use

Seven ground-water appropriation well permits are found within about 1.5 miles of the Collins Draw lease boundaries (Figure 7A-4). All wells are used for stock purposes except one which CCIC uses for ground-water monitoring (Table 7A-2). Two wells have sufficient artesian pressure to flow at the land surface at rates of 1 to 5 gpm (Wyoming State Engineer, various). A number of the wells were drilled to depths which indicate that the wells may produce water from the experiment-mining aquifer.

Description of Facilities

The permit area for the CCIC experiment site consist of 42.4 acres in sections 35 and 36, T.43N., R.76W., as shown on Figure 7A-5. Figure 7A-6 shows the facilities at the Collins Draw mine area (Permit 3 RD). The A-1 well field covers approximately 1/4 acre and consists of 12 wells spaced about 20 ft apart arranged in a "staggered line drive"

Table 7A-1. Average baseline concentrations for the AB-Sand, 1-Sand, and Stray Sand aquifers at the Collins Draw mine (modified after U.S. Nuclear Regulatory Commission, 1983).

Parameter mg/L	AB-Sand	1-Sand	Stray Sand
TDS (calculated)	543	394	322
TDS (105°C)	544	407	323
Conductivity 77°F (Lab) (µmhos/cm)	743	621	540
Conductivity 25°C (Field) (µmhos/cm)	1607	1245	967
Sodium (calculated)	143	106	103
Sodium (observed)	147	105	90
Potassium	7	7	9
Calcium	37	28	12
Magnesium	5	2	2
Sulfate	156	150	68
Chloride	93	19	44
Carbonate	0	9	28
Bicarbonate	207	150	114
pH (Lab) (units)	8.0	8.2	8.8
pH (Field) (units)	7.5	7.6	9.1
Ammonia as N	.33	.11	0.2
Nitrate as N	.02	.14	0.4
Nitrite as N	.09	.04	0.2
Aluminum [.05]	ND	ND	ND
Arsenic [.01]	.024	ND	ND
Barium [.05]	ND	ND	ND
Boron [1.0]	ND	ND	ND
Cadmium [.002]	ND	ND	ND
Chromium [.01]	ND	ND	ND
Copper [.01]	.01	ND	ND
Fluoride	.13	.17	0.4
Iron [.01]	2.85	.24	0.1
Lead	ND	ND	ND
Manganese [.01]	.05	.02	ND
Mercury [.001]	ND	ND	ND
Selenium [.01]	.07	ND	ND
Nickel [.04]	ND	ND	ND
Zinc [.01]	.01	ND	ND
Molybdenum [.05]	ND	ND	ND
Vanadium [.05]	ND	ND	ND
Uranium [.001]	.03	.09	.02
Radium-226 (pCi/L)	4.4	16.2	6.2
Temperature °C (Field)	14.2	14.1	15

[ ] Detection limits.
ND--Not detected.

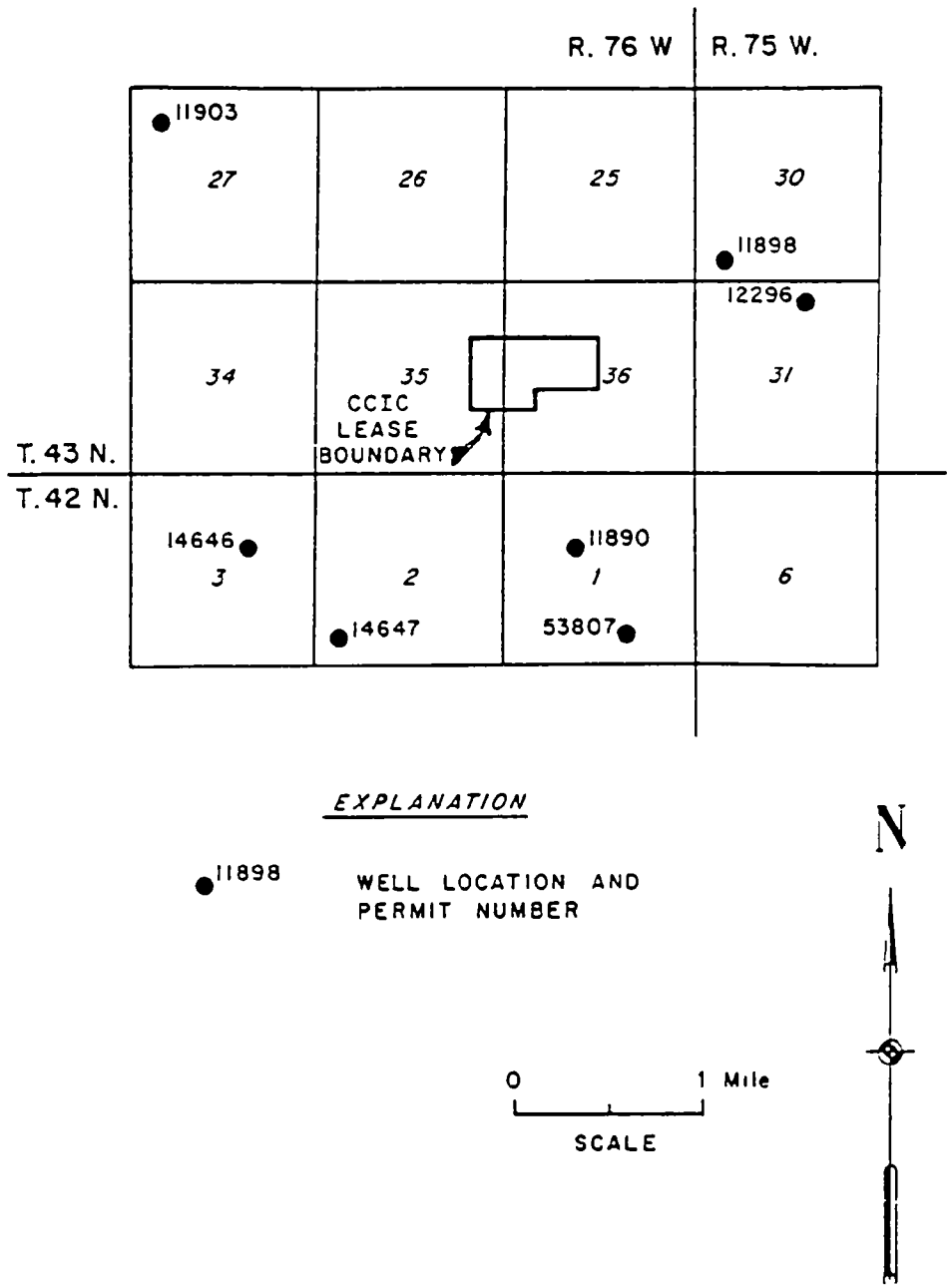


FIGURE 7A-4 · LOCATIONS OF PERMITTED WATER WELLS NEAR THE COLLINS DRAW PROJECT AREA

[5-140]

Table 7A-2. Water Well Permits Within About 1.5 Miles of the Collins Draw Permit Boundaries

Permit Number	Location (¼ ¼ Section, T, R)	Owner/ Well Name	Well Depth (feet)	Water Use	Depth to Water (feet)
P11903W	NW/NW 27, 43N, 76W	Brown Land Co. Doughstick No. 2	960	Stock	Flowing 1 gpm
P11898W	SW/SW 30, 43N, 75W	Brown Land Co. Ray's No. 1	400	Stock	115
P12296W	NW/NE 31, 43N, 75W	Ruby Ranch JDR No. 8	800	Stock	--
P11890W	SE/NW 1, 42N, 76W	Brown Land Co. Adam Foote No. 1	375	Stock	105
P53807W	SW/SE 1, 42N, 76W	Cleveland Cliffs CD-MN 7	578	Monitor	116
P14647W	SW/SW 2, 42N, 76W	Taylor Ranch Taylor 21-2	8	Stock	Flowing 5 gpm
P14646W	SW/NE 3, 42N, 76W	Taylor Ranch Taylor 21-1	383	Stock	80

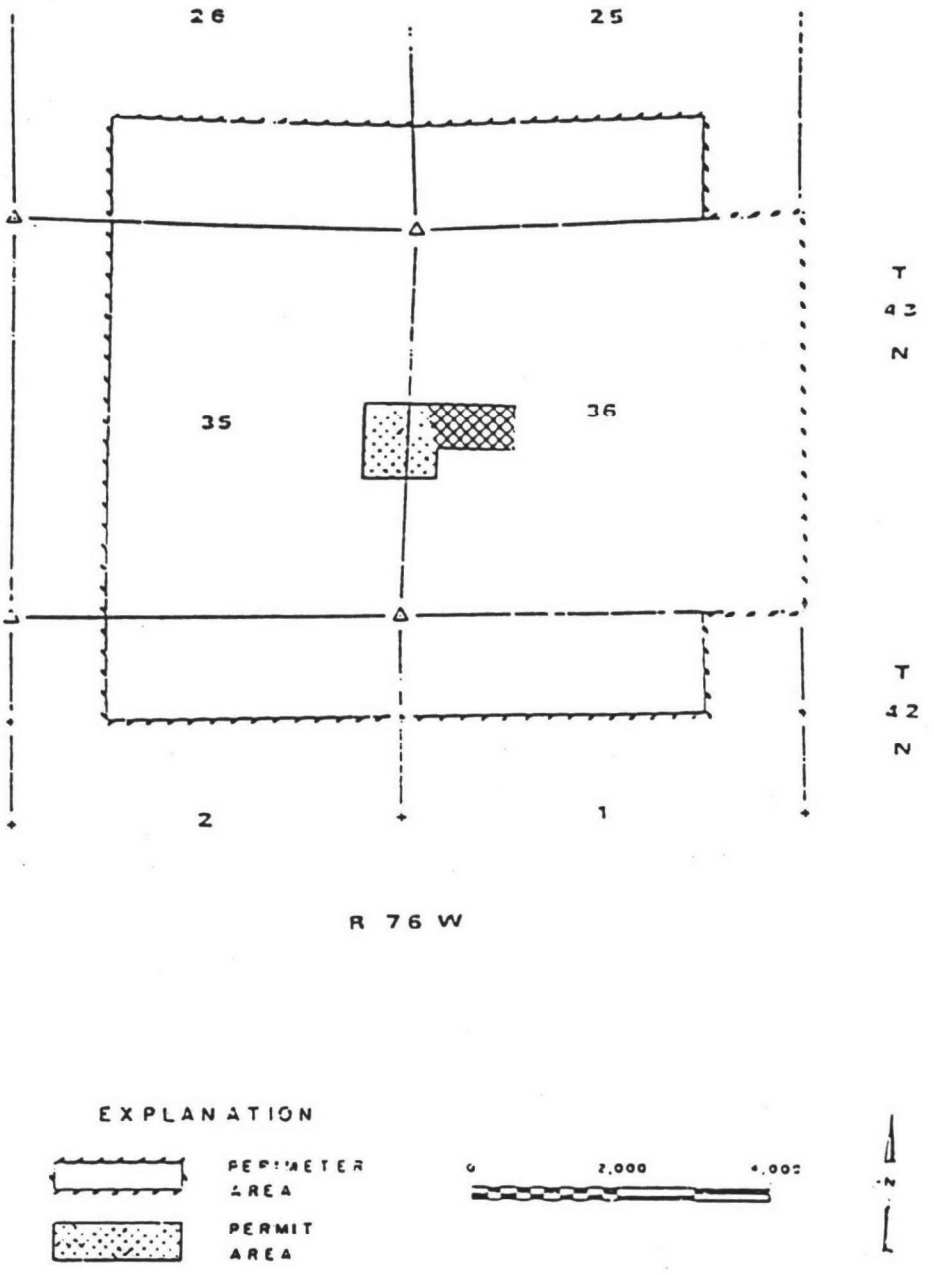


Figure 7A-5. Collins Draw Permit Boundary.

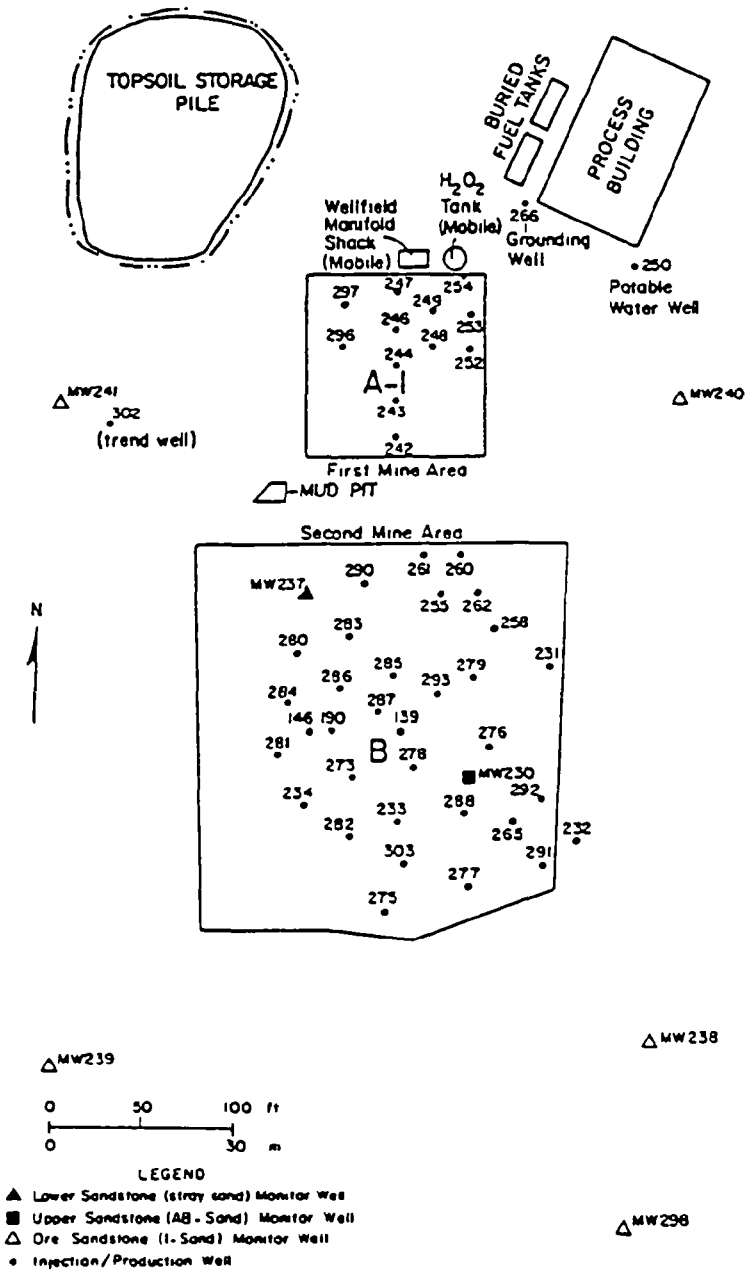


Figure 7A-6. Location Map of the Facilities at the Collins Draw Mine (after Cleveland Cliffs Iron Company, 1981a).

pattern. Wells 242, 243, 296, and 297 were not used in mining operations; the latter two were added to the well field for restoration operations. The B field consists of 33 wells, although mining operations utilized only 20 wells that initially formed four connecting production cells. These cells were irregularly shaped 7-spot patterns with well spacings ranging between 20 and 40 ft.

Well drilling and completion were planned to prevent escape of lixiviants to any part of the overburden. The first series of wells were drilled and completed using the design shown in Figure 7A-7. Basically, the procedure was to drill to the top of the mineralized sand, set the casing, and cement the annulus between the casing and the original hole wall. After the cement set up, the mineralized sand zone was drilled out and the hole deepened until the underlying shale or siltstone was encountered. The ore-sand interval was then screened using a telescoping screen and rubber packer, or left open. Alternative completion techniques involved drilling to the bottom of mineralized sand, setting casing with or without screen attached, and then cementing the annulus between the casing and hole wall with the aid of a cement basket designed to prevent cement from reaching the mineralized zone. The total depth of all wells ranged from approximately 470 to 500 ft (CCIC, 1981a).

Several types of casing ranging in diameter from 2 to 8 inches were used. The typical well was 4 to 6 inch nominal diameter and was cased with PVC, CPVC or fiberglass pipe. Wells 139, 146, and 191 were cased with a lightweight 6 5/8-inch steel casing.

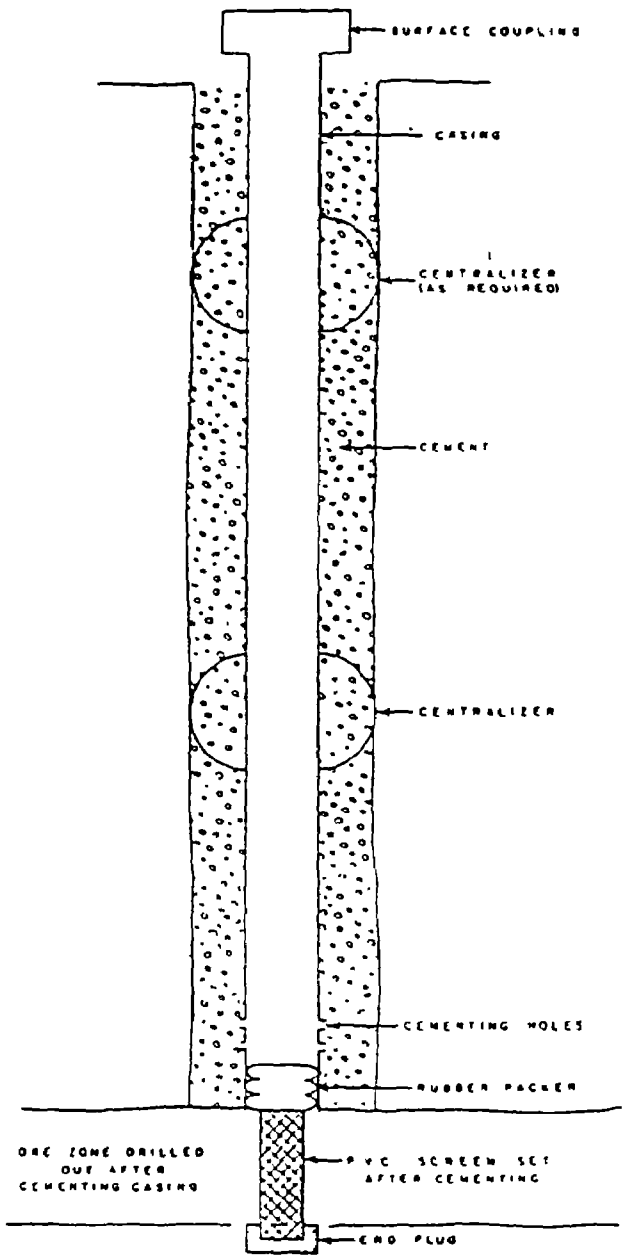


Figure 7A-7. Typical Well Completion, Collins Draw (from Permit 3 RD).

Monitor wells were drilled and completed using both techniques described above. All monitor wells in or below the production zone were screened. A summary of the monitor well completion data is given in Table 7A-3.

Operational History

Mining Phase

Research and development testing at the Collins Draw mine began in the A-1 well field in March 1980 and was expanded to the B well field in November 1980 (Figure 7A-6). Ammonium carbonate lixiviant was used in both well fields.

Approximately 340,000 gallons of water that had been treated by reverse osmosis to remove calcium were injected into the production zone of the A-1 field before leaching began. This injection was intended to displace formation water containing high calcium concentrations which would react with ammonium carbonate lixiviant and cause precipitation of calcium carbonate. Injection of the ammonium carbonate lixiviant and an oxidant (hydrogen peroxide and/or oxygen) commenced on April 2, 1980. The lixiviant, which contained from 1 to 5 grams per liter (g/L) carbonate and from 1 to 4 g/L ammonium, was injected at rates of 0.1 to 20 gpm under well head pressures ranging from 15 to 30 pounds per square inch (psi). Approximately 1.3×10^6 gallons of lixiviant were used in mining the A-1 well field. The average rate of lixiviant injection was 4.2 gpm.

Table 7A-3. Monitoring Well Completion Data, Collins Draw Project.

Hole Number	Relation to Production Zone	Casing Size	Total Depth	Cement Depth	Screened Interval
237 W	Below	5"	501	493	481.4-501
238 W	In	5"	529	452	462-529
239 W	In	5"	465	407	407-465
240 W	In	5"	519	444	462-519
241 W	In	5"	475	428	418-475
230 W	Above	6"	395	312	Open hole No screen

1 Well 237 W was an attempt to locate any aquifer lying below the production zone. No aquifer was found.

2 Well 230 W is completed in and open to the "A" Sand aquifer and is immediately above the production zone.

From April 2 to July 3, 1980, the A-1 well field was operated as follows: Wells 248 and 249 were utilized as production wells and wells 244, 246, 247, 252, 253, and 254 were injection wells. In July, wells 252, 253, and 254 were shut down and the mode of operation (production or injection) of the remaining wells, with the exception of well 249, was changed frequently until termination of the test on November 3, 1980. Well 249 was operated exclusively as a production well during mining of the A-1 well field. Production and injection rates were balanced at the Collins Draw Project because no evaporation pond was constructed to contain waste water. CCIC did not routinely bleed mining solution from the circulating solutions.

Injection of lixiviant at the B well field began on November 4, 1980, with the transfer of approximately 900,000 gallons of solution from the A-1 well field production zone into the B well field production zone. The operational mode (production or injection) of any given well was varied during the course of the B well field mining test in an effort to achieve desired operating flow rates. Lixiviant injection and solution recovery were conducted in a manner similar to that of the A-1 well field. Mining continued in the B well field until July 23, 1981, when restoration was initiated.

Uranium was recovered by passing the produced solution through ion exchange resins which captured the ammonium uranyl tricarbonate complex. A strong ammonium carbonate solution was used to strip the uranium complex from the ion exchange resins (CCIC, 1981a, p. 53). Table 7A-4 presents reported chemical analyses for the solutions injected and produced during B well field operations. Solutions injected and

Table 7A-4. Reported Chemical Analysis of Lixiviant and Produced Solution in the B Well Field at the Collins Draw Mine (after Cleveland Cliffs Iron Company, 1981; from WDEQ files).

Parameter	Concentration Injected Lixiviant	Concentration Production Solution (4/19/81)
TDS	4,100 - 15,100	2,940 - 3,060
Sodium	138	138
Calcium	40	40
Magnesium	2	2
Sulfate	420	420
Chloride	475	475
Carbonate	1,000 - 5,000	1,404
Bicarbonate	1,000 - 5,000	--
Hydroxide	82	82
pH	9.1 - 9.7	9.1
Conductivity (umhos/cm)	4,147	4,147
Ammonia (NH_4 as N)	1,000 - 4,000	420
Nitrate	10.0	10.0
Nitrite	1.25	1.25
Fluoride	0.57	0.57
Total Alkalinity	2,582	2,582
Total Hardness	108	108
Boron	<0.01	<0.01
Aluminum	<0.05	<0.05
Arsenic	0.056	0.056
Barium	<0.03	<0.03
Cadmium	<0.002	<0.002
Chromium	<0.01	<0.01
Copper	<0.01	<0.01
Iron	<0.01	<0.01
Lead	<0.01	<0.01
Manganese	<0.01	<0.01
Mercury	<0.0005	<0.0005
Nickel	<0.02	<0.02
Selenium	2.2	2.2
Zinc	<0.005	<0.005
Molybdenum	0.06	0.06
Uranium	0 - 2	30 - 150
Vanadium	4.2	4.2
Radium-226 (pCi/L)	237.6	237.6

produced at the A-1 well field reportedly were similar in composition to those of the B well field.

Restoration Phase

Several techniques were used in an attempt to restore background or near background water quality in the ore zone aquifer at the Collins Draw Mine. Restoration of the A-1 well field was initiated on November 4, 1980 with the transfer of lixiviant from the A-1 well field to the B well field. A total of about 900,000 gallons of solution was pumped from the A-1 well field ore zone through wells 246, 248, and 249. This procedure resulted in a partial ground-water sweep of the 1-Sand and a general improvement in ground-water quality. Ammonia concentrations were reduced from 720 mg/L to 420 mg/L. A more complete ground water sweep was considered impractical by CCIC because no evaporation ponds had been constructed that could contain the volume of water which would have been produced by an extended sweep.

Recirculation, with treatment at the surface by ion exchange, was employed subsequent to the lixiviant transfer to further reduce the concentrations of ammonium (NH_4^+) and uranium in the ground water. As ammonium ions from the ground water were replaced by hydrogen ions from the ion exchange resin, the lower pH water injected into the ore zone reportedly dissolved calcium carbonate from the host sandstone. Increased calcium concentrations resulted in the displacement of ammonium and hydrogen ions in the cation exchange resin and in the production zone aquifer itself, which resulted in an increase in ammonia concentration from 420 to 630 mg/L (NRC, 1983). About 700,000 gallons

of water were treated by ion exchange; the process was terminated due to poor efficiency of the resins for ammonium removal and reduced well productivity.

Reverse osmosis (R.O.) technology was utilized next for restoration of the A-1 well field. Solution was produced from the ore zone aquifer and passed through the R.O. unit; the treated water then was injected into the ore zone. This method was utilized for only 33 days because CCIC considered it ineffective in reducing ammonia concentrations. However, information provided by CCIC shows that ammonia concentrations were reduced in the withdrawn ground water from 630 to 140 mg/L by the R.O. method. About 2,200,000 gallons of ground water were treated by R.O. during this period.

Removal of ammonia by air stripping was the next method of restoration applied to the A-1 well field. Sodium hydroxide and/or potassium hydroxide was added to ground water produced from the well field to promote the conversion of ammonium (NH_4^+) to ammonia (NH_3). The water then was circulated through an air stripping column to volatilize and remove the ammonia. The treated water was injected into the ore zone following this procedure. Air stripping was discontinued after 132 days on July 25, 1981, when ammonia concentrations in produced water had stabilized at 25 mg/L as N. Approximately 4,400,000 gallons of water were circulated through the air stripping column and subsequently reinjected into the 1-Sand. Table 7A-5 presents a summary of the restoration effects described above.

The last of the initial restoration efforts at the A-1 well field involved injection of clean ground water into the ore-zone in

Table 7A-5. Summary of A-2 Well Field Restoration Effects, Collins Draw Mine, Wyoming (after Cleveland Cliffs Iron Company, 1984).

Method	Millions of Gallons Treated or Injected	Pore Volumes	Time (days)	NH_3 as N (mg/L)
Ground Water Sweep	.9	5.4	15	420
Cation Exchange	.75	4.5	11	630
Reverse Osmosis	1.1	6.5	33	140
Air Stripping	4.4	26	132	25

November-December 1982, to dilute remaining ammonia and TDS concentrations. The water was obtained from the project's potable water source that contained less than 500 mg/L TDS and no detectable selenium, uranium, or ammonia (CCIC, 1984).

Restoration of the B well field began on July 14, 1981 by pumping well 286, treating the produced solution by air stripping for ammonia removal, and then reinjecting the treated water through wells 280, 283, 284, and 285. Potassium hydroxide was added to the water prior to entry into the air stripping column to promote the volatilization of ammonia and to maintain elevated TDS concentrations in the water injected into the ore zone. CCIC believed that high TDS concentrations in the injected fluid would promote removal of ammonium from clays in the ore zone aquifer by ion exchange. Subsequently, various combinations of pumping and injection wells in the B well field were utilized to supply water to the air stripping unit and to inject the treated water into the ore zone aquifer. From August 3 to November 19, 1981, fresh water was injected into the ore zone aquifer through wells 260 and 261. Over 25,000 gallons of ground water had been treated in this manner when the process was terminated in January 1982.

A ground-water sweep of the B well field ore zone aquifer was initiated following the acquisition of a surface discharge permit. This permit was necessary to accommodate discharge because no evaporation pond had been constructed at the site. From February 2 to March 23, 1982 over 3,300,000 gallons of ground water were removed from the ore zone aquifer; this water was discharged to the surface and was not reinjected. Overall water quality improved and ammonia levels dropped to 120 mg/L following the ground water sweep.

Air stripping for ammonia removal was employed again from March 23 to July 13, 1982. From July 13 to November 10, 1982, ground water sweeping was conducted and the produced water was discharged to the surface under a NPDES permit. Finally, from November 11 to December 23, 1982, approximately 5,000 gallons of "outside" water were injected into each of 14 wells (some of which are in the A-1 Well field) selected by the Wyoming Department of Environmental Quality in an attempt to reduce ammonium, selenium, and arsenic concentrations further by dilution. Ammonium levels averaged 2.54 mg/L at the culmination of B well field initial restoration efforts.

Post-Restoration Ground Water Quality

Following the conclusion of initial restoration efforts at the A-1 well field, ground water was sampled over a six month period to ascertain the adequacy of restoration and the stability of water quality in the mined aquifer. Restoration was determined to be unsuccessful because the average concentrations of total dissolved solids (TDS), ammonium, arsenic, selenium, vanadium, Radium-226, and pH exceeded either baseline or Wyoming DEQ Class I ground-water quality standards (Table 7A-6).

Initial restoration at the B well field ended with injection of approximately 5,000 gallons of "outside" water into the wells. Following this work, samples were collected from all A-1 and B well field wells to determine ammonium, selenium and arsenic concentrations. Table 7A-7 presents the analyses for this round of post-restoration sampling. The data show that arsenic concentrations were below the

Table 7A-6. Comparison of water quality before and after restoration of the A-1 well field at the Collins Draw mine (after Cleveland Cliffs Iron Company, 1982, and U.S. Nuclear Regulatory Commission, 1983).

Parameter (mg/L)	Baseline Average[a]	Class I Standard	Average after 6 Month Stability Period[b]
TDS	414	500	582
Ammonia	0.18	0.5	35
Arsenic	<0.02	0.05	0.335
Selenium	<0.01	0.01	0.79
Vanadium	<0.05	--	0.33
pH (units)	7.5 to 8.7	6.5 to 8.5	9.1
Radium-226 (pCi/L)	21.6	5	>100

[a]Average of all wells sampled in A-1 and B well fields.

[b]Average of A-1 wells.

Table 7A-7. Final restoration sampling results, Collins Draw Mine, Wyoming (after Cleveland Cliffs Iron Company, 1983b).

Well No.	Date	Ammonia (mg/L)	Arsenic (mg/L)	Selenium (mg/L)	Sample[1] Type
190	12-09	13.8	0.015	0.112	P
231	12-09	1.51	0.005	0.126	P
232	12-10	1.68	0.006	0.010	P
233	12-09	5.70	0.015	0.058	P
234	12-14	0.85	0.006	0.025	P
237	12-09	2.38	0.009	0.126	P
242	12-09	0.57	0.012	0.101	P
243	12-09	0.20	0.002	0.005	B
244	12-09	0.85	0.003	0.010	B
246	12-09	4.50	0.008	0.019	P
247	12-09	0.36	0.003	0.004	B
248	12-09	11.60	0.076	0.223	P
249	12-09	<0.05	0.002	0.014	B
252	12-09	27.00	0.008	0.166	P
253	12-09	0.24	0.002	0.004	B
254	12-09	0.85	0.009	0.018	P
255	12-09	21.00	0.009	0.792	B
258	12-10	13.80	0.006	0.230	B
260	12-10	<0.05	0.002	0.021	P
261	12-09	0.85	0.003	0.030	B
262	12-10	5.70	0.009	0.094	B
265	12-11	<0.05	<0.001	0.002	B
273	12-10	1.51	0.002	0.002	B
275	12-11	<0.05	<0.001	<0.001	B
276	12-14	2.20	0.011	0.054	P
277	12-10	6.50	0.005	0.030	P
278	12-11	<0.05	0.002	<0.001	B
280	12-10	<0.05	0.002	0.003	B
281	12-10	<0.05	0.002	0.002	B
282	12-10	<0.05	0.002	<0.001	B
283	12-10	<0.05	0.002	0.005	B
284	12-10	<0.05	0.002	0.002	B
285	12-09	0.85	0.015	0.162	P
286	12-10	<0.05	0.002	0.003	B
287	12-10	0.27	0.002	0.007	B
288	12-10	<0.05	<0.001	0.001	B
290	12-10	0.20	0.002	0.006	B
291	12-13	<0.05	<0.001	0.001	B
292	12-10	<0.05	0.002	0.001	B
293	12-10	<0.05	0.002	0.003	B
296	12-09	2.70	0.002	0.006	B
297	12-09	0.74	0.096	1.220	P
303	12-13	<0.05	0.002	0.001	B

[1] P = Pumped; B = Bailed

Class I standard in all but two wells (248 and 297); selenium concentrations were above the Class I standard of 0.01 mg/L in 20 wells and exceeded 0.10 mg/L in 10 wells. Ammonia concentrations were below 30 mg/L (a target set by the Wyoming WDEQ/WQD) in all wells.

The most recent water-quality data available for review were reported by CCIC (1983a) in a submittal to the WDEQ/LQD and are summarized in Table 7A-8. These post-restoration data are averaged for 10 wells in the B well field sampled 10 months after restoration efforts culminated. This monitoring revealed that ammonium, TDS, selenium, uranium, sulfate, pH, and Radium-226 values continued to exceed baseline and/or Class I standards. Figure 7A-8 is a graph of uranium and NH_4^+ concentrations in the B well field after restoration. In addition, the average concentrations of TDS, sulfate, ammonium, and selenium increased steadily over the 10 month period.

Wastewater Disposal

The omission of an evaporation pond, the most common means of excess water disposal, in the Collins Draw mine facilities required CCIC to operate with balanced production and injection rates. Had an evaporation pond or other means of disposal been available, other restoration methods such as directional ground-water sweeping with reinjection of treated water could have been more feasible. The existence of disposal facilities would also have benefited reverse osmosis operations by providing more flexibility in the disposal of the waste stream.

Table 7A-8. Comparison of Water Quality Bedore and 10 Months After Restoration of the B Well Field at the Collins Draw Mine (after Cleveland Cliffs Iron Company, 1982 and 1983; U.S. Nuclear Regulatory Commission, 1983).

Parameter (mg/L)	Baseline[a] Average	Class I Standard	Concentration After 10 Month Stability Period	
			Average[b]	Range
TDS	414	500	594	341 - 770
Sulfate	159	250	252	171 - 388
pH (units)	6.0 - 8.7	6.5 - 8.5	8.7	7.6 - 9.5
Ammonia	0.18	0.5	34.3	1.2 - 57
Selenium	<0.01	0.01	1.02	<.001 - 3.17
Uranium	0.05	5.0	5.28	1.4 - 9.0
Radium - 226 (pCi/L)	21.6	5.0	36.4 ± 6.0	10.5 - 82

[a] Average of all wells sampled in A-1 and B Well Field.

[b] Average of B Field Wells.

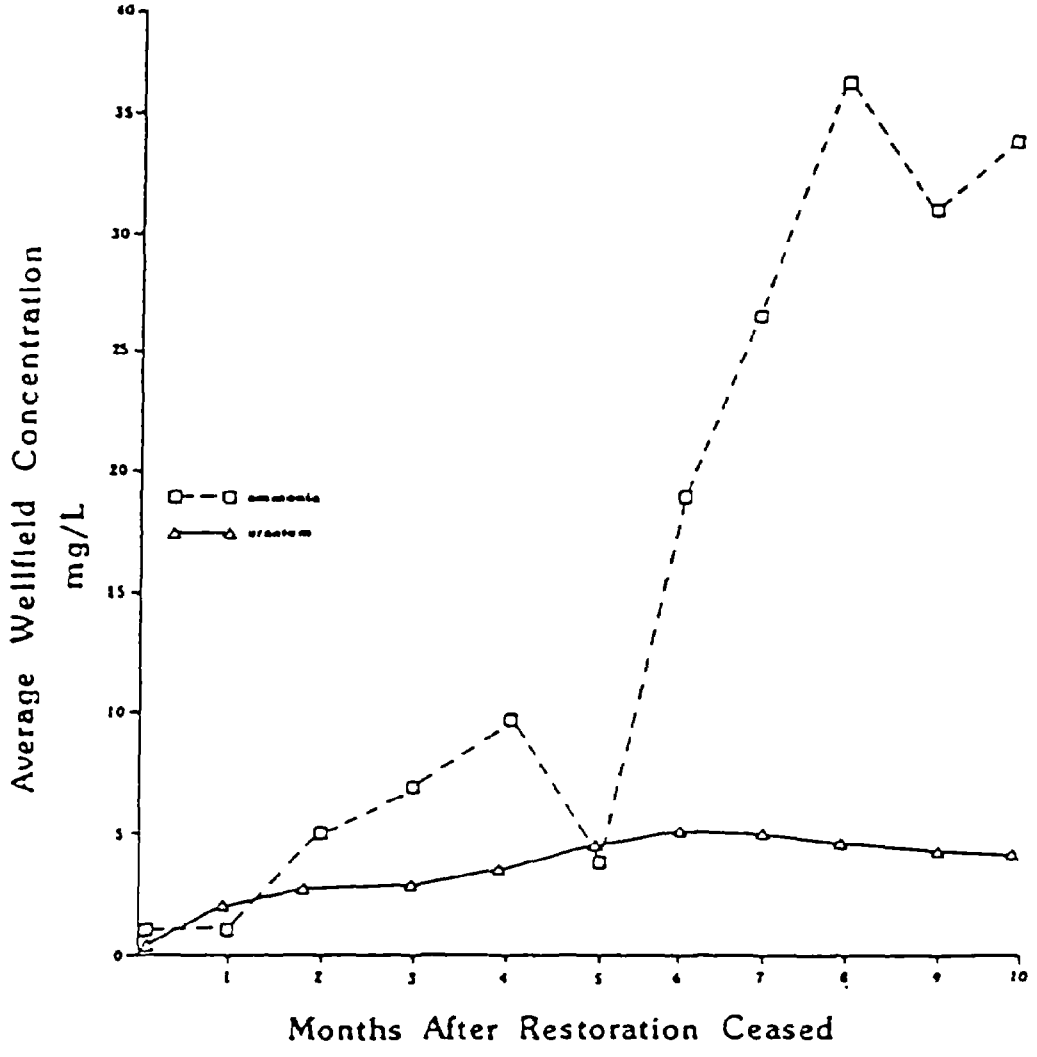


Figure 7A-8. Concentrations of uranium and ammonia in the B well field following restoration (modified after Cleveland Cliffs Iron Company, 1983a).

Disposal facilities are necessary during production to allow recovery in excess of injection. Their absence prevented CCIC from over-producing for an extended period of time. In theory, in situ uranium leaching can be accomplished with completely balanced production and injection rates. However, in reality, fluctuations in production and/or injection rates occur often. Continuous overproduction provides a measure of operating safety that was unavailable to CCIC.

CCIC (1984) reported that difficulty in reducing radium concentrations to acceptable levels in reverse osmosis waste water inhibited discharge of the waste stream to the surface and this detracted from the success of reverse osmosis restoration. Four additional complicating factors hindered the successful completion of restoration by reverse osmosis. These are:

1. The WDEQ placed stringent limits on the amount of radium, uranium, and total gallons of waste water that CCIC could discharge to their subsurface drain field. CCIC was not able to operate reverse osmosis for a sufficient period of time under these limitations to successfully restore the 1-Sand aquifer. Reverse osmosis probably would not have been more effective than the air stripping in reducing ammonium concentrations, however, total dissolved solids would have been reduced.
2. CCIC did not have adequate storage facilities to contain the waste stream from the reverse osmosis unit. Without the ability to discharge the waste stream to the drain field, CCIC was unable to use reverse osmosis effectively to restore the 1-Sand aquifer.

3. Problems with calcium precipitation caused plugging of reverse osmosis resins and membranes. A 20% bleed stream was necessary to avoid plugging problems. Disposal of this large bleed stream was hindered by the absence of adequate waste water storage facilities.

4. Reverse osmosis was not effective at reducing ammonium concentrations to baseline concentrations. Reverse osmosis reduced the bulk of the ammonium in the withdrawn ground water (from 630 to 140 mg/L); however, reverse osmosis probably would have been ineffective at reducing relatively low concentrations of ammonium in the withdrawn ground water.

These problems probably could have been overcome if an evaporation pond had been available for the disposal of the reverse osmosis waste stream.

Evaluation of Restoration Techniques Applied at Collins Draw

The piecemeal manner in which CCIC approached restoration of the A-1 and B well fields did not promote success in reducing both the ammonium and total dissolved solids concentrations to premining quality. Ion exchange, reverse osmosis and air stripping were fairly effective at reducing ammonium concentrations in the withdrawn ground water, but they were ineffective in reducing total dissolved solids to baseline ranges. Longer-term restoration efforts employing enhanced methods of permanent ammonium removal from clays would be necessary to maintain low ammonium concentrations in the ground water because ammonium is continually desorbing from ion-exchange sites on the clays in the aquifer into the

ground water. The reinjection of withdrawn ground water treated by reverse osmosis, ion exchange or air stripping will not reduce the ammonium concentrations on the clays significantly. These methods are capable of reducing the ammonium concentrations only in the withdrawn ground water.

The attempts to remove ammonium from clays in the aquifer by maintaining a high total dissolved solids concentration in the ground water could be considered an enhanced method of ammonium removal. However, CCIC did not make any attempt to control the pH of the injected solutions, nor did they make a sufficient effort to reduce the high dissolved solids concentration in the ground water to premining levels after the completion of the procedures for ammonium removal.

After the completion of procedures to remove ammonium from clays in the aquifer, a more rigorous approach to restoration (such as directional ground-water sweeping, as has been conducted successfully at other in situ mines) probably would have been more effective at removing lixiviant and reducing dissolved solids in the mined aquifer. In directional ground-water sweeping, restoration theoretically progresses across the mined portion of the aquifer. Pumping contaminated ground water from wells within the production well field(s) and injecting water of baseline or better quality (i.e., treated by reverse osmosis or electrodialysis) into the aquifer beyond the zone of contamination produces this effect. Such a restoration program would have combined the effectiveness of ground-water sweeping with the advantages of conserving water. In addition, substantially less waste water storage capacity is needed than with regular ground water sweeping; however,

waste water storage facilities would be needed to contain the waste water from bleed streams.

Attempts by CCIC to reduce total dissolved solids by dilution were ineffective. By injecting "outside" water into the 1-Sand, CCIC was able to reduce the dissolved solids concentration in the immediate vicinity of the injection wells. However, ground water with elevated levels of dissolved solids was pushed out of the well field, and remains in the aquifer at the present time.

Past and Present Ground-Water Impacts

Ground water in well patterns A-1 and B at the Collins Draw site has not, at the time of this report, been sufficiently restored to satisfy the WDEQ/LQD that pre-mining baseline quality has been achieved. The principal problems with restoration progress at this time are elevated concentrations of ammonia, uranium, radium, selenium, sulfate, and total dissolved solids (TDS). The WDEQ/LQD is involved in continuing actions to rectify the situation at Collins Draw, by requiring the site operator to undertake additional activities to accomplish ground-water restoration.

Prediction of Future Ground-Water Impacts

Predictions of future effects of the activities which have taken place at the Collins Draw in situ mining site cannot be accurately made at this time. The ultimate level of ground-water restoration which will

be attained at the site is not known, since the operator is under direction from the WDEQ/LQD and NRC to continue restoration actions. Prediction of future impacts based upon the present level of restoration is misleading, since it is probable that the amount of contaminants in the Collins Draw ground water will be reduced before final abandonment of the site. None the less, computer modeling of future impacts based upon the present level of ground-water contamination at the Collins Draw has been performed. This was done to give some idea of the possible impacts resulting from an improperly restored in situ uranium mining experiment.

Although the aquifer affected by the in-situ mining has not been completely restored to its baseline condition, the facility site has not yet been abandoned. The operator is under direction by both the WDEQ-LQD and the Nuclear Regulatory Commission to develop plans for additional restoration activities, but the extent to which these activities will be successful is not clear at this time. For this reason, future ground-water impacts of the Collins Draw project cannot be accurately predicted at this time.

A worst case scenario of future impacts can be considered, however. A plausible assumption for such a scenario would be that no further restoration is accomplished, and that the A-1 and B well fields are ultimately abandoned with chemical concentrations in the aquifer at the same levels as at present. These chemicals would begin moving out of the project area at a rate approximating the local ground-water velocity (6.3 feet per year).

Chemical concentrations of ammonia, selenium, radium, uranium and the other contaminants injected or mobilized during the experiment would be gradually attenuated as the "slug" of contaminated water moved into previously uncontaminated areas of the aquifer. Ammonia and radium concentrations, for example, would be reduced as the ammonium and radium ions in solution were eventually adsorbed on ion exchange sites in the formation. Uranium would eventually reprecipitate as a salt in the formation, in much the same manner as the uranium was originally deposited along a "roll front" along the boundary between up-gradient (oxidized) formation materials and down-gradient (reduced) formation materials. Other contaminants would be similarly redeposited as mineral species within the formation.

The distance which these contaminants would move before being reduced to background concentrations would vary, depending upon a number of factors involving the aquifer geochemistry and interaction among the contaminants. Use of a model to predict this information for all of the contaminants of concern at Collins Draw would be a complex undertaking, and is beyond the scope of this study. It appears, however, that even under worst case conditions, the chemical contaminants in the A-1 and B well fields would not migrate to any location where ground water from the affected aquifer is presently being withdrawn for use.

Recommendations for Mitigation of Existing Ground-Water Pollution

A wastewater evaporation/storage pond could be constructed at the Collins Draw site, and additional restoration activities could then be undertaken and continued for a sufficient length of time to achieve

restoration. The restoration techniques previously practiced by the facility operator would appear to be adequate for this purpose, if adequate wastewater management facilities are available to receive the inevitable byproduct streams. Techniques which might be employed include removal of ammonia from formation clays by ion exchange, using concentrated solutions of cations such as sodium and calcium; lowering of TDS in the aquifer by treating formation water by reverse osmosis prior to reinjection; and/or a ground-water sweep, practiced either following or in lieu of the other techniques mentioned. All of these techniques, and others, were practiced with relative success at Collins Draw. The only drawback to each is that substantial quantities of wastewater are produced and the facility operator has not, prior to this time, had adequate wastewater management facilities to enable continuation of the techniques for the time necessary to achieve restoration. This problem has been exacerbated, but not caused, by the original use of ammonia in the mining process.

Prevention of Ground-Water Pollution at Similar Sites

The following recommendations are made for the prevention of problems similar to those suffered at Collins Draw at other experimental in situ uranium mines. Each recommendation is accompanied by a brief explanation including the reasons for which it has been made.

1. Adequate surface facilities should be required for any injection project or facility where ground-water restoration is anticipated. Specifically, experimental in situ uranium mining facilities should be required to have sufficient wastewater treatment or storage capacity to handle the maximum

quantity of wastewater which might reasonably be expected to be produced during mining and restoration operations. The necessary capacity must be determined by consultation between experienced professional staff of the permit applicant and the regulatory agencies. In the case of the Collins Draw project, the applicant did not propose a wastewater pond, and the WDEQ did not require one. This may have been due to a lack of experience by the individual parties preparing and reviewing the permit application. It should be stressed, however, that regulatory staff members should be encouraged to raise questions concerning the peripheral facilities at an in situ mine, when their experience warns them that inadequacies in such facilities may threaten irrepairable contamination of ground water.

2) Pre-mining investigations should be sufficiently thorough to determine the approximate level of effort which will be required during the ground-water restoration phase of the experiment. Such investigations should take into account the chemical interactions of the lixiviant(s) to be used and formation minerals. At Collins Draw, the operator should have been aware that restoration of an aquifer mined with ammonia would require greater effort than if the same aquifer were mined with sodium carbonate or bicarbonate. Such an awareness might have prompted the operator, and the regulatory agencies involved, to give greater thought to the need for substantial wastewater management capacity at the site.

CHAPTER 7B

RENO RANCH PROJECT - ROCKY MOUNTAIN ENERGY COMPANY

Introduction

The Rocky Mountain Energy Company's (RMEC) Reno Ranch Project was selected for one of the three in situ uranium mining studies because: 1) it initially used sulfuric acid as a lixiviant; 2) sodium carbonate was also used as a lixiviant; and 3) adequate data are available to assess the effects of the project on the local ground water.

Site Hydrogeology

The Reno Ranch Project site is located in the central Powder River Basin in sections 27 and 28, T.43N., R.73W., Campbell County, about 40 miles south of Gillette, Wyoming. The Wasatch Formation of Eocene age out crops at the surface. It is composed of sandstone, claystone, siltstone, carbonaceous shale and thin coal seams. Sinuous lenses of sandstone deposited in a fluvial setting and which contain all known occurrences of uranium in the area, are from 500 feet to several miles wide, 1 to 8 miles long, and 10 to 100 feet thick. The north-south geologic cross-section presented on Figure 7B-1 details the stratigraphy in the project area. The sandstones are medium- to coarse-grained and arkosic (Hodson, 1973). At the Reno Ranch site, the depth to the top of the ore-bearing aquifer, also called the host sand, is 280 feet and the thickness of the aquifer is about 120 feet.

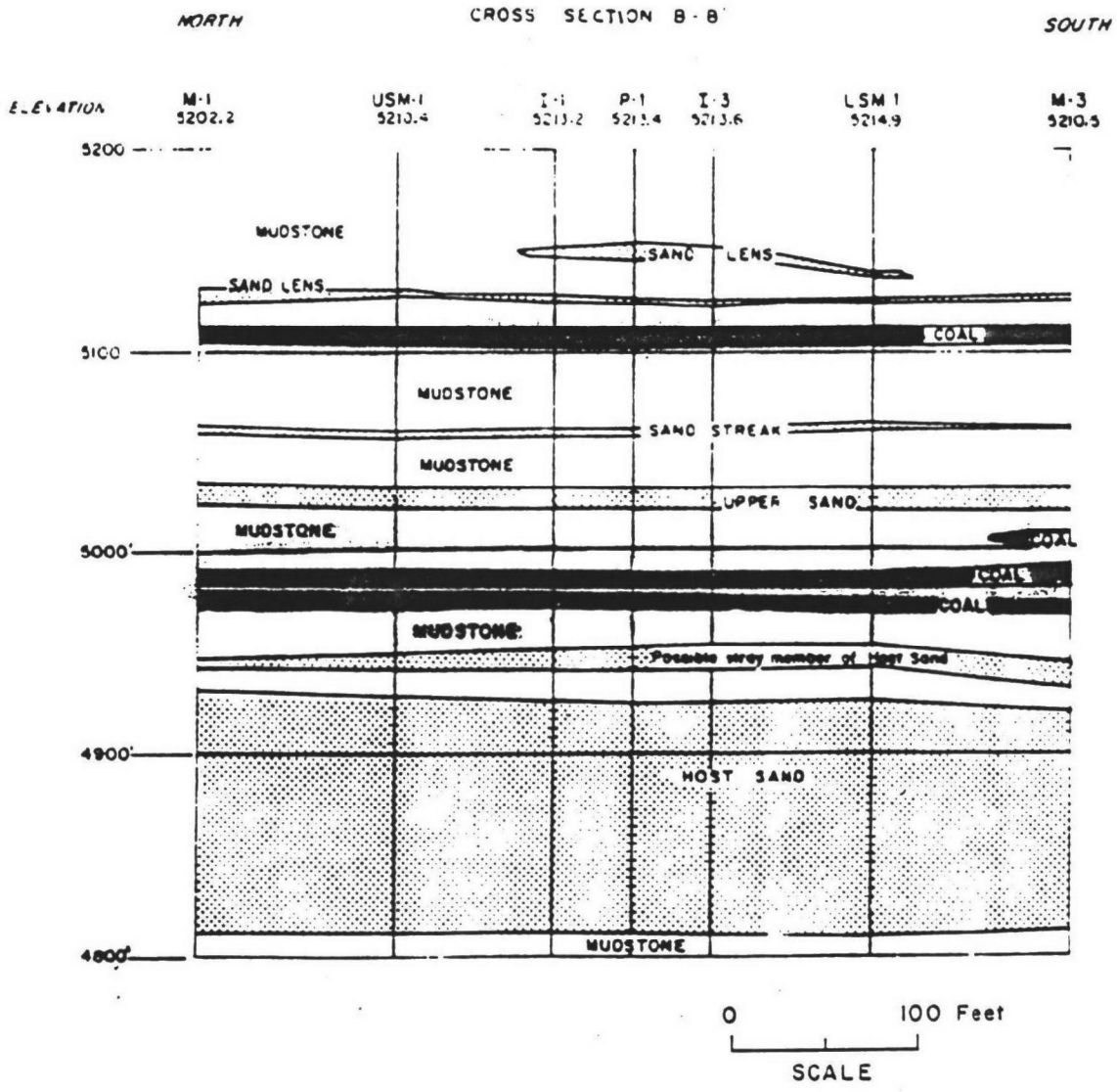


Figure 7B-1. Geologic Cross-Section Through the Reno Ranch Project Site (from Permit 479).

Ground-Water Occurrence and Flow

The Wasatch Formation, which is the principal water-bearing formation in this area, consists of a series of local confined and unconfined aquifers. Depths to water locally range from zero to 315 feet below ground surface in the vicinity of the Reno Ranch site. Wells in deeper aquifers are likely to produce more water than are wells in shallow aquifers. Wells open to thick saturated sandstones in the Wasatch Formation can produce over 250 gpm (Feathers and others, 1981). Yields from existing wells of record in the local area of Reno Ranch range from 5 to 40 gpm (Wyoming State Engineer, various). Recharge to the Wasatch locally is from precipitation; discharge of water is to small springs and seepage along stream drainages, by evaporation and transpiration, and by pumping of wells.

An aquifer test conducted as part of the pre-permit site characterization revealed an anisotropic confined aquifer having a mean transmissivity of 235 ft^2/day, a mean hydraulic conductivity of 2.0 ft/day, and a storage coefficient of 4.6×10^{-4}.

The direction of local ground water flow was obtained from data derived from production-zone wells and is shown with the potentiometric surface of the production zone aquifer on Figure 7B-2. Using the hydraulic gradient computed from the potentiometric surface and measured values of directional transmissivity, thickness, and a porosity of .28, a ground-water flow of 3.1 feet per year in a direction N 36°E was obtained. This is consistent with the regional ground-water trend found by other investigators (In Situ Consulting, 1978).

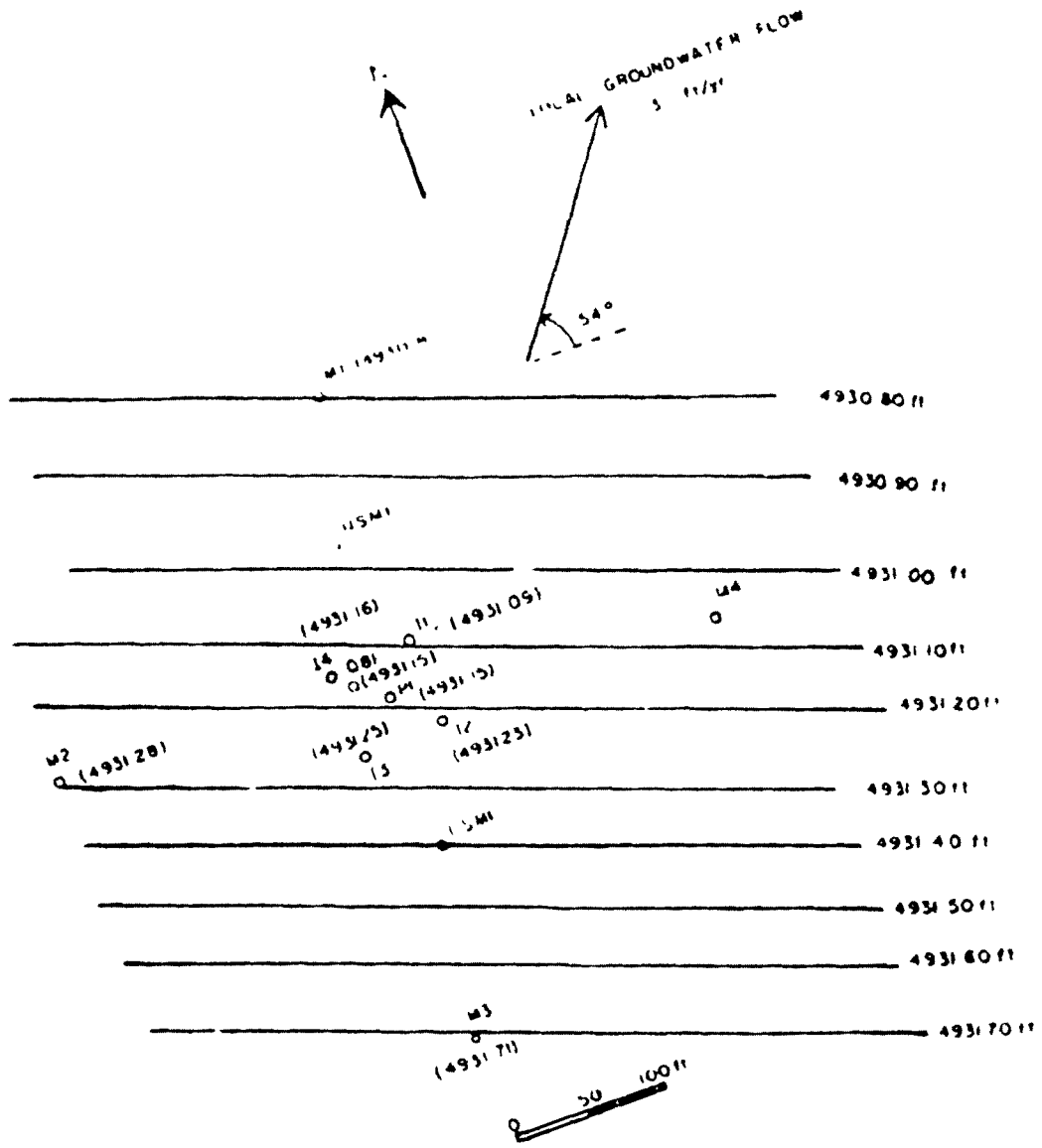


Figure 7B-2. Potentiometric Surface Elevation, Reno Ranch Project (from WDEQ Files).

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Ground-Water Quality

Baseline water-quality data were obtained by RMEC from wells USM-1 and LSM-1, drilled into the upper and lower sands respectively. (The lower sand underlies the confining mudstone at the bottom of the host sand). Table 7B-1 presents the range of baseline water-quality parameters for wells in those aquifers. The quality of water in the upper sand is generally better than that of the water in the lower sand, although neither water meets all of the quality criteria for Class I, II, or III waters. Both waters exceed the Class I and II standards for boron and pH, and the Class II and III standard for vanadium. The Class I iron standard is also exceeded by both waters, but iron concentrations are below the treatability limit of 5.0 mg/L. Water from the upper sand also exceeds the manganese standard for Class I and II waters. Water from the lower sand exceeds the Class I standards for ammonia and TDS, and exceeds the Class I and II standards for selenium and sulfate. Except for pH and vanadium, both waters meet the livestock (Class III) use suitability standards.

Table 7B-2 lists constituent concentrations from wells in the production zone. The overall water quality in the host sand is good. However, because of elevated concentrations of numerous constituents, it does not meet the standards for Class I, II, or III waters. Class I standards for TDS, radium, selenium, and sulfate are exceeded in all cases, and for pH, boron, and manganese in some cases. Class II standards for TDS, sulfate, radium, and vanadium are exceeded in all cases, and for pH, boron, and selenium in some cases. Class III standards for mercury, radium, and vanadium are exceeded in all cases,

Table 7B-1. Reno Ranch Project Baseline Water-Quality Ranges (from WDEQ files).

	USM-1	LSM-1
Alkalinity	85. - 262.	127. - 1370.
Aluminum	ND - 1.45	.30 - 1.03
Ammonia	ND - .21	ND - 26.0
Arsenic	ND - .03	ND - .03
Bicarbonate	59. - 322.	0. -
Boron	ND - 1.25	.04 - 1.08
Calcium	10. - 24.	114. - 203.
Carbonate (as CO_3)	0. - 129.	58. - 225.
Chloride	17. - 36.	13. - 66.
Conductivity	300. - 710.	1840. - 2800.
Flouride	.95 - 1.07	.29 - .60
Hardness (as $CaCO_3$)	46. - 70.	327. - 507.
Iron	ND - .45	ND - 3.
Magnesium	2. - 28.	ND - 60.
Manganese	ND - 1.10	ND - .02
Nitrate	ND - .5	ND - .2
Potassium	6. - 13.	16. - 52.
pH	8.1 - 10.2	10.6 - 12.06
Selenium	ND -	ND - .04
Silica	ND - 6.4	ND - 12.8
Sodium	95. - 110.	80. - 240.
Sulfate	11. - 59.	25. - 614.
TDS	315. - 494.	1046. - 1377.
U_3O_8	.001 - 1.1	ND - 2.
Vanadium	ND - 6.	ND - 10.

All data reported as ppm or mg/l. ND=Non Detectable

The parameters listed below were non-detectable:

Barium	Copper	Molybdenum	Silver
Cadmium	Lead	Nickel	Zinc
Chromium Hexavalent	Mercury	Nitrate	

Table 7B-2. Baseline Concentrations for RMEC Reno Ranch Pattern I Compliance Wells.

Parameter	Wells: Production P-1	Production P-2	Monitor M-1	Monitor M-2	Monitor M-3	Monitor M-4
pH	7.9-8.6	7.9-8.6	7.9-8.3	7.9-8.2	8.2-10.8	7.8-9.0
Conductivity	1400-2000	1400-2000	1220-1570	1250-1760	1300-2000	1220-1650
Bicarbonate	13-98	13-98	57-122	56-121	48-102	33-102
Carbonate	0-75	0-75	0-48	.32	0-32	0-65
Alkalinity ($CaCO_3$ eq)	11-80	11-18	47-100	46-99	39-84	27-84
Calcium	80-120	18-120	79-99	88-119	88-113	90-117
Chloride	8-18	8-18	14-21	6-22	10-19	8-17
Magnesium	15-29	15-29	13-22	15-28	17-29	19-29
Potassium	10-20	10-20	7-11.2	7-11.3	8-14	8-12.9
Sodium	210-323	210-323	201-208	220-290	220-272	200-278
Sulfate	700-900	700-900	486-776	640-860	625-821	670-953
TDS	1124-1492	1124-1492	1006-1292	1103-1392	1063-1466	970-1452
Aluminum	.1 - .28	.1 - .28	.1 - .18	.1 -.49	.1 -0.6	.1 -.2
Arsenic	.01- .03	.01- .03	.01- .03	.01-.03	.01- .02	ND- .01
Barium	.1	.1	.1	.1	.1	.1
Boron	.11-2.6	.11-2.6	.1 -2.6	.1 -1.49	.1 - .36	90-117
Cadmium	.01	.01	.01	.01	.01	.01
Chromium	.01	.01	.01	.01	.01	.01
Copper	.01	.01	.01	.01	.01	.01
Fluoride	ND- .22	ND- .22	.1 - .67	.1 - .57	.1 - .23	.1 -.14
Iron	.01- .21	.01- .21	.01- .24	.01- .17	.1 - .13	.1 -.34
Lead	.01	.01	.01	.01	.01	.01
Manganese	.01- .03	.01- .03	.01- .07	.01- .09	.01- .02	.01-.04
Mercury	.0001	.0001	.0001	.0001	.0001	.0001
Molybdenum	ND- .08	ND- .08	.01	ND- .05	ND- .09	ND-.1
Nickel	.01	.01	.01	.01	.01	.01
Selenium	ND- .05	ND- .05	.01-.02	.01- .02	.01- .02	.01-.02
Vanadium	.05- .38	.05- .38	.05-.17	.05- .17	.05- .14	ND-.05
Zinc	.01	.1	.1	.1	.1	.01
Uranium	.15-1.05	.15-1.05	.023-.102	.007- .027	.205- .750	.27-.55
Radium	160-686	160-686	109-398	11.7-23.9	67-207	40-136

ND - Not detectable

All units mg/L except pH (std units), conductivity (umhos/cm) and radium (pCi/l)

and for boron and pH in some cases. Generally, Class II (irrigation use) standards are met and in many cases, the majority of the minor constituents are in the range of Class I (domestic use) water. Sulfate and boron are consistently in the range of Class III (livestock use) water. The concentrations of the other major constituents were in the range of Class II water or better. Vanadium, exceeded Class II and Class III standard by 40 to 380 percent, and radium concentrations ranged from 2.3 to 137 times the 5 picocuries per liter (pCi/L) standard Class I, II, and III.

Ground-Water Use

All but 2 wells drilled within 1 mile of the permit boundaries are used for stock watering. Those two exceptions were drilled by H.R. Underwood as observation wells to evaluate the subsurface water supply. Table 7B-3 lists the water well permits within one mile of the Reno Ranch permit boundaries. Figure 7B-3 shows the locations of wells listed in Table 7B-3 (Wyoming State Engineer, various).

Description of Facilities

The Reno Ranch permit area covers 39.32 acres, of which about 1 acre was used for surface facilities. Injection wells I1, I2, I3, and I4 were drilled in a five-spot pattern around the central production well P1. Observation well OB-1 was drilled inside the pattern. Monitor wells M1, M2, M3, and M4 were drilled outside the pattern to monitor subsurface flow movement during solution mining operations. All

Table 7B-3. Water Well Permits With One Mile of the Reno Ranch Permit Boundaries.

Permit Number	Location, S, T, R	Owner/ Well Name	Depth (feet)	Use	Water Level (feet)
2880	SWSW 22, 34N, 72W	Ed Willard Willard No. 2	230	Stock	210
20033	SWNE 23, 34N, 72W	H.W. Underwood Patterson No. 1	50	Stock	15
2882	SWNW 26, 34N, 72W	Ed Willard Willard No. 4	205	Stock	150
2883	NWNE 28, 34N, 72W	Ed Willard Willard No. 5	80	Stock	60
2881	NWNE 32, 34N, 72W	Ed Willard Willard No. 3	90	Stock	65
18841	SWSW 32, 34N, 72W	Floyd Reno & Sons Tucker Well	300	Stock	200
25454	NWNE 33, 34N, 72W	H.R. Underwood Underwood 1	460	Obs Abandoned	280
25455	NENE 34, 34N, 72W	H.R. Underwood Underwood No. 2	240	Obs Abondoned	No Water
20037	NENE 35, 34N, 72W	H.R. Underwood Patterson No. 5	200	Stock	50

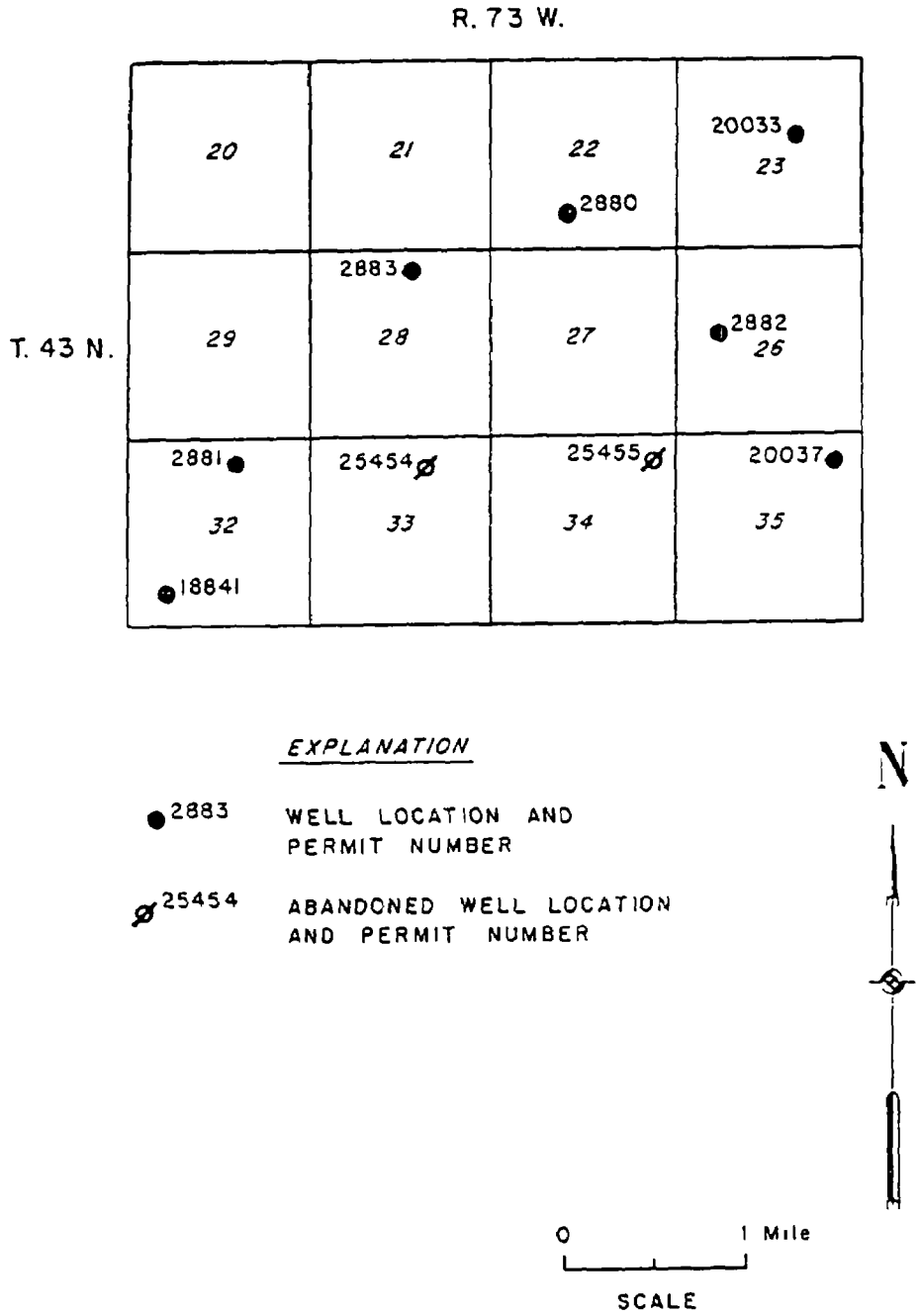


FIGURE 7B-3 LOCATIONS OF PERMITTED WATER WELLS NEAR THE RENO RANCH PROJECT AREA

[5-177]

injection and production wells were completed in the ore zone. Observation well OB-1 and monitor wells M1, M2, M3, and M4 were completed through the entire thickness of the aquifer. Wells USM1 and LSM1 were completed in the upper and lower sands, respectively.

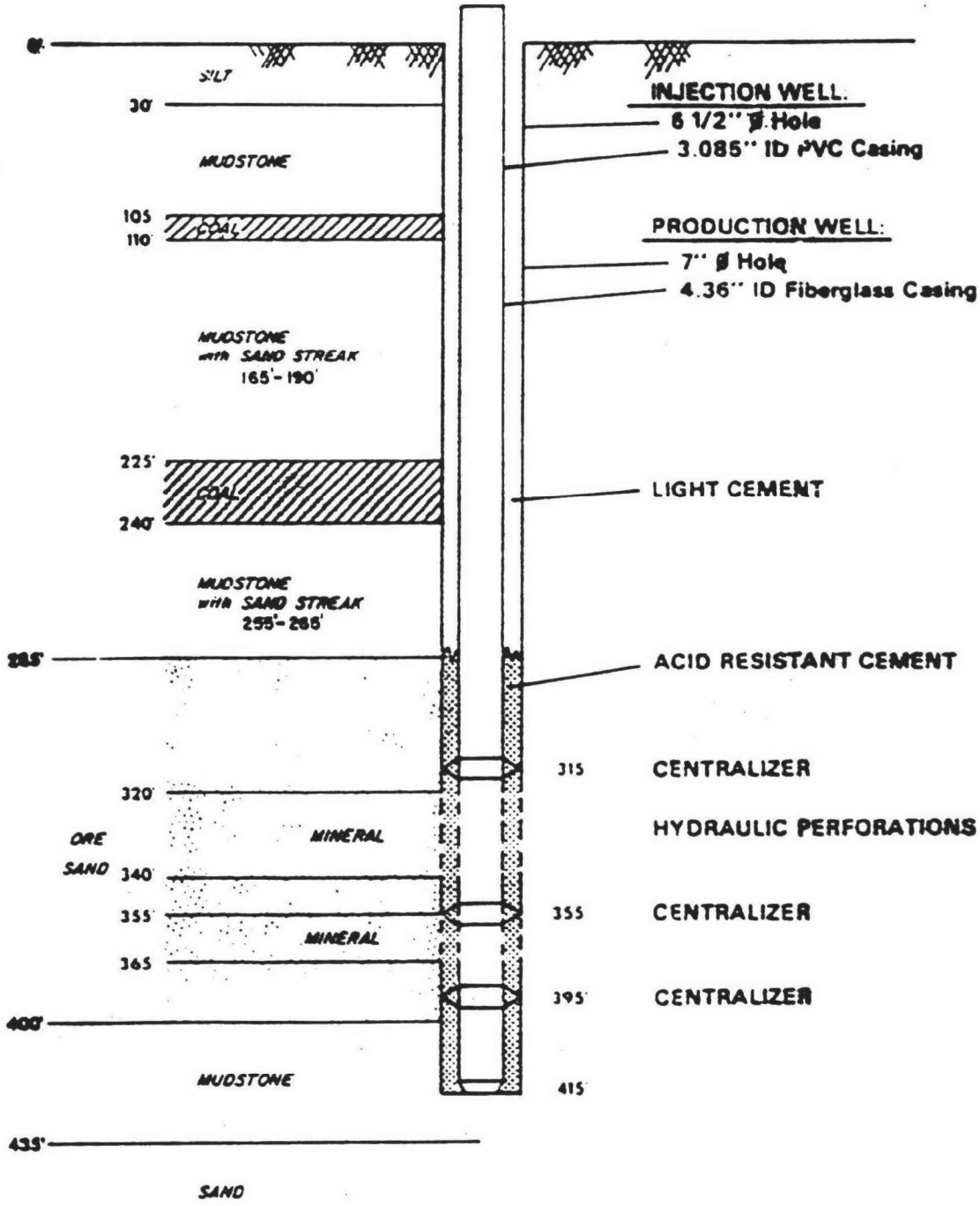
The wells at Reno Ranch were constructed by inserting fiberglass or PVC casing of a diameter smaller than the drill hole to a depth below the production zone. The casing was then anchored in place by pumping a cement, or cement-bentonite slurry, from the bottom of the hole up the annulus of the bore until the annulus was filled to the ground surface. Once the cement hardened, the hole was re-entered and completed to allow contact with the ore-bearing strata in the host formation (Permit No. 479).

The production and injection wells in Pattern II were originally completed by a combination of perforating and under-reaming, whereas the monitor wells were perforated. Figure 7B-4 shows typical well completions. Once the wells were completed, they were flushed by air-lifing or sustained pumping to remove residual cuttings, cement, and other potential contaminants. The Pattern II production, injection, and monitor wells were completed in basically the same manner used for Pattern I.

Figure 7B-4.

TYPICAL INJECTION-PRODUCTION WELL DIAGRAM

RENO RANCH SITE



Operational History

Pattern I

Pattern I Mining

Injection of sulfuric acid for the purpose of leaching uranium in test Pattern I began in February 1979. Soon after acid injection began, problems with scaling due to gypsum formation were encountered. The gypsum was precipitated in the intergranular voids in the ore zone aquifer, and caused a substantial and increasing loss of permeability. By the middle of June 1979, scaling had become quite significant with a resultant loss in circulation between injection and recovery wells. Operations during the latter part of June and July 1979 were directed toward removal of scaling and re-establishment of circulation in the ore zone. By August 1979, the pattern was back in production, however, uranium values were significantly lower than anticipated and circulation problems persisted. The scaling problem was compounded by a fungus growth which contributed to well screen and filter plugging. By November 1979, the combination of circulation problems, low uranium recovery rates and high acid consumption suggested that leaching of the pattern should be discontinued and restoration efforts initiated. As of November 12, 1979, Pattern I leaching was terminated.

Pattern I Restoration

Acid injection was terminated and initial restoration of the pattern began November 16, 1979. Preliminary restoration efforts

involved routing of the production flow from Well OB-1 (approximately 18 gpm) to the ion exchange columns for uranium and calcium removal. A bleed stream of approximately 5 gpm was discharged to a lined evaporation pond while the production fluid, following uranium and calcium removal, was reinjected into the pattern.

This restoration procedure continued through December 14, 1979, when production from Well P-1 was initiated. Well P-1 was adjusted to produce at about 15 gpm with Well OB-1 producing at approximately 10 gpm, for a total production flow of 25 gpm. Because the flow from Well P-1 was essentially barren of uranium and the flow from Well OB-1 was depleted of uranium, the total flow was routed directly to the calcium removal columns. During the remainder of December 1979, the flow through the calcium columns was gradually decreased while the flow to the injection tank (for reinjection) was correspondingly increased until the calcium columns were bypassed, with the total flow going to the injection tank.

On December 21 1979, the total production flow was routed to the evaporation pond and restoration of the pattern by means of a ground-water sweep began. Production from the two wells continued at approximately 25 gpm through the remainder of December 1979 and January, February, and March 1980.

During the first part of March 1980, a water treatment circuit was designed and constructed for the purpose of raising the pH of injected water from the 4.0-4.2 range to a pH of 7.5-8.5. Following potassium carbonate and flocculant addition, the production flow was routed to a liquid/solids separator. The underflow from this separator, containing

precipitated calcium, metals and radionuclides, was discharged at a rate of about 4 gpm into a lined evaporation pond. The liquid overflow was reinjected into Pattern I at a pH of 7.0 to 7.5 at approximately 15 gpm. This method, though more successful than the earlier ion exchange process, was unable to accomplish restoration of Pattern No. 1 ground water for pH, sulfate, and TDS.

The restoration difficulties at Reno Creek Pattern I stemmed from the use of an acid lixiviant to mine an ore body containing substantial amounts of basic minerals. This caused two major problems. First, the acid dissolved a portion of these basic minerals (particularly calcite and gypsum) liberating not only uranium but many other chemical species. In particular, relative large quantities of liberated calcium and magnesium moved through the aquifer toward the production wells. As the ground water moved through the formation, however, the acid was progressively removed by reaction with basic minerals and adsorption of hydrogen ions (acid components) upon cation exchange sites on clay particles. The ground-water pH subsequently rose, and the calcium and magnesium in solution were reprecipitated as sulfates. (The ground water contains high concentrations of dissolved sulfate.) This was the primary cause of the scaling which had such a deleterious effect upon mining activities. A more serious long term effect, however, was that many of the minor (and toxic) constituents of the minerals, such as vanadium, radium, and uranium were not fully reprecipitated at the final aquifer pH, and remained as dissolved contaminants after the cessation of mining activities.

Compounding this liberation of contaminants was a second problem. The hydrogen ions adsorbed in the formation were preferentially held on the cation exchange sites of the formation clays. In simple terms, displacement of the hydrogen ions from those exchange sites would require a concentration of some other cation (calcium or sodium, for example) much higher than the hydrogen ion concentration that was originally required to displace the cations (calcium, mangnesium, and sodium) during the mining operation. Consequently, merely flushing "clean" water through the formation will not readily remove the hydrogen ions from the aquifer. Because of this fairly large supply of adsorbed acid, aquifer pH remained below baseline levels even after extended restoration efforts. As a result, uranium, vanadium, radium, sulfate, and total dissolved solids (TDS) concentrations could not be reduced to their baseline levels.

Failure of the uranium recovery activities and restoration efforts at Pattern I at Reno Ranch can be traced to the use of an acid lixiviant. The facility operator had previously used this type of lixiviant successfully at other sites, and apparently chose to use acid at Reno Ranch based upon that experience. The geochemistry of the Reno Ranch site, however, was substantially different from that of the other sites at which the operator had successfully used an acid lixiviant.

The problems encountered at Reno Ranch Pattern I could have been avoided by more careful attention to aquifer geochemistry. There are, however, factors which lessen the environmental impact of the failed restoration at Pattern I. Aquifer contamination was limited to a very small area and it is believed that over a long period of time the

aquifer will gradually return to its baseline quality. Active restoration at Pattern I concluded in 1981. Final water quality in the pattern is discussed in the Ground-Water Impacts section of this chapter.

Pattern II

Pattern II Mining

RMEC used a sodium bicarbonate lixiviant for this pattern which was a short distance from Pattern I. The carbonate pilot plant operated at an average injection rate of 40 gpm. After the lixiviant circulated through the ore-bearing strata and was pumped back to the surface, it passed ion exchange columns for uranium recovery. The lixiviant was then fortified with carbonate ion by the addition of solid sodium carbonate at a rate of up to 70 pounds per hour, and carbon dioxide gas was sparged into the lixiviant to maintain a pH of 7.5. The solution then flowed to the well field surge tank where, prior to reinjection, oxidant was added and solution pH was adjusted with gaseous CO_2 to the pH of the ground water.

Pattern II Restoration

Restoration of the pattern was accomplished by circulating the ground water through a reverse osmosis (R.O.) system. The contaminated water entered the R.O. system where it was separated into two streams: a clean product water (permeate), and a concentrated brine stream containing salts and radionuclides. Permeate was reinjected into the well field and the brine discharged to the synthetically-lined

evaporation pond. The cycling of water through the aquifer and R.O. system continued until the production water quality stabilized within the background water-quality use category range. Restoration of Pattern II proceeded uneventfully and was successful in returning the post-mining ground water to background quality or better.

Past and Present Ground-Water Impacts

Pattern I employed a sulfuric acid-based lixiviant, and trouble was experienced not only with restoration but also with the uranium leaching operations. Uranium was never successful mined from Pattern I, due to a succession of problems including well plugging and failure to mobilize sufficient uranium for economic recovery.

Following the abandonment of mining attempts at Reno Creek Pattern I, restoration attempts were unsuccessful. The injected acid had preferentially adsorbed onto ion exchange sites on clays in the formation. As a result, the formation pH remains well below baseline levels. The very low pH has led to continued mobilization of uranium, radium, vanadium, iron, aluminum, manganese, calcium, magnesium, potassium, sulfate, fluoride and chloride in the ground water. The permittee was not able to develop any method to remove the acid from the ion exchange sites in the formation other than circulating a strongly concentrated basic solution of positively-charged cations through the Pattern I well field. Injection of such a solution was felt by WDEQ and NRC personnel to pose a greater threat to the ground water than allowing the ground water to remain unrestored. For this reason, the Reno Ranch

operator was allowed to cease ground-water restoration attempts at Pattern I, although ground-water monitoring was required for several years after the end of restoration attempts. At this time, all restoration and monitoring activities have ceased. The ground water in Pattern I remains in its contaminated state.

The baseline ground-water quality in Pattern I did not generally meet the standards for Class I or Class II ground waters in Wyoming. The principal constituents in the ground water which violated those standards were sulfate, total dissolved solids, vanadium, and especially radium. The concentrations of these constituents have all been dramatically increased in the unrestored aquifer, and other constituents have also been elevated beyond the standards for ground-water Classes I and II. Table 7B-4 illustrates the quality of water in Pattern I wells as of August 1982, almost 3 years after mining ended.

Ground water from this aquifer is not used in the immediate area for any purpose, though there are stock wells which may withdraw water from the aquifer within a few miles of Pattern I. At this time the contamination of the Pattern I aquifer in the immediate vicinity of the Reno Ranch site is not having any effect on the public health or welfare.

Prediction of Future Ground-Water Impacts

Over a long period of time, sufficiently large quantities of the highly buffered aquifer water will move through the well field and neutralize the acid remaining on the formation's ion exchange sites. As

Table 7B-4. Post Active (August 27, 1982) Restoration Analytical Results for RMEC, Reno Ranch Compliance Wells.

	Wells					
	Production		Monitor			
Parameter	P-1	P-2	M-1	M-2	M-3	M-4
pH	4.6	4.5	R	R	R	R
Conductivity	2800	3000	1700	1800	R	2000
Bicarbonate	R	R	130	R	R	R
Carbonate	R	R	R	R	R	R
Alkalinity ($CaCO_3$ eq)	R	R	110	R	R	R
Calcium	280	280	R	R	120	130
Chloride	45	66	R	R	R	R
Magnesium	66	73	R	R	R	R
Potassium	33	47	R	R	R	R
Sodium	R	R	230	R	R	R
Sulfate	1600	1800	R	R	R	R
TDS	2400	2500	R	R	R	R
Aluminum	5.1	5.3	3.3	R	2.4	1.5
Arsenic	R	R	R	R	R	R
Barium	.2*	.2*	.2*	.2*	.2*	.2*
Boron	R	R	R	R	R	R
Cadmium	R	R	R	R	R	R
Chromium	R	R	R	R	R	R
Copper	R	R	R	R	R	R
Fluoride	.6	.5	R	R	R	R
Iron	35	42	2.4	R	1.3	.8
Lead	R	R	R	R	R	.023
Manganese	1.1	1.2	R	R	R	.080
Mercury	R	R	R	R	.0002	R
Molybdenum	R	R	R	R	R	R
Nickel	.06	.05	.03	R	.03	.02
Selenium	R	R	R	R	R	R
Vanadium	.79	R	R	R	R	R
Zinc	R	R	R	R	R	R
Uranium	1.2	R	R	R	R	R
Radium	860	1200	R	R	R	R

All units mg/l except pH (std units), conductivity (umhos/cm) and radium (pCi/l).

ND Not detectable
R Restored to or below baseline levels
* Detection limit to high to determine restoration success

a result, the various cationic and anionic species in solution will reprecipitate and the aquifer will gradually approach its background quality. This type of "natural" restoration would not prevent harm to any nearby user of the ground water. At Reno Ranch, however, there is no such user.

Although the aquifer affected by attempted in situ mining of Pattern I has not been restored to its baseline condition, the Reno Ranch facility site is being abandoned. The chemical contaminants injected and mobilized in Pattern I will therefore move away from the project area at a rate approximating the local ground-water velocity (3.1 feet per year). Low ground-water pH and elevated concentrations of vanadium, radium, uranium and the other contaminants will coincide with this movement. This contamination will be attenuated as the "slug" of contaminated water moves into previously uncontaminated areas of the aquifer, however. Hydrogen ions in the contaminated ground water will eventually be neutralized by contact with basic (calcium bearing) formation minerals, raising the pH. Elevated vanadium and radium concentrations, which are a result of the lowered aquifer pH, will subsequently be reduced as the vanadium and radium ions in solution are adsorbed on ion exchange sites in the formation. Likewise, uranium will reprecipitate in the formation and be deposited along a new "roll front" as the pH of the affected ground water is returned to normal.

The distance which these contaminants would move before being reduced to background concentrations will vary, depending upon a number of factors involving the aquifer geochemistry and interaction among the contaminants. Use of a model to predict this information for all of the

contaminants of concern at Reno Ranch would be a complex undertaking, and is beyond the scope of this study. It appears, however, that the chemical contaminants in the Pattern I ground-water will not migrate to any location where ground water from the affected aquifer is presently being withdrawn for use. This statement is based upon the absence of any nearby (within several miles) wells appropriating water from this aquifer, the known high background levels of radium in the water, the limited areal extent of the Pattern I well field, and the high buffering capacity of the formation minerals. This capacity was demonstrated by the failure of mining within Pattern I, and will result in the attenuation of chemical contamination of the aquifer within a relatively short distance of the project site.

Recommendations for Mitigation of Existing Ground-Water Pollution

At the present time, it appears that little can be safely and practically done to alleviate the contamination of the ground water affected by the Pattern I well field at the Reno Ranch site. The minerals in the affected aquifer have been altered, more or less permanently, by the attempted acid leaching of uranium.

Prevention of Ground-Water Pollution at Similar Sites

In order to prevent a recurrence of the problems encountered with restoration of Pattern I, close attention must be paid to aquifer geochemistry when planning and permitting similar facilities. Incompatibility between formation minerals and the mining lixiviant was the only apparent reason for the failure of restoration at this site.

The experiment operator was able to restore the nearby Pattern II ground water without exceptional difficulty. As far as may be determined from the WDEQ files, the operator also evidenced some willingness to attempt restoration of Pattern I using untried techniques which would probably have been unusually expensive for an experiment of this size.

Original use of acid lixiviant at Reno Ranch appears to have been based solely upon the operator's successful use of acid in a different location. Use of an acid lixiviant, and subsequent restoration problems, could have been avoided if personnel of either RMEC or WDEQ had been aware of the disastrous consequences of such use in an aquifer containing large amounts of calcite. In the future, regulatory personnel should be encouraged to make use of such experiences. WDEQ personnel should not be hesitant to advise and, if necessary, direct permit applicants in the use of appropriate lixiviants (and techniques) in the mining phase of projects such as Reno Ranch. As a result of the failure of the Pattern I project and studies of aquifer geochemistry elsewhere in areas of Wyoming containing uranium ore, WDEQ has barred further use of sulfuric acid lixiviants for uranium in situ leaching projects.

CHAPTER 7C

BILL SMITH PROJECT - KERR-MCGEE NUCLEAR COMPANY

Introduction

The Kerr-McGee Nuclear Company's (KMNC) Bill Smith Project was selected as one of the in situ uranium leaching projects to be assessed because 1) it was one of two sites identified in the state as an experiment in solution mining in a conventional underground uranium mine (stopes leaching); and 2) adequate data appeared to be available. However, the quality of data from the Bill Smith Project files was less than anticipated and information from the second such project has been utilized. The second project, the Bill Smith 6001 Project, was located west of and directly adjacent to the Bill Smith Project. The experiments were similar in procedures and methods so that data and results from both projects can be combined.

Site Hydrogeology

The Bill Smith Project is located in Section 36, T36N, R74W, Converse County, about 40 miles northeast of Casper, Wyoming. The Wasatch Formation of Eocene Age out crops in the in situ experiment area (Sharp, et al., 1954). It consists of about 500 feet of interbedded sandy siltstones and shale separating relatively clean sandstones in which ground water occurs under unconfined water-table conditions (Hodson, et al., 1973). The uranium-bearing sandstone in the Bill Smith Mine is designated by Kerr-McGee as the "O" sand of the Fort Union

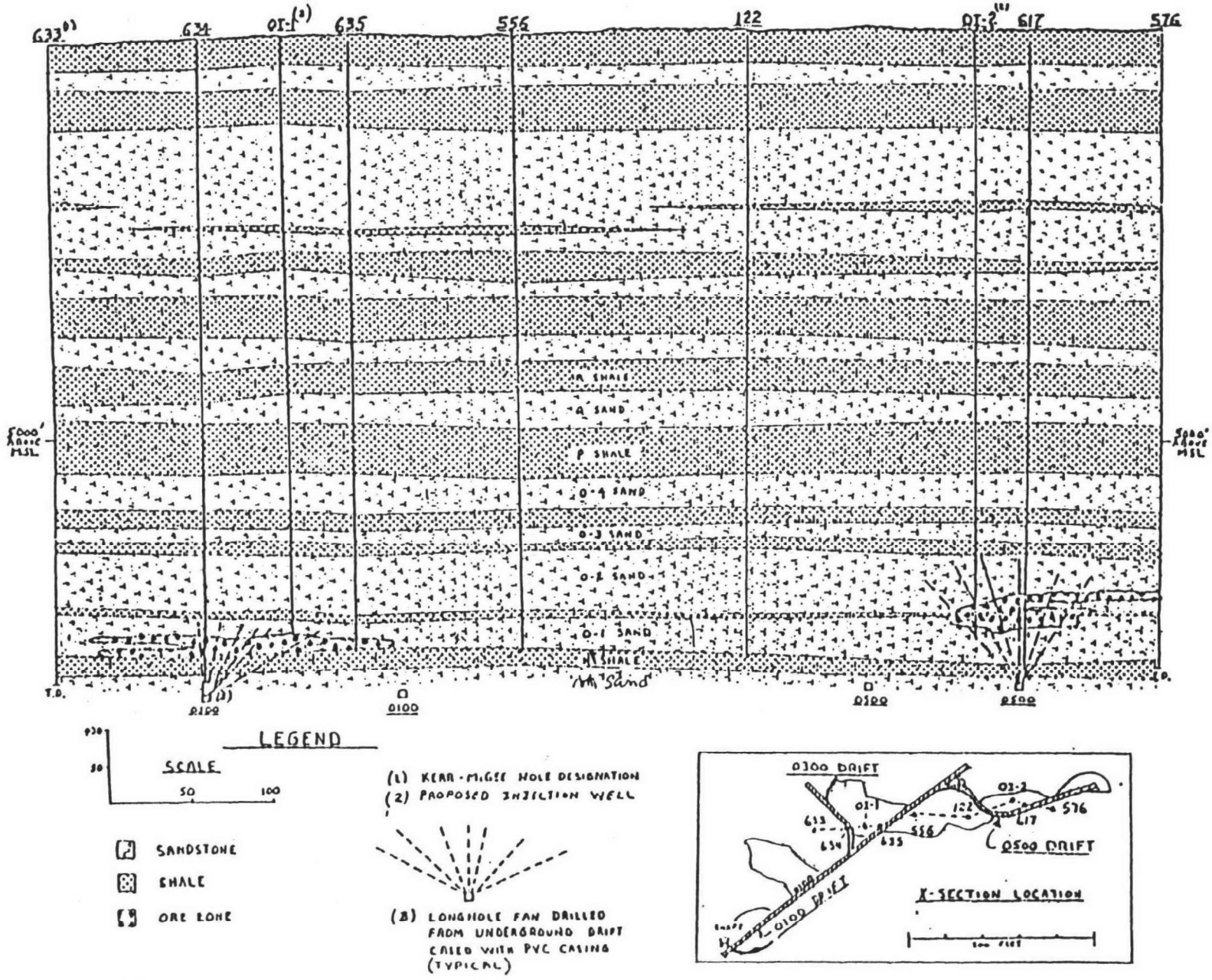
Formation, and occurs at an approximate depth of 850 feet. The "P" shale, which separates the overlying "Q" sand from the "O" sand, is about 60 feet thick and functions as an aquitard between the water-table aquifer system and an artesian aquifer system existing in the "O" sand. The "O" sand is made up of the O-1, O-2, O-3, and O-4 sand segments in the test area. The shale stringers between the "O" sand segments in the project area are limited in areal extent and are not continuous into other areas. Therefore, the total "O" sand, made up of the four segments in this local area, is considered a single aquifer unit (Permit 4 RD). The "N" shale is found below the "O" sand, and separates it from the underlying "M" sand which is about 50 feet thick. A site cross-section (Figure 7C-1) shows the relationships of the stratigraphy described above.

Aquifers in the test area generally yield 5 to 20 gpm but some wells yield in excess of 100 gpm (Hodson, 1973). The regional ground water flow in the Fort Union Formation is northeast under normal conditions. However, at the test site and areas near the mine, the water movement is into the mine workings.

Two pumping wells, TW-1 and TW-2, and 10 observation wells were constructed specifically for aquifer testing near the mine. Figure 7C-2 is a map of the mine area and the test well locations.

The TW-2 well was pumped for a 10-day period in July 1975 at an average rate of 550 gpm. The TW-1 well was pumped for a 6-day period staring September 29, 1975 at 425 gpm. Based on an analysis of drawdown and recovery data, the following conclusions were drawn (Permit 4 RD):

Figure 7C-1. Geologic Cross-Section Through Kerr-McGee Bill Smith Project Site (from WDEQ Files).



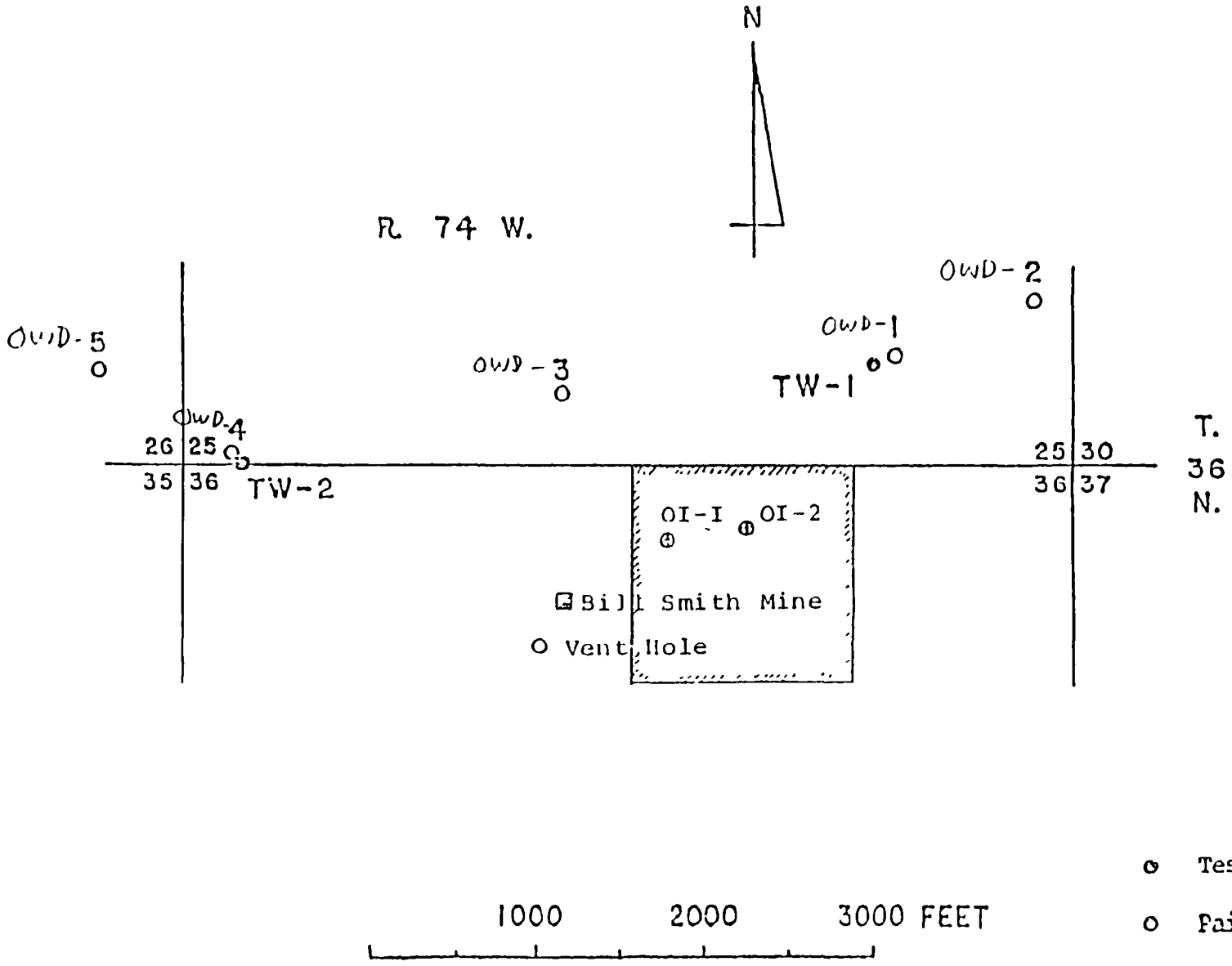


FIGURE 7C-2-- MAP OF BILL SMITH MINE AREA AND TEST WELL LOCATIONS
(from WDEQ Files)

Revised March 6, 1980

1. The average transmissivity of the artesian aquifer system between wells OWD-3 and OWD-5 is about 1000 ft^2/day; the average storage coefficient is about 3×10^{-4}.
2. Transmissivity in the vicinity of well TW-1 is about 735 ft^2/day and in the vicinity of well OWD-2 is less than 670 ft^2/day; the storage coefficient is about 4×10^{-4}.
3. Pumping of wells TW-1 and TW-2 created a cone of pressure relief extending to more than 10,000 feet from the wells during the 6- and 10-day pumping periods.
4. Pumping of wells TW-1 and TW-2 induced water-table conditions to occur in the immediate vicinity of each well as the hydrostatic head was lowered below the top of the "O" sand.
5. The hydrostatic head in the water-table aquifer overlying the "P" shale is higher in elevation than the head in the underlying "O" and "M" sands; consequently, there is a hydraulic gradient downward through the "P" shale. Pumping of wells TW-1 and TW-2 did not cause noticeable changes in the water level in observation wells tapping the water-table aquifer; therefore, there was no apparent increase in the rate of water movement through the "P" shale during the pumping period (Permit 4 RD).

The results of the pump tests conducted in the Fort Union Formation aquifers are found in Table 7C-1. Figure 7C-3 is a map of the potentiometric surface as reported to the DEQ on 1-21-80.

Table 7C-1. Properties of the Principal Fort Union Aquifer, Bill Smith Project Site (from WDEQ Files).

Kerr-McGee Well No.	Location (T-R-Sec. ¼ ¼)	Aquifer Transmissivity TW-1 Pump Test (gpd/ft.)	Aquifer Transmissivity TW-2 Pump Test (gpd/ft.)	Estimated Permeability (gpd/ft^2)	Storage Coefficient (dimensionless)
TW-1	36-74-25dd	3400	--	17	--
TW-2	36-74-25cc	--	6300	27	--
OWS-1	36-74-25dcd	--	--	--	--
OWD-1	36-74-25dcd2	5300	7800	22	0.00035
OWS-2	36-74-25ddb	--	--	----	
OWD-2	36-74-25ddb2	4700	8300	28	0.00031
OWS-3	36-74-25cdd	--	--	----	
OWD-3	36-74-25cdd2	7300	7700	27	0.00035
OWS-4	36-74-25ccc	--	--	----	
OWD-4	36-74-25ccc2	9500	7500	23	0.00015
OWS-5	36-74-26dda	--	--	----	
OWD-5	36-74-26dda2	8700	7700	25	0.00023

Figure 7C-3.

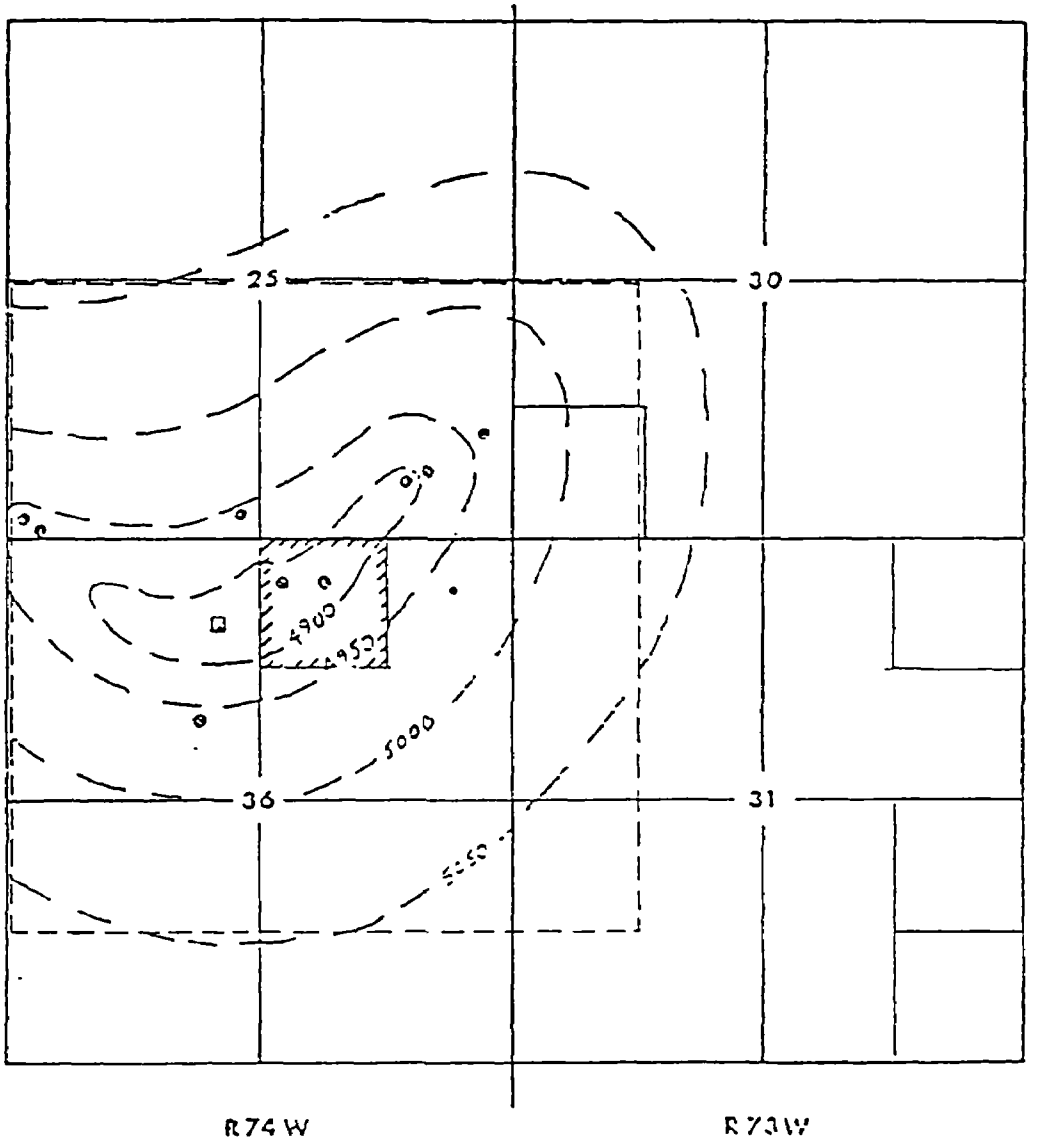
GENERAL TEST AQUIFER PIEZOMETRIC CONTOURS[1]

LICENSE AREA AND ADJACENT LANDS

KERR-McGEE BILL SMITH PROJECT

CONVERSE COUNTY WYOMING

(from Permit 4RD)



LICENSE AREA

LIMITS OF ADJACENT LANDS

BILL SMITH MINE SHAFT

—5000— EXPECTED 'O' SAND PIEZOMETRIC SURFACE – FEET ABOVE MSL

(1) THE CONTOURS ARE BASED ON VERY LIMITED DATA BUT ARE BELIEVED REPRESENTATIVE FOR THE TEST SITE.

Ground Water Quality

Baseline water quality parameters over a 4-year period are presented in Tables 7C-2 and 7C-3. Table 7C-2 presents 1977 data from test wells 1 and 2 and from mine discharge water in 1979. It also gives the quality of water from the 0300 and 0500 drifts in the mine in 1980 from the Bill Smith Project. Table 7C-3 presents water quality data from the Bill Smith 6001 Area Project in the adjacent quarter section. Water quality data from 1980 from the 0600 drift discharge and from the 6001 area monitor well in August, 1981 is given. The baseline qualities are marginal for Class I domestic uses because of slightly high concentrations of sulfate (180-304 mg/L) and total dissolved solids (TDS) (487-620 mg/L). The concentrations for sulfate exceed standards for agriculture use but are within those for livestock use. TDS values are within standards for agriculture and livestock use. However, radium 226 exceeds limits for any ground-water use classification. The pCi/L values range from 51.7 to 159 in discharge water from mine drifts and from 18.0 to 28.7 in test wells.

Ground Water Use

Table 7C-4 presents an inventory of all wells in the KMNC area and adjoining lands of the Bill Smith Project and 6001 Project areas. These include wells used in the 2 pump tests conducted prior to the experimental lixiviant injection and wells constructed for all other uses.

Three well permits are held in the area within about 1.5 miles radius of the stopes leaching experimental areas (Figure 7C-4). One of

Table 7C-2. Baseline Ground Water Quality Parameters, Kerr-McGee Bill Smith Project (from WDEQ Files).

	0300 Drift Discharge 8/5/80	0500 Drift Discharge 8/5/80
Aluminum[1]	.21	.22
Arsenic	.009	.006
Barium	.03	.04
Boron	.4	.3
Bicarbonate	160	137
Carbonate	<5	<5
Cadmium	<.01	<.01
Calcium	110	76
Chloride	<5	<5
Chromium	<.001	<.001
Copper	<.001	<.001
Fluoride	.3	.3
Iron	.014	.020
Lead	.001	.001
Manganese	<.001	<.001
Magnesium	31	32
Mercury	<.001	<.001
Molybdenum	.002	.003
Nickel	.006	.016
Nitrates (As N)	.40	1.8
Potassium	13	9
Selenium	.018	.016
Silver	<.002	<.002
Sodium	28	28
Sulphate	304	264
Zinc	.015	.021
Uranium	.40	.10
Vanadium	.009	<.003
Total Dissolved Solids	620	507
Conductivity (umhos)	787	682
Ra-226 (pCi/ℓ)	73.5	68.6
pH (std. units)	7.8	8.0

[1]All units are mg/l unless noted otherwise.

Table 7C-2. Baseline Ground Water Quality Parameters, Kerr-McGee Bill Smith Project (from WDEQ Files) (cont'd).

	Test Well I (1977 ER)[2]	Test Well 2 (1977 ER)	Bill Smith Mine Disch 9/25/79	10/17/79
Aluminum[1]	.002	.001	.026	.028
Arsenic	.001	<.001	.007	.007
Barium	-	-	.026	.2
Boron	.35	.30	.5	.2
Bicarbonate	230	220	197	179
Carbonate	-	-	<5	10
Cadmium	-	-	<.001	<.001
Calcium	81	83	84	91
Chloride	<5	<5	3.3	<5
Chromium	.001	<.001	<.001	<.001
Copper	.003	.002	.001	<.001
Fluoride	-	-	.34	.28
Iron	.98	1.0	.001	.001
Lead	-	-	<.001	<.001
Manganese	.051	.054	.002	.009
Magnesium	25	28	32	29
Mercury	-	-	<.001	<.001
Molybdeum	-	-	.006	.002
Nitrates (As N.)	<.01	<.01	.1	.3
Selenium	-	-	.006	<.001
Silver	-	-	<.001	<.001
Sodium	30	29	26	27
Sulphate	180	210	222	257
Zinc	.003	.003	.60	.020
Uranium	.014	.016	.35	.40
Total Disolved Solids	-	-	490	514
Radium 226 pCi/l	22.5	28.7	77.8	51.7
pH - Standard units	7.2	7.5	7.9	7.9

(1) All units are mg/l except where listed otherwise.

(2) Environmental report to NRC on the Kerr-McGee mill - July, 1977

Table 7C-3. Baseline Ground Water Quality Parameters, Bill Smith 6001 Area Project (from WDEQ Files).

	6001 Area Monitor Well				
	7/17/81	7/22/81	7/27/81[2]	7/27/81[2]	7/31/81
Aluminum [1]	.03	.08	<.05[3]	<.5	<.05
Arsenic	.004	.006	<.002	<.005	<.002
Barium	.08	.09	<.02	<.2	<.02
Boron	<.1	.15	< 1	.4	< 1
Bicarbonate	204	203	210	175	205
Carbonate	ND[4]	ND	ND	ND	ND
Cadmium	<.005	<.005	<.005	<.005	<.005
Calcium	110	110	105	101	107
Chloride	3	2	4	3	5
Chromium	<.01	<.01	<.01	<.01	<.01
Copper	<.01	<.01	<.01	<.01	<.01
Fluoride	.5	.5	.43	.5	.6
Iron	.04	.02	<.05	.45	.08
Lead	<.05	<.05	<.05	<.05	<.05
Manganese	.02	.02	.03	.03	.03
Magnesium	33	33	30	26	32
Mercury	<.001	<.001	<.001	<.001	<.001
Molybdenum	.006	.005	<.05	.008	<.05
Nickel	<.01	<.01	<.01	.02	<.01
Nitrates (As N)	< 1	< 1	.47	< 1	.44
Potassium	10	9	12	8	12
Selenium	.005	.003	<.005	<.005	<.005
Silver	<.001	<.001	--	--	--
Sodium	30	29	33	29	33
Sulphate	294	290	231	252	221
Zinc	.61	.73	.98	.86	.98
Uranium	.002	.005	.018	.016	.017
Vanadium	<.05	<.05	<.05	<.05	<.05
Total Dissolved Solids	582	569	519	542	511
Conductivity (umhos)	1274	1290	1055	1205	1099
Ra-226 (pCi/ℓ)	18	19	21	18	23
pH (std. units)	7.6	7.5	7.8	7.6	7.9

(1) All units are mg/ℓ unless noted otherwise
(2) Two different laboratories.
(3) Not detected at level indicated as less than
(4) ND = Not detected.

Table 7C-3. Baseline Ground Water Quality Parameters, Bill Smith 6001 Area Project (from WDEQ Files)(cont'd).

	DRIFT 0600 DISCHARGE		
	10/22/80	10/28/80	10/30/80
Aluminum [1]	<.05	<.05	<.05
Arsenic	<.002	<.002	<.002
Barium	<.02	<.02	<.02
Boron	<1	<1	<1
Bicarbonate	200	205	205
Carbonate	0	0	0
Cadmium	<.1	<.1	<.1
Calcium	83	95	95
Chloride	7	4	4
Chromium	<.01	<.01	<.01
Copper	<.01	<.01	<.01
Fluoride	0.44	0.43	0.44
Iron	.08	.08	.09
Lead	<.05	<.05	<.05
Manganese	<.01	<.01	<.01
Magnesium	29	25	25
Mercury	<.001	<.001	<.001
Molybdenum	<.05	<.05	<.05
Nickel	<.01	<.01	<.01
Nitrates (As N)	0.71	0.58	0.58
Potassium	10	10	10
Selenium	<.002	<.002	<.002
Silver	<.01	<.01	<.01
Sodium	32	32	32
Sulphate	202	241	260
Zinc	<.05	<.05	<.05
Uranium	.322	.275	.299
Vanadium	<.05	<.05	<.05
Total Dissolved Solids	487	532	548
Conductivity (umhos)	7440	7600	7390
Ra-226 (pCi/ℓ)	125	159	156
pH (std. units)	7.46	7.41	7.48

[1] All units are mg/ℓ unless noted otherwise.

Revised 12/22

Table 7C-4. Water Well Permits Within About 1.5 Miles of the Bill Smith/Bill Smith 6001 Project Areas.

Permit Number	Location, S, T, R	Owner/ Well Name	Depth (feet)	Use	Water Level (feet)
6898	NENE 30, 36N, 73W	W. Vollman Vollman No. 7	32	Stock	--
6984	SWNE 30 36N, 73W	W. Vollman Vollman No. 2	100	Stock	85
70183	NWSW 30, 36N, 73W	Sequoyah OM-30-376	900	Monitor	--

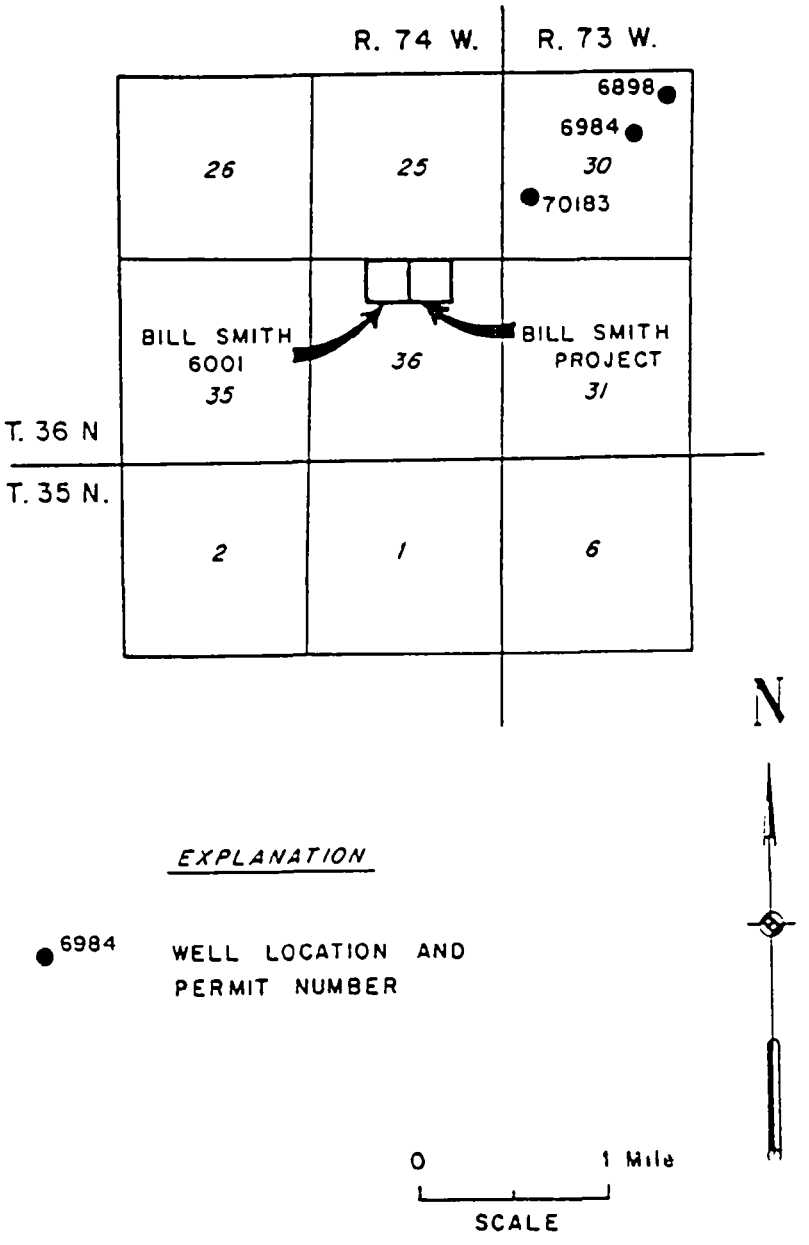


FIGURE 7C-4. LOCATIONS OF PERMITTED WATER WELLS NEAR THE BILL SMITH PROJECT AREA

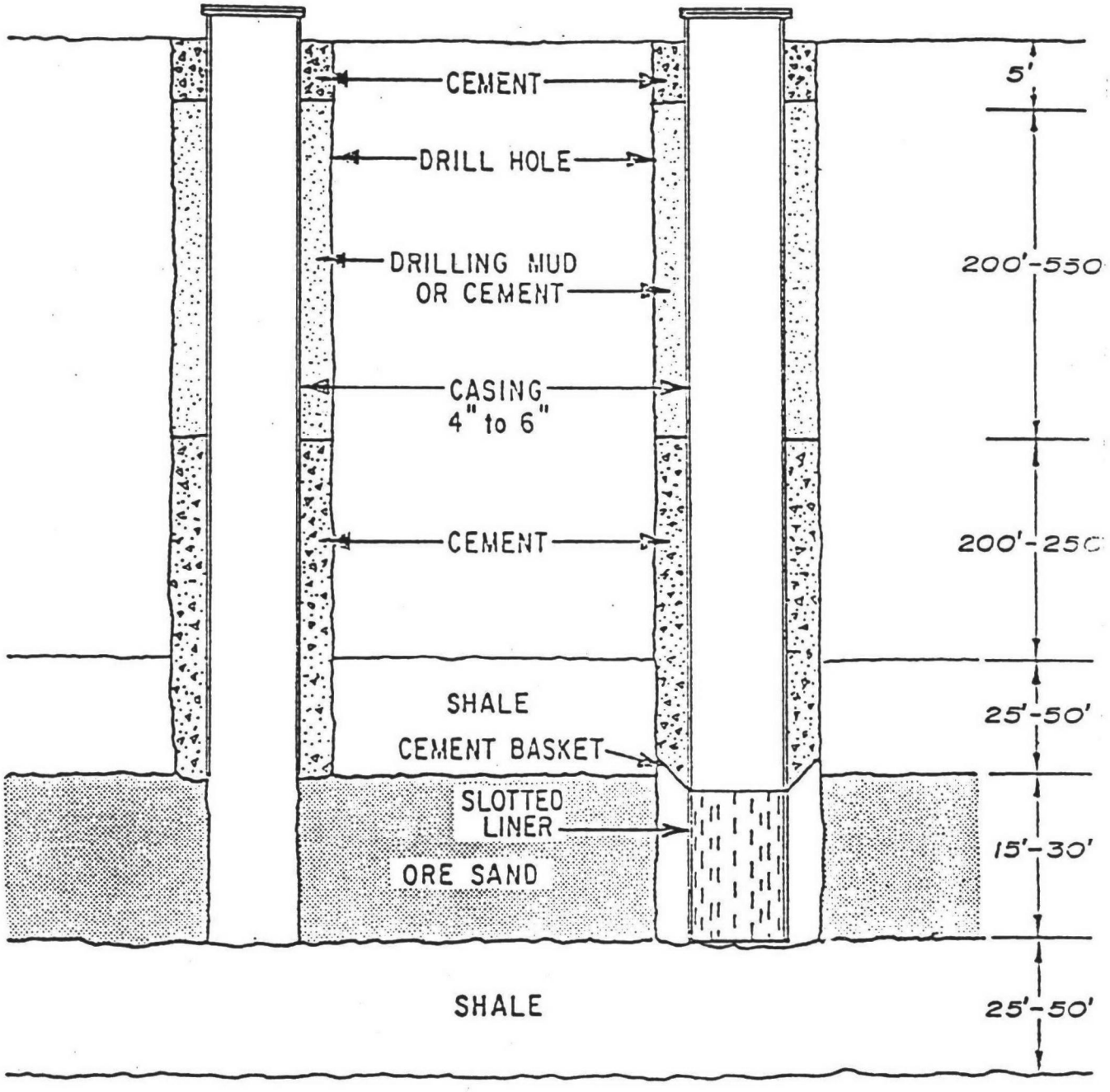
these is for monitoring, and no use is made of the water. The other two are for shallow wells for stock watering (see Table 7C-4) (Wyoming State Engineer). The stock wells obtain water from the unconfined ground water in the colluvium and upper Wasatch Formation strata, neither of which is connected to the confined aquifer containing the uranium ore.

Description of Facilities

The Bill Smith Project is located on a 40 acre tract in the NW¼ NE¼ of section 36, T36N, R74W, Converse County. The facilities occupy only 0.5 acres of the permit area. Figure 7C-2, presented previously, shows the surface well pattern for the leaching experiment. The injection wells were drilled with a small rotary drilling unit using a bentonite additive in native drilling mud. The wells were drilled to the top of the specified completion interval, and four inch fiberglass casing was run and cemented in place. After the cement had set, the wells were deepened and completed open hole with an inside gravel pack. The wells are dry to the top of the gravel pack due to the longhole dewatering in the test area; therefore, no well development was employed. Figure 7C-5 shows two types of well completions used in the Bill Smith and Bill Smith 6001 stopes leaching experiments. Injection wells underwent mechanical integrity testing prior to beginning of leaching operations. Drift surveys indicated that wells were drilled fairly straight with a maximum deviation of 4.63 feet in well M4.

Figure 7C-5.

TYPICAL WELL COMPLETIONS



Operation History

The leaching experiment was preceeded by ground water sampling designed to obtain baseline water characteristics for comparison with the same parameters during the experiment and more importantly, during aquifer restoration after the project was completed. The Bill Smith Project application was presented to the DEQ and permit 4 RD was granted in 1980. The uranium production zone is indicated on the cross-section of Figure 7C-1 with the "ore zone symbol". The relative locations of the underground haulage drifts are also indicated on the cross-section and are labelled 0300, 0100, and 0500. The only underground workings in the project area are the haulage drifts. The injection wells, OI-1 and OI-2, are shown on the cross-section.

The vertical limits in the test area are the underlying "N" shale and the overlying shale stringers in the respective areas. The lateral movement of the leach solution was expected to be limited to within 25 feet of the injection wells by the large number of cased longholes, drilled up from the mine drifts in the area. The fluid flow paths from the injection wells to the adjacent cased longholes are indicated on the attached cross-section (Figure 7C-1). Two injection wells were drilled, cased, and cemented to total depths of about 850 feet, terminating in the "O" sand above the Bill Smith mine workings. Longholes were drilled and cased upward from the mine workings into the "O" sand.

Mine water with hydrogen peroxide or oxygen, added to a concentration of 0.5 g/L, and mine water with sodium carbonate/bicarbonate concentration of up to 2 g/L and the above oxidants, were used a leach solutions in the two injection wells. This

Table 7C-5. Baseline vs. Post Test Water Quality, Kerr-McGee Bill Smith Project (from WDEQ Files).

	0300 Drift Discharge			0500 Drift Discharge		
	High Baseline Value	8/10/82	9/03/82	High Baseline Value	8/10/82	9/03/8
Aluminum[1]	.21	<.05	<.05	.22	<.05	<.05
Arsenic	.009	<.002	<.002	.006	<.002	<.00
Barium	.20	<.02	<.02	.22	<.02	<.02
Boron	.5	<.1	.3	.5	<.1	<.1
Bicarbonate	213	215	215	223	210	195
Carbonate	<5	ND[2]	ND	<5.0	ND	ND
Cadmium	< .01	<.01	<.01	<.01	<.01	<.01
Calcium	110	107	122	110	102	123
Chloride	<5	6	5	<5	7	5
Chromium	.001	<.01	<.01	.005	<.01	<.0
Copper	.002	<.01	<.01	.001	<.01	<.01
Fluoride	.3	.38	.34	.3	.40	.3
Iron	.014	<.05	<.05	.020	<.05	<.05
Lead	.001	<.05	<.05	.001	<.05	<.05
Manganese	.008	.02	.02	.020	.02	.0
Magnesium	31	28	23	34	23	11
Mercury	<.001	<.001	<.001	<.001	<.001	<.00
Molybdenum	.005	<.05	<.05	.007	<.05	<.05
Nickel	<.01	<.01	<.01	.016	<.01	<.0
Nitrates	.40	2.2	1.7	1.8	2.0	1.6
Potassium	13	11	11	9	11	11
Selenium	.018	<.002	<.002	.016	.008	.00
Silver	<.002	<.01	<.01	<.002	<.01	.02
Sodium	28	35	34	29	36	35
Sulphate	304	312	280	278	245	248
Zinc	.015	.018	<.005	.021	.016	.0
Uranium	.40	1.48	.37	.10	.86	.60
Vanadium	<.01	<.05	<.05	<.01	<.05	<.05
Total Dissolved Solids	620	605	580	556	572	529
Conductivity (umhos)	787	760	740	682	765	700
Ra-226 (pCi/l	89.7	146.3	*	68.6	43.4	*
pH (std. units)	7.8	8.0	8.2	8.0	8.0	8.2

[1]All units are mg/l unless noted otherwise.

[2]Not detected - detection limit not reported.

oxidizing lixiviant permeated the uranium bearing sands to solubilize the uranium and drained into the mine workings principally through the cased longholes. During chemical injection, well head pressure for the injection wells was limited to 50 psi surface pressure. Leach solution injection rates of less than 25 gpm were used for a period of about 60 days.

Samples were taken underground as the injected water entered the mine and the samples were analyzed to determine if uranium was solubilized. All produced water was pumped to the surface, treated in existing facilities, and discharged to the surface. The Bill Smith Project and the Bill Smith 6001 *in situ* stopes leaching experiments were completed in 1982.

Past and Present Ground-Water Impacts

Table 7C-5 compares the baseline and the post-test water qualities in samples taken from the 0300 and 0500 drifts in the Bill Smith Project (Permit 4RD). Table 7C-6 contains the same comparison from the 0600 and 6000 drifts in the Bill Smith 6001 area (Permit 8RD). The data presented show that the mine waters remained near the background water quality levels. Comparisons of the baseline concentrations and the sampling results in 1982 show both positive and negative changes over the life of the project. Table 7C-7 presents uranium concentrations from drift discharge points in both projects. After chemical injection was terminated, reduced concentrations were recorded over the following 2 months. Restoration uranium concentrations were near but above high

Table 7C-6. Baseline vs. Post Test Quality Parameters, Bill Smith 6001 Area Project (from WDEQ Files).

	0600 Drift Discharge			6000 Drift Discharge		
	High Baseline Value	8/10/82	9/03/82	High Baseline Value	8/10/82	9/03/82
Aluminum[1]	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	<.002	<.002	<.002	.004	<.002	<.002
Barium	<.02	<.02	<.02	<.02	<.02	<.02
Boron	<1.0	<.1	<.1	<1.0	<.1	.3
Bicarbonate	205	205	205	215	254	200
Carbonate	0	ND[2]	ND	ND	ND	ND
Cadmium	<.1	<.005	<.005	<.005	<.005	<.005
Calcium	95	98	107	124.0	161.0	115
Chloride	7	7	6	6.0	30.0	6
Chromium	<.01	<.01	<.01	<.01	<.01	<.01
Copper	<.01	<.01	<.01	<.01	<.01	<.01
Fluoride	.44	.43	.40	.72	.44	.40
Iron	.09	<.05	<.05	.09	<.05	<.05
Lead	<.05	<.05	<.05	.07	<.05	<.05
Manganese	<.01	.02	.02	.02	.06	.02
Magnesium	29	28	20	35	43	18
Mercury	<.001	<.001	<.001	<.001	<.001	<.001
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05
Nickel	<.01	<.01	<.01	<.01	.03	<.01
Nitrates (as N)	.71	1.9	1.7	.52	2.0	1.6
Potassium	10	11	10	12	14	10
Selenium	<.002	<.002	<.002	<.005	.005	<.002
Silver	<.01	<.01	<.01	-	<.01	.02
Sodium	32	36	32	34	54	32
Sulphate	260	247	256	320	420	248
Zinc	<.05	.02	.01	<.1	.039	.01
Uranium	.32	1.68	.50	.81	7.19	.58
Vanadium	<.05	<.05	<.05	<.05	<.05	<.05
Total Dissolved Solids	548	527	532	620	847	528
Conductivity (umhos)	7600	765	685	1030	1020	690
Ra-226 (pCi/l)	159.0	118	*	39.0	31.1	*
pH (std. units)	7.5	8.0	8.1	8.1	8.0	8.1

[1]All units are mg/l unless noted otherwise.

[2]Not detected - detection limit not reported.

*Results not yet available.

Table 7C-7. Uranium Concentrations Underground Monitoring Points, Bill Smith Project (from WDEQ Files).

	Uranium - mg/l		
	0300 Drift Discharge	0500 Drift Discharge	0600 Drift Discharge
July 1, 1982	6.1	1.4	3.7
July 6, 1982	6.6	2.1	2.7
July 8, 1982	5.7	3.0	3.2
July 12, 1982	4.8	2.4	3.5
July 15, 1982	2.8	2.2	2.2 (3)
July 19, 1982	4.6	2.6	3.2
July 22, 1982	2.9	2.5	1.9
July 26, 1982	2.6	1.7	1.6
July 29, 1982	1.8	1.0	1.2
August 2, 1982	1.9	1.9	2.0
August 5, 1982	2.6	1.1	2.4
August 10, 1982	1.5	0.9	1.7
August 23, 1982	1.6	1.0	1.7
September 3, 1982	0.4	0.6	0.5
September 13, 1982	0.8(1)	0.8(1)	0.3(2)

(1) Total flow to the station from the North haulage drift.

(2) Total flow to the station from the South haulage drift.

(3) Chemical injection terminated July 16, 1982

baseline values for the 0300 and 0500 drifts in the Bill Smith Project and were slightly below high baseline value for the 0600 drift in the Bill Smith 6001 Project. No excursions of either injected or pregnant lixiviants were detected in any monitoring wells. The environmental impact from those stopes leaching experiments appears to have been insignificant. Reasons for this are, 1) the induced gradient of water into the mine prevents excursions in any other direction; 2) the strength of the lixiviant which was less than normally employed for in situ uranium mining; 3) the ability of the pre-existing mine water treatment facilities to handle the volume of fluids pumped to the surface; 4) the short duration (60 days) of injection; and 5) the small size of areas involved.

The quality of ground water affected by the Bill Smith stopes leaching experiment is not known to differ significantly from baseline water quality at this time. It is, in fact, probably not accurate to discuss ground water affected by the project, since all such water has probably been removed from the subsurface as mine pumpage. The large quantities of ground water which have moved into this area, and been withdrawn as pumpage from the Bill Smith mine, have probably obliterated the effects of the experiment upon the aquifer. There are no known remaining ground water effects resulting from this experiment.

Prediction of Future Ground-Water Impacts

No future impacts of the Bill Smith stopes leaching experiment are predicted to occur. The quality of the ground water in the aquifer

where the experiment was conducted is not believed to be significantly different from background quality; nor are there believed to be any additional constituents or contaminants in the aquifer due to the experiment. No computer modeling of this situation has therefore been performed.

Lixiviant was injected immediately adjacent to the Bill Smith underground mine workings, in quantities which were almost negligible when compared with the amount of ground water which had to be removed from those workings to keep them from flooding. As a result, recovery of the lixiviant with the mine pumpage was assured. Furthermore, the injected lixiviant was a relative dilute (compared to those used at other in situ uranium projects) sodium carbonate/bicarbonate solution. The combination of these factors means that serious or long-term aquifer contamination arising from this project is virtually impossible.

Prevention of Ground-Water Pollution at Similar Sites

A combination of favorable conditions prevented the occurrence of serious ground-water pollution at the Bill Smith project. These conditions included a very large ground-water gradient away from the lixiviant injection location toward a recovery location; relatively weak lixiviant solution; and a very small experiment size. It should not be assumed that all stopes leaching experiments will have these advantages, however. Permit applications for such projects should be scrutinized with the same care as applications for any other project intended to recover minerals from the subsurface using injection of chemicals.

SECTION 5.2.4

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	From Report on Class V Injection Well Inventory and Assessment in Arizona
AUTHOR: (OR INVESTIGATOR)	Engineering Enterprises, Inc.
DATE:	February, 1987
FACILITY NAME AND LOCATION:	Noranda Lakeshore Mines, Inc. Casa Grande, Arizona USEPA Region IX
NATURE OF BUSINESS:	Copper Solution Mining
BRIEF SUMMARY/NOTES:	The facility uses approximately 419 injection wells to distribute leach fluid (93% sulfuric acid) into a block caved zone previously mined using conventional methods. Leach solution is collected via collection drifts, and is pumped to the surface where copper is extracted at the solvent extraction/electrowinning plant. In addition to leach operations within the block caved zone, injection of leachate into un-mined portions of the vein is being conducted on a pilot basis. The goal of this activity is to determine if such operations are economically feasible. It has been reported that more fluid is recovered than is actually leached through the mine, indicating that no leachate is allowed to enter the local groundwater system. Water wells on the nearby Pafago Indian Reservation are monitored regularly, per request by the Bureau of Land Management, for Drinking Water Standards.

UNDERGROUND INJECTION CONTROL PROGRAM INSPECTION REPORT

FACILITY NAME: Noranda Lakeshore Mines, Inc.

NAME AND PERMIT/EPA ID NUMBER OF INJECTION WELL(S): AZS000000079

NATURE OF BUSINESS: Experimental solution mining (copper)

DATE(S) OF INSPECTION: 9/9/86 TIME: _____

INSPECTOR(S):

Name(s): M. E. Quillin & Gary Cipriano
Affiliation(s): Engineering Enterprises, Inc.
Phone Number(s): (405) 329-8300

ADDITIONAL PARTICIPANTS:

Name(s): John Kline & Ernie Ahrens Bill Bohrer (EPA)
Affiliation(s): Noranda Lakeshore Mines
Phone Number(s): (602) 836-2141

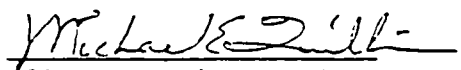
GENERAL SITE CONDITIONS DURING INSPECTION [weather, well(s) operational status, ease of entry, general housekeeping etc.]:

PURPOSE OF INSPECTION: To observe injection operations at surface and within mine workings

INSPECTION RESULTS (SUMMARIZED), COMMENTS AND REMARKS:

All above-ground and mine injection facilities observed and photographed. Surface treatment facilities observed.

I certify that I conducted the inspection described in the attached report and that, to the best of my knowledge, this report is accurate.



Signature of Inspector

Michael E. Quillin, Geologist, Engineering Enterprises, Inc.
Name, Title and Affiliation of Inspector

9/23/86
Date of Completed Report

UIC INSPECTION REPORT

SECTION I - GENERAL INFORMATION

1. Facility Name, Address and Telephone Number:

   Name Noranda Lakeshore Mines, Inc.
   Address P. O. Box C-6, Casa Grande, AZ 85222
   Telephone Number (602) 836-2141
   EPA/Facility ID Number: AZ5000000079

2. Facility Contact:

   Name John T. Kline
   Title/Affiliation Chief Metallurgist, Noranda
   Telephone Number Same

3. Injection Well(s) Identification:

   Injection Well(s) Identification _____

4. Location of Injection Well(s):

   Latitude/Longitude _____
   Township/Range, Section T10, 11S - R4, 5E Pinal and Pima Counties, AZ
   Street Address _____
   Other _____

5. Name and Address of Legal Contact (if different from above): _____

6. Types of Permits Issued for this Facility (include permit numbers and names of federal, state and local agencies and programs which regulate the facility): NA

7. Number and Operational Status of Injection Well(s):

Well Class/Type	Active	Under Construct.	Abandoned	Idle	Other
Class V	419				

   Comments/Remarks (include reasons for abandonment):

8. Visual Appearance of Injection Well(s) (Attach photographs if available):

SECTION II - HYDROGEOLOGIC ENVIRONMENT AND INJECTION WELL INFORMATION

1. Well(s) Construction Details (complete attached diagram for simple Class V well(s) and/or provide sketch of well(s); sketch or provide photograph of well head): See attached

   a. Total Depth _____

   b. Casing: _____

      Diameter: _____ Grade: _____ Wt. (#/ft) _____ Depth: _____ to _____

      Diameter: _____ Grade: _____ Wt. (#/ft) _____ Depth: _____ to _____

      Diameter: _____ Grade: _____ Wt. (#/ft) _____ Depth: _____ to _____

      Diameter: _____ Grade: _____ Wt. (#/ft) _____ Depth: _____ to _____

      Diameter: _____ Grade: _____ Wt. (#/ft) _____ Depth: _____ to _____

   c. Tubing: _____

      Diameter: _____ Grade: _____ Wt. (#/ft) _____ Depth: _____ to _____

   d. Cement (also indicate drilling mud):

      Depth _____ to _____ Grade _____ Additives _____

      Depth _____ to _____ Grade _____ Additives _____

      Depth _____ to _____ Grade _____ Additives _____

      Depth _____ to _____ Grade _____ Additives _____

      Depth _____ to _____ Grade _____ Additives _____

   e. Annular Fluid Type: _____ Inhibitors: _____

   f. Packer Type: _____ Depth: _____

   g. Fluid Seal: Yes No

   h. Completion Type:

      Perforated Openings (holes/ft) Depth _____ to _____
      Depth _____ to _____
      Depth _____ to _____

      Screened Openings (sq in/LF) Depth _____ to _____
      Depth _____ to _____
      Depth _____ to _____

      Open Hole _____

SECTION II - HYDROGEOLOGIC INFORMATION (continued)

2. Geologic Environment:

a. Name of Injection Formation/Interval Tertiary Lakeshore Stock Complex
Geologic Age of Injection Formation _____
Depth (Subsea) to top of Formation 1000-1500 ft.
Depth (Subsea) to Base of Formation 2500-3000 ft.
Depth (Subsea) of Injection Zone(s): 1000-3000 ft.

From _____ To _____ Lithology _____ TDS _____
From _____ To _____ Lithology _____ TDS _____
From _____ To _____ Lithology _____ TDS _____
From _____ To _____ Lithology _____ TDS _____
Lithology: Quartz Monzonite Porphyry
Additional Information: _____

b. Confining Formation Name(s): Tertiary Fanglomerate & Cretaceous volcanics
Permeability: medium to high, dependent on fracturing. sediments.
Geologic Age of Confining Formation: _____
Lithology: Coarse-grained, poorly sorted Fanglomerate finely crystaline volcanic

Depth of Confining Zone(s):

From Surface To 3000' Lithology _____
From _____ To _____ Lithology _____
Dependent upon structural complexity
Additional Information: _____

c. Recent Geologic History Including Seismic/Volcanic Activity

3. Subsurface Geology and Hydrology for Well Site:

Attach the following information or note that the information is to be requested at the time of inspection. Where applicable, information on an area within a 1/2 mile radius of the well bore should be included.

a. Map of facility grounds with well locations shown.
b. Indicate the depth to the base of the lowest USDW.
c. Well logs on injection wells.
d. As-built diagram of injection well(s).
e. Location (horizontal and vertical) and data (water quality and availability) for public drinking water supply wells and for monitoring wells which are part of the injection project.
f. Geologic cross section(s) through injection well(s) down to at least the base of the lowest injection zone.
g. Regional hydraulic gradient within the injection zone (direction and quantity).
h. Bibliograpny of information used in preparing Section II, parts 2 and 3.

UIC INSPECTION REPORT

SECTION III - OPERATING DATA

1. Description of Injection Operation (including brief history):
   Area originally mined conventionally via block caving. Injection of in-situ leach material into caved zone via surface injection facility. Also conducting solution mining into un-mined ore body via in-mine horizontal - sub horizontal injection wells.
   See letter (W Enclosures) to Carol Boughton from John Kline, dates 7/23/85 For further details

2. Surface Facilities/Treatment Processes:

   Solvent extraction plant and electrowinning plant.
   See Fig. 5

3. Industrial/Wastewater Sources (processes by which the injected fluid is produced):

   NA

4. Generalized Fluid/Waste Category(ies)/Composition:

   93% surfuric acid solution

5. Method of Delivery of Fluid to the Injection Well(s):

   Flowline

SECTION III - OPERATING DATA (continued)

6. Mechanical Integrity Testing (include copy of pressure recording charts/records):

   Date of Last MIT none Type of MIT _____
   Results _____

7. Operational Monitoring of Injection Well (at time of inspection): See Table 4

   Injection Rate _____ Injection Pressure _____ Annular Pressure _____
   Fluid Temperature _____ Ambient Temperature _____ pH _____
   Daily Volume (average) _____ Daily Volume (maximum) _____
   Monthly Volume (ave) _____ Monthly Volume (max) _____
   Pressure Gauge Type _____ Pressure Range _____ Increment _____
   Calibration Date _____ Recorder Type _____ Location _____

8. Any Previous Problems with Well(s): No

   If yes, describe

9. Attach the following information (note if unavailable):

   1. All Appropriate Analyses of Injectate
   2. All Appropriate Operating Records
   3. Date and Report of Last Major Workover

SECTION IV - SAMPLING INFORMATION (if applicable)

1. Sample Data

   Sample ID _____ Date _____
   Time _____ Sampling Point _____
   Sample Type _____
   Analyses Requested _____

   Preservatives Used _____
   _____
   Name(s) of Collector(s) _____

2. Field Data

   Temperature _____ pH _____
   Specific Conductance _____

3. Chain of Custody

   Identify Analytical Laboratory to be Used

   Indicate Chain of Custody Form and field data form are attached to sample(s) by circling YES

SECTION V - RECORDKEEPING

1. List Records Reviewed and Reasons for their Review (reference all documents that were borrowed or copied):
   a) Environmental assessment, dated 10/82, submitted by Noranda to US Dept. of Interior, Mineral Management Service
   b) "Hydrometallurgy at Lakeshore", 4/83, AZ-Conference-AIME
   c) Noranda's in-house files
   d) Open files, office of Waste and Water Quality Management, Division of Environmenta Health Services, Dept. of Health Services, Phoenix, AZ

2. Describe any Inadequacies in Record Keeping Procedures (Note if any required information was unavailable or incomplete or inaccurate with special attention paid to pressure and flow measurement records and construction schedules if relevant):

   None -- Wells monitored constantly via computer.

SECTION VI - FINDINGS AND CONCLUSIONS

1. Describe all Findings and Remarks:

   Very well-monitored system; it is in operator's best interest to recover all injected fluid, as it is 'pregnant' with elemental copper. Hydrogeology supports argument that injections is several miles from USDW.

2. List Conclusions:

   Injection operation is maintained such that virtually all injectate is recovered. Should systematically test wells for integrity--no regulations regarding this at present.

3. List Recommendations:

   None.

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605523 SPECIMEN NO

Before completing, please read instructions on reverse side

5/21/86 DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO (1-7)
0 4

LAB NAME AND ADDRESS — LAB ID NO (32-36): 0 0 0 1 0

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36)		
Mo	Day	Yr
0 5	2 0	8 6

SAMPLE (37, 38-41)	
Type	Time (Hrs.)
D	1 0 3 7

WATER SYSTEM NAME

SAMPLING POINT—WELL NO. OR EXACT LOCATION
G.K. Village

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLER'S COMMENTS OR INSTRUCTIONS

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C - Check Sample
D - Regular Distribution Sample
P - Plant Tap Sample
R - Raw Water Sample
S - Special Sample

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	0.023	
1010	101	Barium	(1.)	<0.1	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	1.9	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	3.0	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		160.	
1016	101	Calcium		30.	
1017	149	Chloride		127.	
1022	101	Copper		<0.05	
1915	141	Hardness		149.	
1028	101	Iron		<0.1	
1031	101	Magnesium		18.	
1032	101	Manganese		<0.05	
1925	135	pH		8.0	
1052	101	Sodium		155.	
1055	137	Sulfate		120.	
1930	139	TDS		600.	
1095	101	Zinc		0.26	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.02	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE (28-30)

ANALYSIS DATE (22-27)		
Mo	Day	Yr
0 6	1 3	8 6

BMA
ANALYST

COMMENTS

Reviewed by Elizabeth C Stevenson

mm

[5-222]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605522 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/21/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO (1-7)
0 4

LAB NAME AND ADDRESS — LAB ID NO (42-46): 0 0 0 1 0

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36)		
Mo	Day	Yr
0 5	2 0	8 6

SAMPLE (37, 38-41)	
Type	Time (Hrs)
D	1 0 4 7

WATER SYSTEM NAME

SAMPLING POINT—WELL NO OR EXACT LOCATION
Well #3

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	0.02	
1010	101	Barium	(1.)	<0.1	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	2.0	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10)	3.6	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		153.	
1016	101	Calcium		34.	
1017	149	Chloride		158.	
1022	101	Copper		<0.05	
1915	141	Hardness		171.	
1028	101	Iron		<0.1	
1031	101	Magnesium		21.	
1032	101	Manganese		<0.05	
1925	135	pH		7.9	
1052	101	Sodium		174.	
1055	137	Sulfate		140.	
1930	139	TDS		684.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.03	

Pursuant to R9-8-223 check samples are REQUIRED for NY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE (28-30)

ANALYSIS DATE (22-27)		
Mo	Day	Yr
0 6	1 3	8 6

BMA
ANALYST

COMMENTS

Reviewed by Elizabeth C Atkinson
mm

[5-223]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605521 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/21/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO: 0 4 (1-7)

LAB NAME AND ADDRESS — LAB ID NO: 0 0 0 1 0 (42-46)

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36): Mo 0 5 | Day 2 0 | Yr 8 6

SAMPLE: Type (37): D — Time (Hrs.) (38-41): 0 9 4 6

WATER SYSTEM NAME:

SAMPLING POINT—WELL NO. OR EXACT LOCATION: EA-1

MAILING NAME AND ADDRESS:

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE: [X] Clear; [ ] Turbid; [ ] Other (comment)

WATER SUPPLY SOURCE: [X] Well; [ ] Surface

SAMPLE TYPE CODES
C - Check Sample
D - Regular Distribution Sample
P - Plant Tap Sample
R - Raw Water Sample
S - Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	[0.05]	<0.02	
1010	101	Barium	[1.]	0.13	
1015	101	Cadmium	[0.010]	<0.005	
1020	101	Chromium	[0.05]	<0.02	
1025	107	Fluoride	[1.4-2.0]	2.0	
1030	101	Lead	[0.05]	<0.02	
1035	103	Mercury	[.002]	<0.001	
1040	109	Nitrates[N]	[10.]	0.3	
1045	101	Selenium	[0.01]	<0.01	
1050	101	Silver	[0.05]	<0.02	
1927	149	Alkalinity		295.	
1016	101	Calcium		122.	
1017	149	Chloride		348.	
1022	101	Copper		<0.05	
1915	141	Hardness		510.	
1028	101	Iron		<0.1	
1031	101	Magnesium		49.	
1032	101	Manganese		2.1	
1925	135	pH		7.9	
1052	101	Sodium		278.	
1055	137	Sulfate		290.	
1930	139	TDS		1380.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.02	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE (28-30):

ANALYSIS DATE (22-27): Mo 0 6 | Day 1 3 | Yr 8 6

BMA — ANALYST

COMMENTS

Reviewed by Elizabeth C. Atkinson

mm

[5-224]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605520 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/21/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO (1-7)
0 4

LAB NAME AND ADDRESS — LAB ID NO (42-46): 0 0 0 1 0

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE	Mo	Day	Yr
(31-36)	0 5	2 0	8 6

SAMPLE	Type (37)	Time (Hrs) (38-41)
	D	1 0 1 7

WATER SYSTEM NAME	SAMPLING POINT—WELL NO OR EXACT LOCATION
	EA-2

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1.)	<0.1	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	1.0	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	7.6	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		164.	
1016	101	Calcium		77.	
1017	149	Chloride		180.	
1022	101	Copper		<0.05	
1915	141	Hardness		114.	
1028	101	Iron		<0.1	
1031	101	Magnesium		37.	
1032	101	Manganese		<0.05	
1925	135	pH		8.1	
1052	101	Sodium		161.	
1055	137	Sulfate		240.	
1930	139	TDS		930.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		0.99	

Pursuant to RQ-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE (28-30)

ANALYSIS DATE	Mo	Day	Yr
(22-27)	0 6	1 3	8 6

BMA
ANALYST

COMMENTS

Reviewed by Elizabeth Atkinson
mm

[5-225]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605519 SPECIMEN NO

Before completing, please read instructions on reverse side

5/21/86 DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO (1-7)
0 4

LAB NAME AND ADDRESS — LAB ID NO (42-46): 0 0 0 1 0

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE	Mo	Day	Yr
(31-36)	0 5	2 0	8 6

SAMPLE	Type (37)	Time (Hrs) (38-41)
	D	0 8 5 0

WATER SYSTEM NAME

SAMPLING POINT—WELL NO OR EXACT LOCATION
EA-3

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C - Check Sample
D - Regular Distribution Sample
P - Plant Tap Sample
R - Raw Water Sample
S - Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	[0.05]	<0.02	
1010	101	Barium	[1]	<0.1	
1015	101	Cadmium	[0.010]	<0.005	
1020	101	Chromium	[0.05]	<0.02	
1025	107	Fluoride	[1.4-2.0]	0.8	
1030	101	Lead	[0.05]	<0.02	
1035	103	Mercury	[.002]	<0.001	
1040	109	Nitrates[N]	[10]	4.6	
1045	101	Selenium	[0.01]	<0.01	
1050	101	Silver	[0.05]	<0.02	
1927	149	Alkalinity		188.	
1016	101	Calcium		30.	
1017	149	Chloride		41.	
1022	101	Copper		<0.05	
1915	141	Hardness		114.	
1028	101	Iron		<0.1	
1031	101	Magnesium		9.5	
1032	101	Manganese		<0.05	
1925	135	pH		8.0	
1052	101	Sodium		117.	
1055	137	Sulfate		100.	
1930	139	TDS		444.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.01	

Pursuant to 89-3-207 check samples are REQUIRED for this and ALL contaminant(s) checked in the exceeds column

LOCATION CODE (28-30)

ANALYSIS DATE	Mo	Day	Yr
(22-27)	0 6	1 3	8 6

BMA
ANALYST

COMMENTS

Reviewed by Elizabeth A Atkinson
mm

[5-226]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605518 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/21/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO	LAB NAME AND ADDRESS	LAB ID NO	SAMPLE DATE (Mo / Day / Yr)	SAMPLE (Type / Time (Hrs))
04	WESTERN TECHNOLOGIES, INC 3737 East Broadway Road P.O. Box 21387 Phoenix, Arizona 85036	00010	05 / 20 / 86	D / 0915

WATER SYSTEM NAME	SAMPLING POINT—WELL NO OR EXACT LOCATION
	EA - 4

MAILING NAME AND ADDRESS	SAMPLE APPEARANCE	WATER SUPPLY SOURCE
Noranda Lakeshore Mines, Inc. P.O. Box C-6 Casa Grande, AZ 85222	X Clear Turbid Other (comment)	X Well Surface

SAMPLER'S COMMENTS OR INSTRUCTIONS

SDWA, $CR^{+}6$, Ni

SAMPLE TYPE CODES
C - Check Sample
D - Regular Distribution Sample
P - Plant Tap Sample
R - Raw Water Sample
S - Special Sample

CONTAMINANT CODE	ANALYSIS METHOD	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1.)	<0.1	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	1.9	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	<0.2	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		307.	
1016	101	Calcium		15.	
1017	149	Chloride		73.	
1022	101	Copper		<0.05	
1915	141	Hardness		62.	
1028	101	Iron		<0.1	
1031	101	Magnesium		5.9	
1032	101	Manganese		<0.05	
1925	135	pH		8.1	
1052	101	Sodium		167.	
1055	137	Sulfate		9.	
1930	139	TDS		494.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.01	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE

ANALYSIS DATE (Mo / Day / Yr): 06 / 13 / 86

BMA — ANALYST

COMMENTS

Reviewed by Elizabeth A Atkinson

mm

[5-227]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605777 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/29/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO
0 4

(1-7)

LAB NAME AND ADDRESS — LAB ID NO: 0 0 0 1 0 (42-46)

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE		
Mo	Day	Yr
0 5	2 8	8 6

(31-36)

SAMPLE	
Type	Time (Hrs)
D	1 2 3 5

(37) (38-41)

WATER SYSTEM NAME	SAMPLING POINT—WELL NO OR EXACT LOCATION
	MS 1

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE	ANALYSIS METHOD	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1.)	<0.5	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.1	
1025	107	Fluoride	(1.4-2.0)	0.5	
1030	101	Lead	(0.05)	<0.1	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	2.4	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		97.	
1016	101	Calcium		8.8	
1017	149	Chloride		53.	
1022	101	Copper		<0.05	
1915	141	Hardness		22.	
1028	101	Iron		<0.1	
1031	101	Magnesium		<1.	
1032	101	Manganese		<0.05	
1925	135	pH		8.3	
1052	101	Sodium		80.	
1055	137	Sulfate		27.	
1930	139	TDS		270.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		0.94	

(10-13) (14-16) (17-20)

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column.

LOCATION CODE (28-30)

ANALYSIS DATE		
Mo	Day	Yr
0 6	2 6	8 6

(22-27)

CJC — ANALYST

COMMENTS

Reviewed by Elizabeth C Atkinson

mm

[5-228]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605783 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/29/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO: 0 4 (1-7)

LAB NAME AND ADDRESS — LAB ID NO: 0 0 0 1 0 (42-46)

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36): Mo 0 5 | Day 2 8 | Yr 8 6

SAMPLE (37-41): Type D | Time (Hrs.) 1 2 5 5

WATER SYSTEM NAME:

SAMPLING POINT—WELL NO. OR EXACT LOCATION: MS 2

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE

X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE

X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1)	<0.5	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	0.6	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	1.7	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		186.	
1016	101	Calcium		23.	
1017	149	Chloride		26.	
1022	101	Copper		<0.05	
1915	141	Hardness		75.	
1028	101	Iron		<0.1	
1031	101	Magnesium		4.3	
1032	101	Manganese		<0.05	
1925	135	pH		7.9	
1052	101	Sodium		89.	
1055	137	Sulfate		23.	
1930	139	TDS		308.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.06	

Pursuant to R9-3-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column.

LOCATION CODE (28-30):

ANALYSIS DATE (22-27): Mo 0 6 | Day 2 6 | Yr 8 6

CJC — ANALYST

COMMENTS

Reviewed by Elizabeth C Atkinson

mm

[5-229]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605782
SPECIMEN NO.

Before completing, please read instructions on reverse side

5/29/86
DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO
0 4

1 7

LAB NAME AND ADDRESS — LAB ID NO: 0 0 0 1 0 (42-46)

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE		
Mo	Day	Yr
0 5	2 8	8 6

31 36

SAMPLE	
Type	Time (Hrs)
D	1 3 3 0

37 — 38-41

WATER SYSTEM NAME	SAMPLING POINT—WELL NO OR EXACT LOCATION
	MS 3

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLER'S COMMENTS OR INSTRUCTIONS

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C - Check Sample
D - Regular Distribution Sample
P - Plant Tap Sample
R - Raw Water Sample
S - Special Sample

CONTAMINANT CODE	ANALYSIS METHOD	CONTAMINANT NAME (MCL)	ANALYSIS RESULTS (mg/l)	EXCEEDS
1005	101	Arsenic (0.05)	<0.02	
1010	101	Barium (1.)	<0.5	
1015	101	Cadmium (0.010)	<0.005	
1020	101	Chromium (0.05)	<0.02	
1025	107	Fluoride (1.4-2.0)	0.4	
1030	101	Lead (0.05)	<0.02	
1035	103	Mercury (.002)	<0.001	
1040	109	Nitrates(N) (10.)	2.6	
1045	101	Selenium (0.01)	<0.01	
1050	101	Silver (0.05)	<0.02	
1927	149	Alkalinity	119.	
1016	101	Calcium	59.	
1017	149	Chloride	248.	
1022	101	Copper	<0.05	
1915	141	Hardness	181.	
1028	101	Iron	<0.1	
1031	101	Magnesium	8.2	
1032	101	Manganese	<0.05	
1925	135	pH	7.8	
1052	101	Sodium	180.	
1055	137	Sulfate	54.	
1930	139	TDS	652.	
1095	101	Zinc	<0.05	
		Nickel	<0.1	
		Chromium VI	<0.05	
		Mass Balance	1.07	

10-13 — 14 16 — 17 20

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE

28 30

ANALYSIS DATE		
Mo	Day	Yr
0 6	2 6	8 6

22 27

CJC
ANALYST

COMMENTS

Reviewed by Elizabeth C Atkinson
mm

[5-230]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605781 — SPECIMEN NO

Before completing, please read instructions on reverse side

5/29/86 — DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO (1-7)
0 4

LAB NAME AND ADDRESS (LAB ID NO 42-46: 0 0 0 1 0)

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36)	Mo	Day	Yr
	0 5	2 8	8 6

SAMPLE (37, 38-41)	Type	Time (Hrs.)
	D	0 9 0 5

WATER SYSTEM NAME	SAMPLING POINT—WELL NO. OR EXACT LOCATION
	MC 2

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1.)	<0.5	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	1.2	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	5.6	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		119.	
1016	101	Calcium		3.1	
1017	149	Chloride		24.	
1022	101	Copper		<0.05	
1915	141	Hardness		8.	
1028	101	Iron		<0.1	
1031	101	Magnesium		<1.	
1032	101	Manganese		<0.05	
1925	135	pH		8.5	
1052	101	Sodium		91.	
1055	137	Sulfate		37.	
1930	139	TDS		316.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		0.97	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column.

LOCATION CODE (28-30)

ANALYSIS DATE (22-27)	Mo	Day	Yr
	0 6	2 6	8 6

CJC
ANALYST

COMMENTS

Reviewed by Elizabeth C Atkinson
mm

[5-231]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605784
SPECIMEN NO

Before completing, please read instructions on reverse side

5/29/86
DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO
0 4

1 7

LAB NAME AND ADDRESS — LAB ID NO: 0 0 0 1 0 (42-46)

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE		
Mo	Day	Yr
0 5	2 8	8 6

31 36

SAMPLE	
Type	Time (Hrs)
D	0 9 4 0

37 — 38-41

WATER SYSTEM NAME

SAMPLING POINT—WELL NO OR EXACT LOCATION
MC 3

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLER'S COMMENTS OR INSTRUCTIONS

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other [comment]

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

CONTAMINANT CODE	ANALYSIS METHOD	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l)	EXCEEDS
1005	101	Arsenic	[0.05]	<0.02	
1010	101	Barium	[1.]	<0.5	
1015	101	Cadmium	[0.010]	<0.005	
1020	101	Chromium	[0.05]	<0.02	
1025	107	Fluoride	[1.4-2.0]	0.8	
1030	101	Lead	[0.05]	<0.02	
1035	103	Mercury	[.002]	<0.001	
1040	109	Nitrates[N]	[10.]	1.4	
1045	101	Selenium	[0.01]	<0.01	
1050	101	Silver	[0.05]	<0.02	
1927	149	Alkalinity		85.	
1016	101	Calcium		23.	
1017	149	Chloride		53.	
1022	101	Copper		<0.05	
1915	141	Hardness		57.	
1028	101	Iron		<0.1	
1031	101	Magnesium		<1.	
1032	101	Manganese		<0.05	
1925	135	pH		8.3	
1052	101	Sodium		134.	
1055	137	Sulfate		160.	
1930	139	TDS		468.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.05	

10 13 — 14 16 — 17 20

Pursuant to R9-8-223 check samples are REQUIRED for NY and ALL contaminant(s) checked in the exceeds column.

LOCATION CODE

28 30

ANALYSIS DATE		
Mo	Day	Yr
0 6	2 6	8 6

22 27

CJC
ANALYST

COMMENTS

Reviewed by Elizabeth C Atkinson

mm

[5-232]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

Before completing, please read instructions on reverse side

SPECIMEN NO: 8605779

DATE REC'D: 5/29/86

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO: 04 (1-7)

LAB NAME AND ADDRESS

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

LAB ID NO: 00010 (42-46)

SAMPLE DATE: Mo 05 (31-32) Day 28 (33-34) Yr 86 (35-36)

SAMPLE: Type D (37) Time (Hrs) 1015 (38-41)

WATER SYSTEM NAME:

SAMPLING POINT—WELL NO OR EXACT LOCATION: MC 4

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLER'S COMMENTS OR INSTRUCTIONS

SAMPLE APPEARANCE: [X] Clear [ ] Turbid [ ] Other (comment)

WATER SUPPLY SOURCE: [X] Well [ ] Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1)	<0.5	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	0.6	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	0.9	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		176.	
1016	101	Calcium		49.	
1017	149	Chloride		89.	
1022	101	Copper		<0.05	
1915	141	Hardness		127.	
1028	101	Iron		<0.1	
1031	101	Magnesium		1.	
0032	101	Manganese		<0.05	
1925	135	pH		7.6	
1052	101	Sodium		191.	
1055	137	Sulfate		250.	
1930	139	TDS		724.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		0.96	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column.

LOCATION CODE (28-30):

ANALYSIS DATE (22-27): Mo 06 Day 26 Yr 86

COMMENTS: Reviewed by Elizabeth Atkinson
mm

ANALYST: CJC

[5-233]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605778 SPECIMEN NO.

Before completing, please read instructions on reverse side

5/29/86 DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO. (1-7): 0 4

LAB NAME AND ADDRESS — LAB ID NO (42-46): 0 0 0 1 0

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36): Mo 0 5 | Day 2 8 | Yr 8 6

SAMPLE: Type (37): D | Time (Hrs) (38-41): 1 0 5 5

WATER SYSTEM NAME:

SAMPLING POINT—WELL NO OR EXACT LOCATION: MN 1

MAILING NAME AND ADDRESS:

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE: [X] Clear [ ] Turbid [ ] Other (comment)

WATER SUPPLY SOURCE: [X] Well [ ] Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1.)	<0.5	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	0.6	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	2.0	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		176.	
1016	101	Calcium		25.	
1017	149	Chloride		51.	
1022	101	Copper		<0.05	
1915	141	Hardness		120.	
1028	101	Iron		<0.1	
1031	101	Magnesium		14.	
1032	101	Manganese		<0.05	
1925	135	pH		7.9	
1052	101	Sodium		87.	
1055	137	Sulfate		35.	
1930	139	TDS		374.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.06	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column.

LOCATION CODE (38-30):

ANALYSIS DATE (22-27): Mo 0 6 | Day 2 6 | Yr 8 6

CJC

COMMENTS

Reviewed by Elizabeth Atkinson

mm

ANALYST

[5-234]

DRINKING WATER QUALITY

INORGANIC CHEMICAL ANALYSIS REPORTING FORM

8605780 SPECIMEN NO

Before completing, please read instructions on reverse side

5/29/86 DATE REC'D

NOTE: WATER SYSTEM MUST COMPLETE ALL BLANKS INSIDE THIS BOX

PWS ID NO (1-7)
0 4

LAB NAME AND ADDRESS — LAB ID NO (42-46): 0 0 0 1 0

WESTERN TECHNOLOGIES, INC
3737 East Broadway Road
P.O. Box 21387
Phoenix, Arizona 85036

SAMPLE DATE (31-36)		
Mo	Day	Yr
0 5	2 8	8 6

SAMPLE	
Type (37)	Time (Hrs) (38-41)
D	1 0 4 0

WATER SYSTEM NAME	SAMPLING POINT—WELL NO OR EXACT LOCATION
	MN 2

MAILING NAME AND ADDRESS

Noranda Lakeshore Mines, Inc.
P.O. Box C-6
Casa Grande, AZ 85222

SAMPLE APPEARANCE	
X	Clear
	Turbid
	Other (comment)

WATER SUPPLY SOURCE	
X	Well
	Surface

SAMPLE TYPE CODES
C – Check Sample
D – Regular Distribution Sample
P – Plant Tap Sample
R – Raw Water Sample
S – Special Sample

SAMPLER'S COMMENTS OR INSTRUCTIONS

CONTAMINANT CODE (10-13)	ANALYSIS METHOD (14-16)	CONTAMINANT NAME	(MCL)	ANALYSIS RESULTS (mg/l) (17-20)	EXCEEDS
1005	101	Arsenic	(0.05)	<0.02	
1010	101	Barium	(1.)	<0.5	
1015	101	Cadmium	(0.010)	<0.005	
1020	101	Chromium	(0.05)	<0.02	
1025	107	Fluoride	(1.4-2.0)	0.4	
1030	101	Lead	(0.05)	<0.02	
1035	103	Mercury	(.002)	<0.001	
1040	109	Nitrates(N)	(10.)	1.9	
1045	101	Selenium	(0.01)	<0.01	
1050	101	Silver	(0.05)	<0.02	
1927	149	Alkalinity		228.	
1016	101	Calcium		97.	
1017	149	Chloride		57.	
1022	101	Copper		<0.05	
1915	141	Hardness		440.	
1028	101	Iron		<0.1	
1031	101	Magnesium		48.	
1032	101	Manganese		<0.05	
1925	135	pH		7.6	
1052	101	Sodium		165.	
1055	137	Sulfate		440.	
1930	139	TDS		1090.	
1095	101	Zinc		<0.05	
		Nickel		<0.1	
		Chromium VI		<0.05	
		Mass Balance		1.03	

Pursuant to R9-8-223 check samples are REQUIRED for ANY and ALL contaminant(s) checked in the exceeds column

LOCATION CODE (28-30)

ANALYSIS DATE (22-27)		
Mo	Day	Yr
0 6	2 6	8 6

CJC
ANALYST

COMMENTS

Reviewed by Elizabeth Atkinson

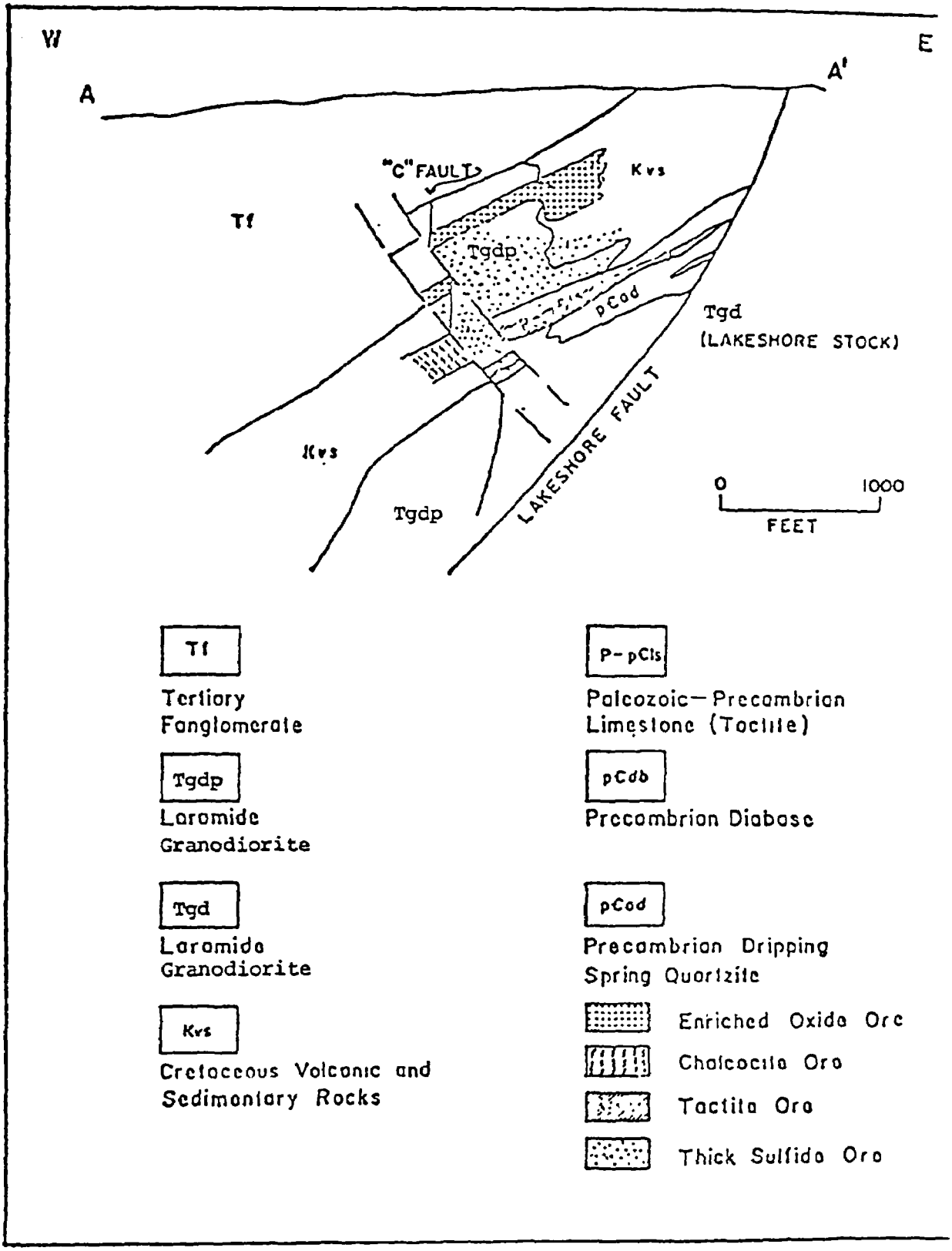
mm

[5-235]

NORANDA LAKESHORE AT A GLANCE

Location:	Slate Mountains 28 miles South-Southwest of Casa Grande, Az. 70 miles South of Phoenix, Az. 60 miles Northwest of Tucson, Az.
Elevation:	1900 feet above sea level
Ecosystem:	Typical Sonoran Desert
Average Temperature Range: (1979 records)	53^{o} Low 87^{o} High
Annual Precipitation:	8 inches
Property:	10,500 acres
Ownership:	Leased from The Papago Indian Tribe by Noranda Lakeshore Mines, Inc.
Operator:	Noranda Lakeshore Mines, Inc.
Work Force:	300 people
Mining Method:	Underground - Block Cave
Ore Treatment:	Hydrometallurgical
Planned Production:	5000 tons/day Oxide Mine

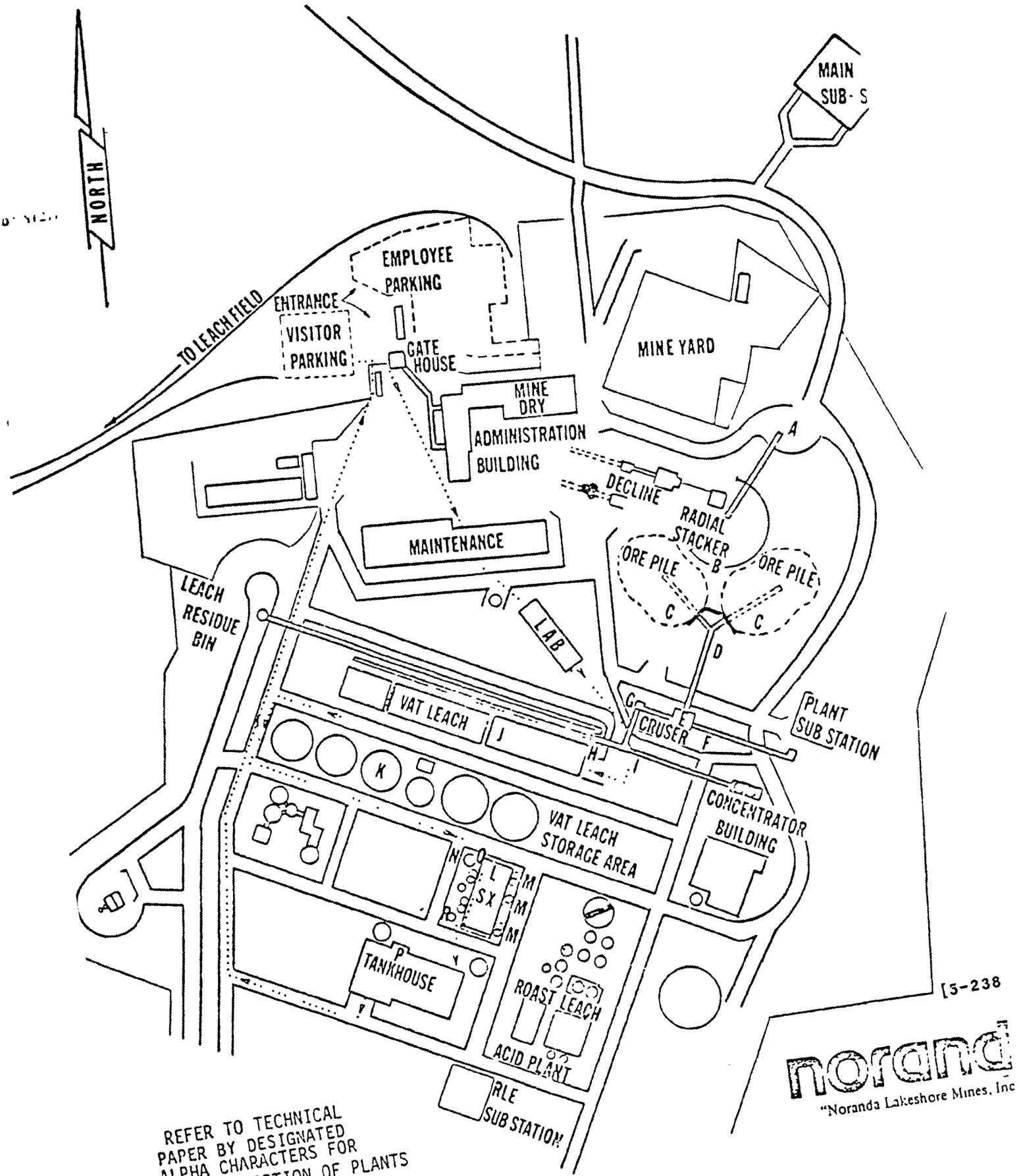
[5-236]



GENERALIZED ECONOMIC CROSS SECTION, LAKESHORE MINE, ARIZO

[5-237

Fig. 1



REFER TO TECHNICAL PAPER BY DESIGNATED ALPHA CHARACTERS FOR PHYSICAL DESCRIPTION OF PLANTS

[5-238

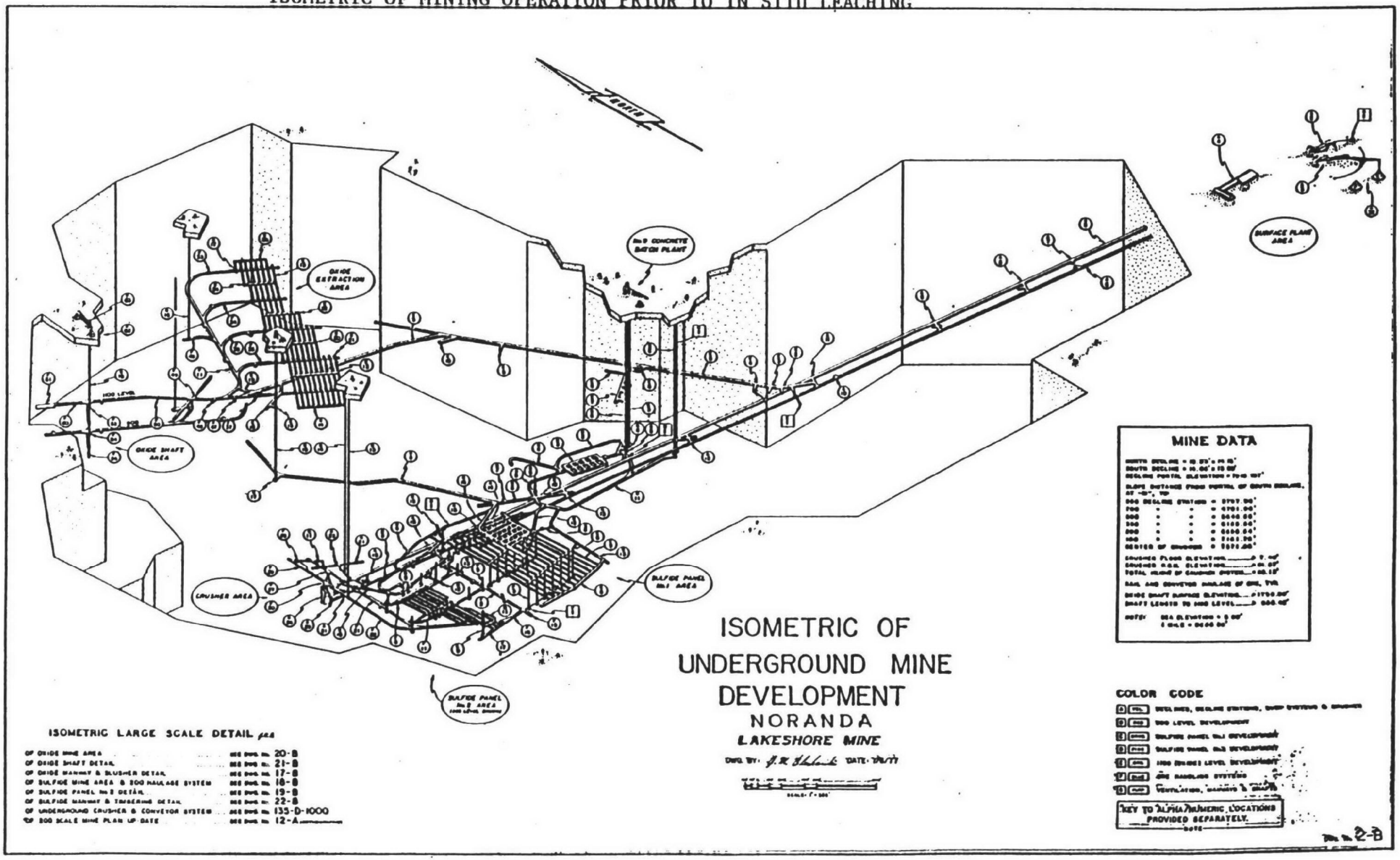
noranda

"Noranda Lakeshore Mines, Inc

NORANDA LAKESHORE MINES INC.

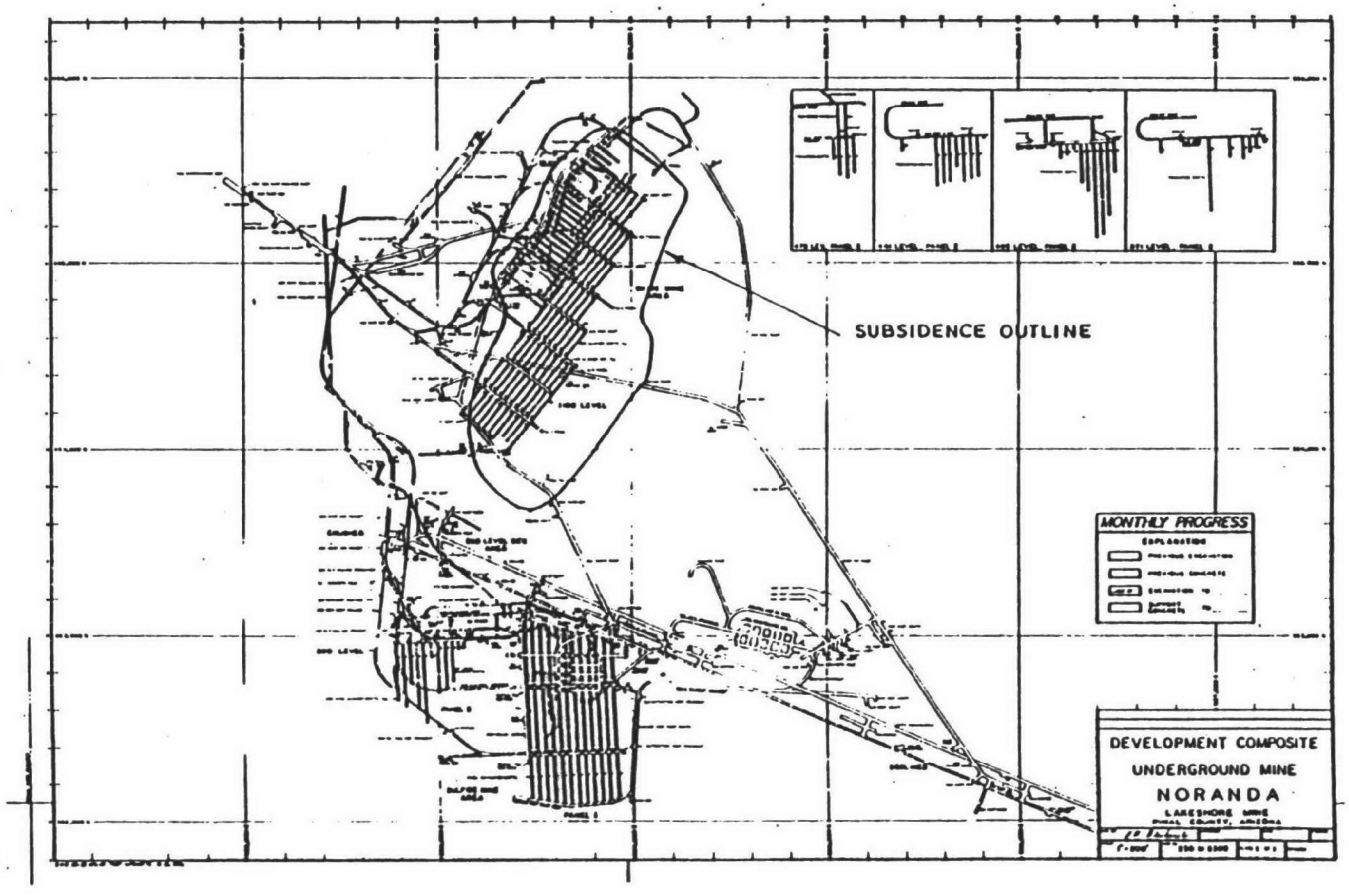
FIGURE 1.

ISOMETRIC OF MINING OPERATION PRIOR TO IN SITU LEACHING

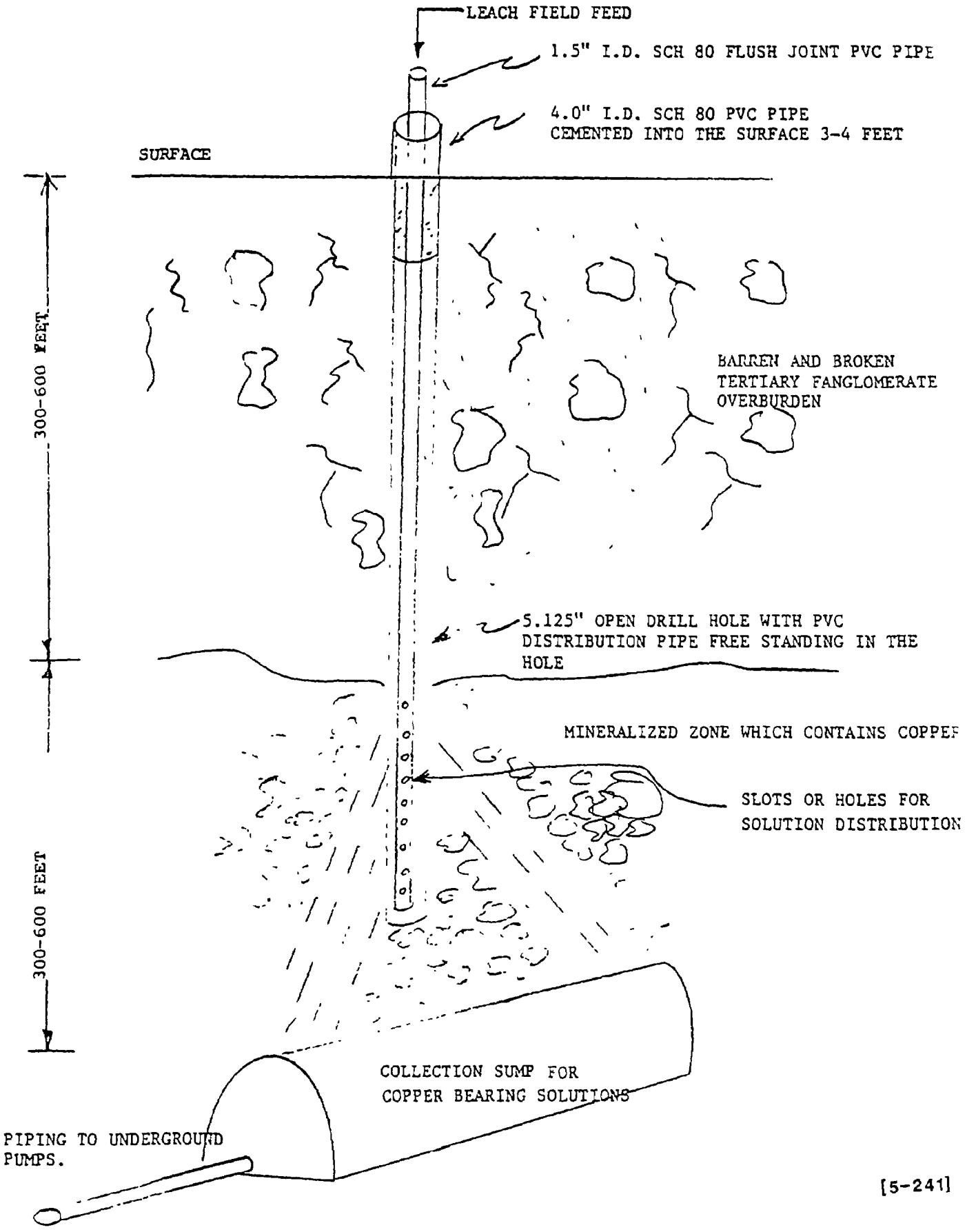


NORANDA LAKESHORE MINES INC.
FIGURE 2.

PLAN VIEW OF SUBSIDENCE AREA RESULTING FROM BLOCK CAVE MINING OPERATION

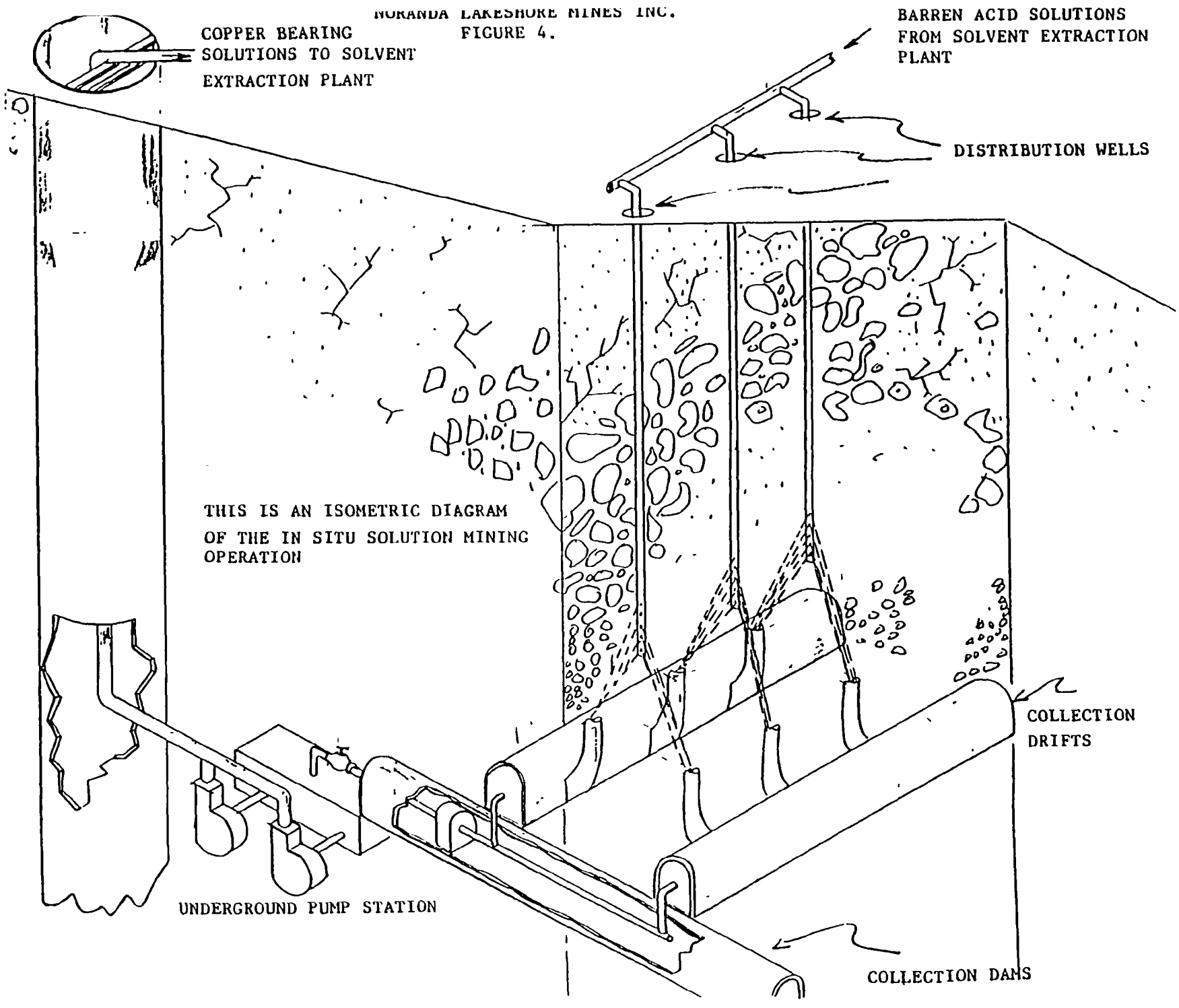


NORANDA LAKESHORE MINES INC.
FIGURE 3.
WELL COMPLETION DIAGRAM OF A TYPICAL SOLUTION DISTRIBUTION WELL



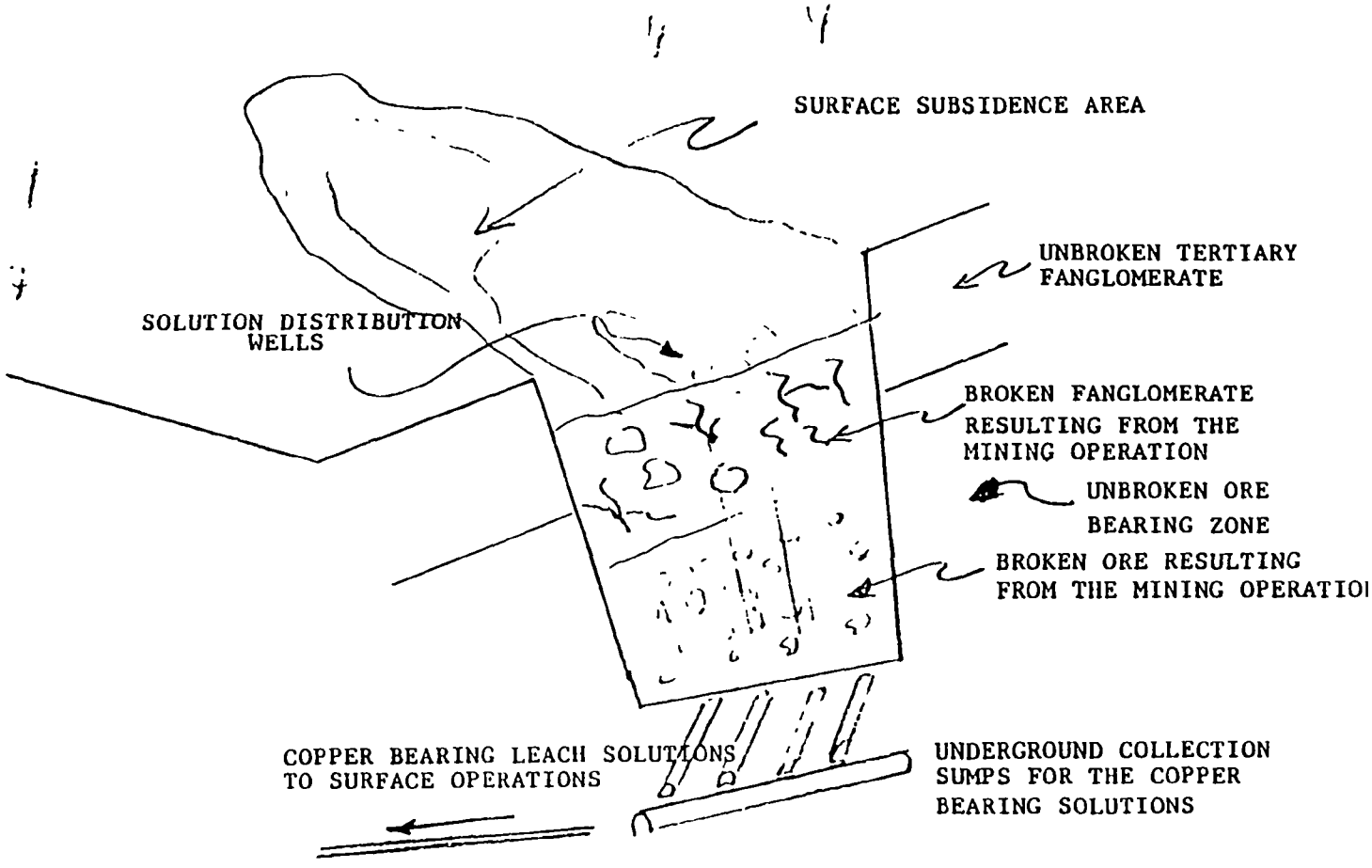
[5-241]

NORANDA LAKESHORE MINES INC.
FIGURE 4.



NORANDA LAKESHORE MINES INC.
FIGURE 4A.

PICTORAL DIAGRAM OF SURFACE SUBSIDENCE



NORANDA LAKESHORE MINES INC.

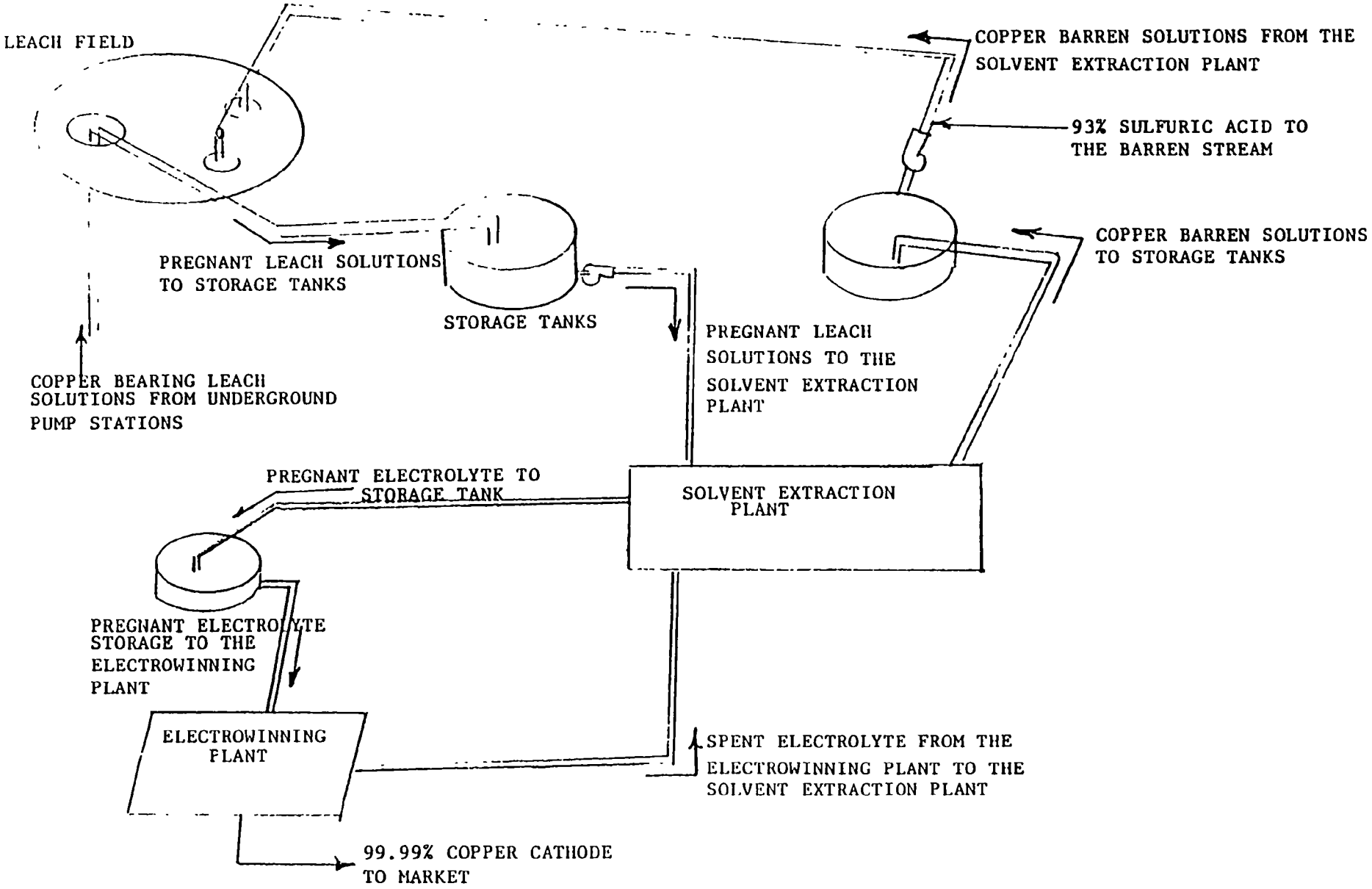
FIGURE 4B

PHOTOGRAPH OF A SET OF TYPICAL DISTRIBUTION WELLS IN THE SUBSIDENCE ZONE.

NORANDA LAKESHORE MINES INC.

FIGURE 5.

PROCESS FLOW DIAGRAM OF THE IN SITU SOLUTION MINING AND SOLUTION PROCESSING



Section 5.3

In Situ Fossil Fuel Recovery Wells Supporting Data

SECTION 5.3.1

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Organic Groundwater Contaminants From Underground Coal Gasification (UCG)
AUTHOR: (OR INVESTIGATOR)	Mattox and Humenick, University of Texas
DATE:	1980
FACILITY NAME AND LOCATION:	Texas, USEPA Region VI
NATURE OF BUSINESS:	Underground Coal Gasification

BRIEF SUMMARY/NOTES: The purpose of this research is to identify and quantify organic compounds that could contaminate groundwater in the vicinity of in situ gasification of Texas lignite. Through field sampling, the extent of groundwater contamination at selected sites was found to be a function of the contaminants' solubility in water.

Conclusions of this study were:

1. In field samples obtained at two sites, phenolic materials were shown to be predominant groundwater pollutants. Lesser amounts of polynuclear and heterocyclic aromatic hydrocarbons were identified.

2. There may be substantial capacity for natural groundwater renovation following UCG. Adsorption on coal is a likely mechanism for immobilization of organics in groundwater.

3. Although large amounts of PNA are produced during UCG, their potential for groundwater pollution is probably limited by their water solubility.

4. The condensed produced water is similar in composition to groundwater sampled from the burn cavity.

5. Most comprehensive study of tar and water condensates is needed to predict water solubilities of organics released to groundwater during gasification.

IN SITU, 4(2), 129-151 (1980)

ORGANIC GROUNDWATER CONTAMINANTS FROM UCG

C. F. Mattox and M. J. Humenick
Environmental Health Engineering
The University of Texas
Austin, Texas 78712

ABSTRACT

The purpose of this research is to identify and quantify the organic compounds that could contaminate groundwaters in the vicinity of in-situ gasification of Texas lignite. Field samples of groundwater and above ground condensate and tar from two sites were analyzed by gas chromatography-mass spectrometry (GC-MS). The extent of groundwater contamination was found to be a complex function of the water solubility of the organics. Phenolic compounds such as phenol, indanol, naphthol, and other alkyl derivatives comprised most of the organics in the burn cavity condensate. Polynuclear aromatic hydrocarbons (PNA) were present in very low concentrations consistent with their solubilities. PNA's containing up to five condensed rings, including benzo[a]pyrene, were detected in the ppb levels. Based on limited sampling, water quality appeared to improve over a one year period after gasification operations were completed at a field test site.

INTRODUCTION

While underground coal gasification (UCG) has inherent environmental advantages compared to conventional conversion technologies, there are areas of environmental concern which need to be investigated. One such concern is the potential contamination of groundwater in the vicinity of UCG operations. The objective of this research is to determine and evaluate the nature of groundwater pollution by organic compounds released to groundwater.

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Field samples of groundwater from two lignite gasification sites in Texas were analyzed by gas chromatography - mass spectrometry (GC-MS) to identify and quantify a variety of organic pollutants. In addition to groundwater, samples of above ground condensate (tar and water) were analyzed.

EXPERIMENTAL

Sample Description

Samples of groundwater, condensed product water, and condensed product tar were obtained from two separate UCG operations in Texas. Two groundwater samples were taken at a site near Fairfield, Texas. These samples were taken directly from the burn cavity shortly after the cessation of gasification (FTSIA0) and one year later (FTSIA1). The remaining samples were obtained from a second site near Tennessee Colony, Texas. Samples were obtained during the operating phase of the project. A baseline groundwater sample (TCPJ) from the Tennessee Colony site will be used to compare water quality before and after gasification. Two samples of the product water (condensed above ground) were analyzed. The first (Water-1) was sampled in September 1978 and the second (Water-2) in January 1979. A sample of produced tar (Tar-1) was taken at the same time as the second water sample. A second tar sample (Tar-2) was obtained in February 1979 while gasifying with oxygen.

Analytical Techniques

Two liters of water were extracted with approximately 300 ml methylene chloride in a continuous solvent extractor (Fig. 1). The sample was adjusted to pH $\geq$ 12 with NaOH and extracted for approximately 16 hours, then acidified to pH $\leq$ 2 with HCl and extracted another 16 hours. The extract was concentrated to one to five ml, depending on the concentration of organics, in a Kuderna-Danish concentrator. The extract was analyzed by GC-MS for all organics except phenol, which was determined by direct aqueous injection.

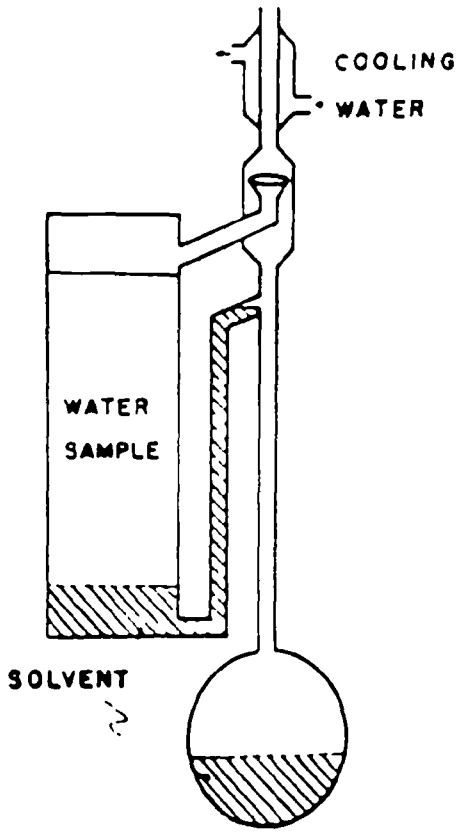


Figure 1. Continuous Solvent Extractor

Soil samples were dissolved in methylene chloride and analyzed directly by GC-MS.

Volatile organics in water were analyzed by purge and trap method according to EPA protocol (1). A five ml sample was purged with helium, volatile organics and were adsorbed onto Tenax GC, a synthetic resin, and were thermally desorbed into the inlet of the GC-MS system.

GC-MS Analysis

Compound separation and identification for all analyses except volatiles was performed on a Finnegan 4000 GC-MS, with INCOS data system. The volatile analysis was performed on a Hewlet Packard 5982A GC-MS, with operational parameters according to EPA

protocol (1). The Finnegan system employed a glass capillary column (.25 mm x 30 m) coated with SP-2100 for chromatographic separation. For quantitation of organics, the sample was injected in the splitless mode and the column was temperature programmed from 50° to 2[illegible] at 5°C/min. Slower rates of programming (2°/min) were used in the initial phases of work to provide maximum chromatographic separation and aid in identification of poorly resolved peaks. The mass spectrometer scanned masses 50 to 300 every two seconds.

Ideally, the identification of a compound is based on the equivalence of retention time and mass spectrum of the sample and pure standard. About 50 percent of the compounds were identified in this manner. The remaining compounds, for which standards were not available, were identified by comparison with mass spectra and retention indices published in the literature.

Quantitation was performed by the addition of an internal standard (usually d_{10}-anthracene) to the extract and by mass chromatography of a prominent ion (mass) in the compounds' spectrum.

$$C = \frac{1}{RF} \; C_{IS} \frac{A}{A_{IS}}$$

- C = concentration of the organic compound in the extract, ppm
- C_{IS} = concentration of internal standard in the extract (usually 20 ppm)
- RF = response factor, a constant characteristic of the organic compound
- A = area of the mass chromatogram of the organic compound
- A_{IS} = area of the mass chromatogram of the internal standard (mass 188 for d_{10}-anthracene)

The above method permits quantitation of two (or more) compounds which are not chromatographically resolved, as long as they contain at least one unique mass in their spectrum. Response factors were

determined from available standards when possible, and estimated when standards weren't available.

Laboratory Procedures

A recovery study of model compounds was used to evaluate the efficiency of the analytical technique. Approximately 20 compounds in a methanol solution were added to two liters of distilled water and extracted in exactly the same procedure as the water samples. The compounds were representative of those found in actual water samples.

A laboratory study was designed to determine the equilibrium distribution of organics between tar and water phases. Ten grams of Tar-1 were added to a liter of tap water and stirred for 24 hours at room temperature. The water was filtered through 0.2 u membrane filters to remove all colloidal oil and provide a definition for solubility. The water sample was then analyzed for organics.

RESULTS AND DISCUSSION

Recovery Studies

The efficiency and limitations of the analytical techniques are reflected in the results of recovery studies as summarized in Table 1. With the exception of phenol and benzonitrile, all compounds were recovered with at least 80 percent efficiency from distilled water in concentrations from 5 ppb to 20 ppm. Since these recoveries lie within the accuracy of GC-MS techniques (about $\pm$ 20% in the ppb range), all hydrocarbons are assumed to be quantitatively extracted. Water soluble, polar compounds are not quantitatively extracted from water by this technique. Phenol was the most soluble compound studied and was only 47 percent recovered. Recoveries of various alkyl phenols, however, were satisfactory. The concentration of phenol in most of the water samples was sufficient to permit direct aqueous analysis, thus eliminating the extraction procedure.

TABLE 1.

Recovery of Model Organic Compounds

Compound	Amount Added	Percent Recovery
Phenol	20 ppm	47%
o-Cresol	20	91
2,5-Xylenol	20	86
p-(tert-Butyl)-phenol	10	103
p-(tert-Butyl)-o-cresol	10	98
5 Indanol	5	110
1-Naphthol	5	90
Pyridine	5	82
Quinoline	5	87
Aniline	5	86
Benzonitrile	5	61
Indene	0.1	99
2-Methyl-naphthalene	0.1	105
Biphenyl	0.05	108
Acenaphthene	0.05	104
Anthracene	0.005	90
Carbazole	0.005	96
Dibenz[a,h]anthracene	0.005	86
Benzo[a]pyrene	0.005	88

Groundwater Analysis

Reconstructed ion chromatograms (RIC) of groundwater samples from a burn cavity are shown in Figure 2. Groundwater TTS1A0 was taken shortly after gas production was terminated, while ground water TTS1A1 was sampled from the same well one year later. Quantitation of major peaks in these chromatograms is summarized in Table 2.

The organics initially released are primarily phenolics, with lesser amounts of PNA's. There appears to be substantial improve-

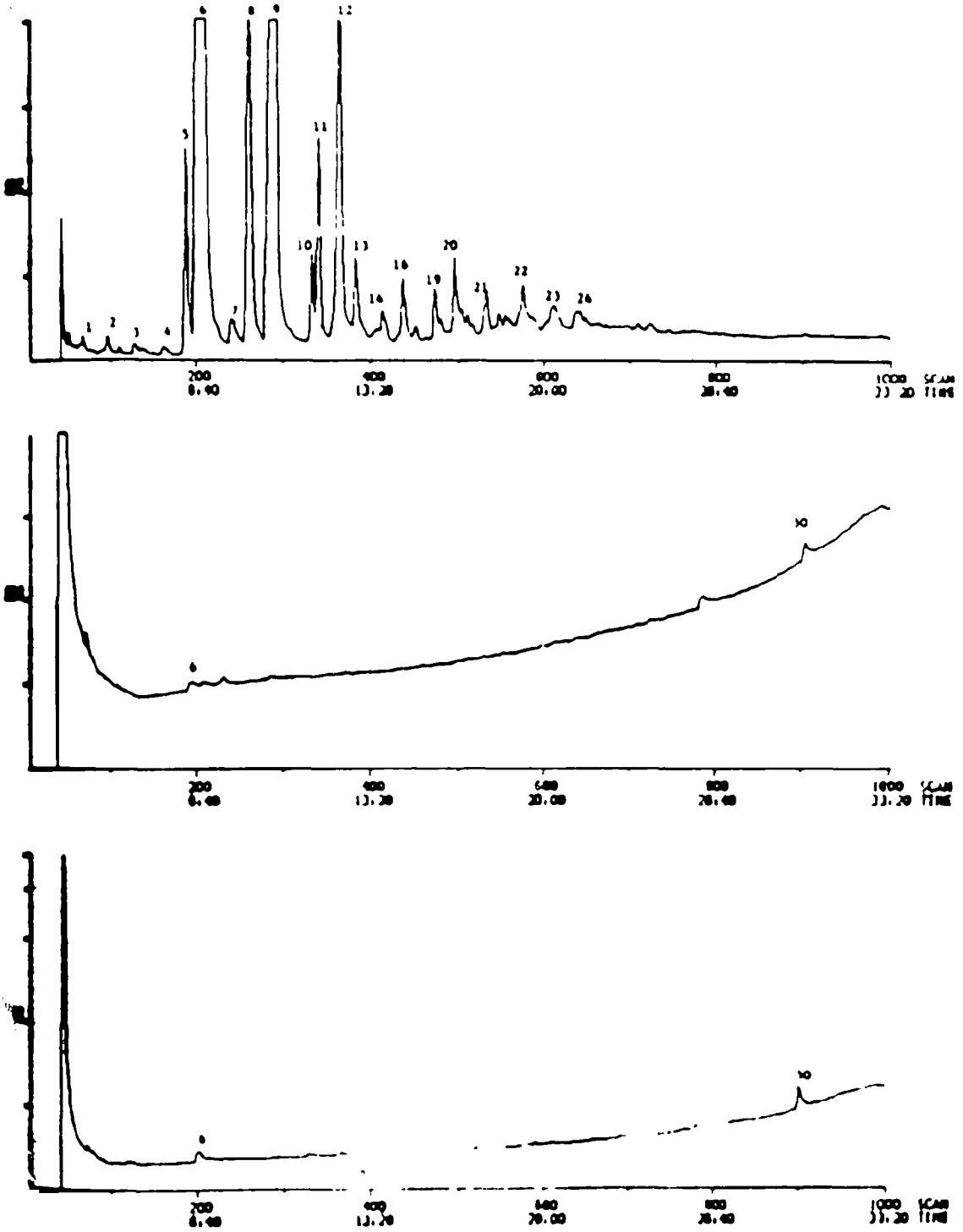


Figure 2.

Chromatograms of Ground Water Samples, Postgasification - TTS1A0 (Top), One Year Later - TTS1A (Middle), Pregasification - TCP3 (Bottom)

TABLE

Component	Groundwater after gasification	Groundwater one year after gasification	Groundwater before gasification
NAPHTHALENE	70 ppb	7 ppb	2 ppb
C_1 - ALKYL	35	2	ND
C_2 - ALKYL	4	ND	ND
C_3 - ALKYL	ND	ND	ND
BIPHENYL	5	ND	ND
C_1 - ALKYL	1	ND	ND
TOTAL 2 RING PNA's	135 ppb	9 ppb	2 ppb
ACENAPHTHYLENE	1 ppb	ND	ND
ACENAPHTHENE	1	1 ppb	1 ppb
C_1 - ALKYL	ND	ND	ND
FLUORENE	5	ND	ND
C_1 - ALKYL	ND	ND	ND
PHENANTHRENE	11	2	ND
ANTHRACENE	2	ND	ND
C_1 - ALKYL	ND	ND	ND
C_2 - ALKYL	ND	ND	ND
C_3 - ALKYL	ND	ND	ND
TOTAL 3 RING PNA's	22 ppb	3 ppb	1 ppb
FLUORANTHENE	4	ND	ND
PYRENE	1	ND	ND
C_1 - ALKYL	ND	ND	ND
C_2 - ALKYL	ND	ND	ND
CHRYSENE			
BENZANTHRACENE	2	ND	ND
C_1 - ALKYL	ND	ND	ND
C_2 - ALKYL	ND	ND	
TOTAL 4 RING PNA's	7 ppb	ND	ND
BENZO[e]PYRENE	1	ND	ND
BENZOPYRENE ISOMERS	2	ND	ND
TOTAL 5 RING PNA's	3 ppb	ND	ND
TOTAL PNA's	140 ppb	14 ppb	1 ppb

Organic Profiles of Groundwater Samples

Component	Groundwater after gasification	Groundwater one year after gasification	Groundwater before gasification
PHENOL	52 ppm	018 ppm	005 ppm
C_1 - ALKYL	29	004	001
C_2 - ALKYL	11	00-	001
C_3 - ALKYL	1 •	004	ND
C_4 - ALKYL	0 8	ND	ND
DIHYDROLS	1 9	ND	ND
C_1 - ALKYL	2 0	ND	ND
C_2 - ALKYL	1 3	ND	ND
NAPHTHOLS	0 35	ND	ND
C_1 - ALKYL	0 17	ND	ND
C_2 - ALKYL	0 01	ND	ND
TOTAL PHENOLICS	100 ppm	02 ppm	007 ppm
PYRIDINE	100 ppm	ND	ND
ALKYL PYRIDINES	660	ND	ND
ANILINE	92	ND	ND
BENZONITRILE	2	ND	ND
QUINOLINE	620	ND	ND
ALKYL QUINOLINES	130	ND	ND
INDOLE	170	ND	ND
CARBAZOLE	1	ND	ND
DIBENZOFURAN	14	ND	ND
DIBENZOTHIOPHENE	2	ND	ND
TOTAL HETERO-CYCLICS	2,200 ppm	ND	ND
ALIPHATIC HYDRO-CARBONS	NM	ND	ND
ALKYL BENZENES	NM	ND	ND
SULFUR, S_8	ND	ND	ND
TOTAL ORGANICS	102 ppm	14 ppm	10 ppm

ND • Not Detected

NM • Not Measured

ment in water quality over a year's time, particularly with regard to phenolic compounds. Unfortunately, documentation of the sampling method and pumping history of the wells is not available. For comparison, limited data from Hoe Creek indicate significant differences in organic concentrations in a well sampled before and after pumping (2). However, if the sample analyses shown in Figure 2 is representative of groundwater quality, then the improvement is comparable to that observed at the Hoe Creek (3) and may be attributed to adsorption, biochemical conversion, or some other mechanism.

The RIC of a groundwater sample in contact with lignite prior to gasification, (TCP3) is also shown in Figure 2 and quantified in Table 2. This sample is representative of the natural water contamination by lignite and will be used for comparison to post gasification groundwater quality.

Tar Analyses

The RIC of two condensed tar samples are shown in Figure 3. Tar was produced during air gasification and Tar II was produced during oxygen gasification. Quantitation of these samples is summarized in Table 3. Approximately 60 percent of the oil could be accounted for as PNA's, phenolics, heterocyclic compounds, and aliphatic hydrocarbons. Water and nonvolatile compounds which are not amenable to GC-MS are probably present in significant quantities. PNA's of up to five condensed rings, including benzo[a]-pyrene, were identified. Higher order PNA's are probably present but are difficult to analyze by GC-MS.

Equilibrium Distribution of Tar Organics

The RIC of water in equilibrium with Tar I is shown in Figure 4 and is quantified in Table 4. The aqueous organics are primarily phenolic (93 percent) while phenols constitute only 7 1/2 percent of the tar, which reflects the high solubility of phenols compared to PNA. Heavier PNA (four to five rings) occur in water at concentrations near their solubility, while lighter PNA concentrations are

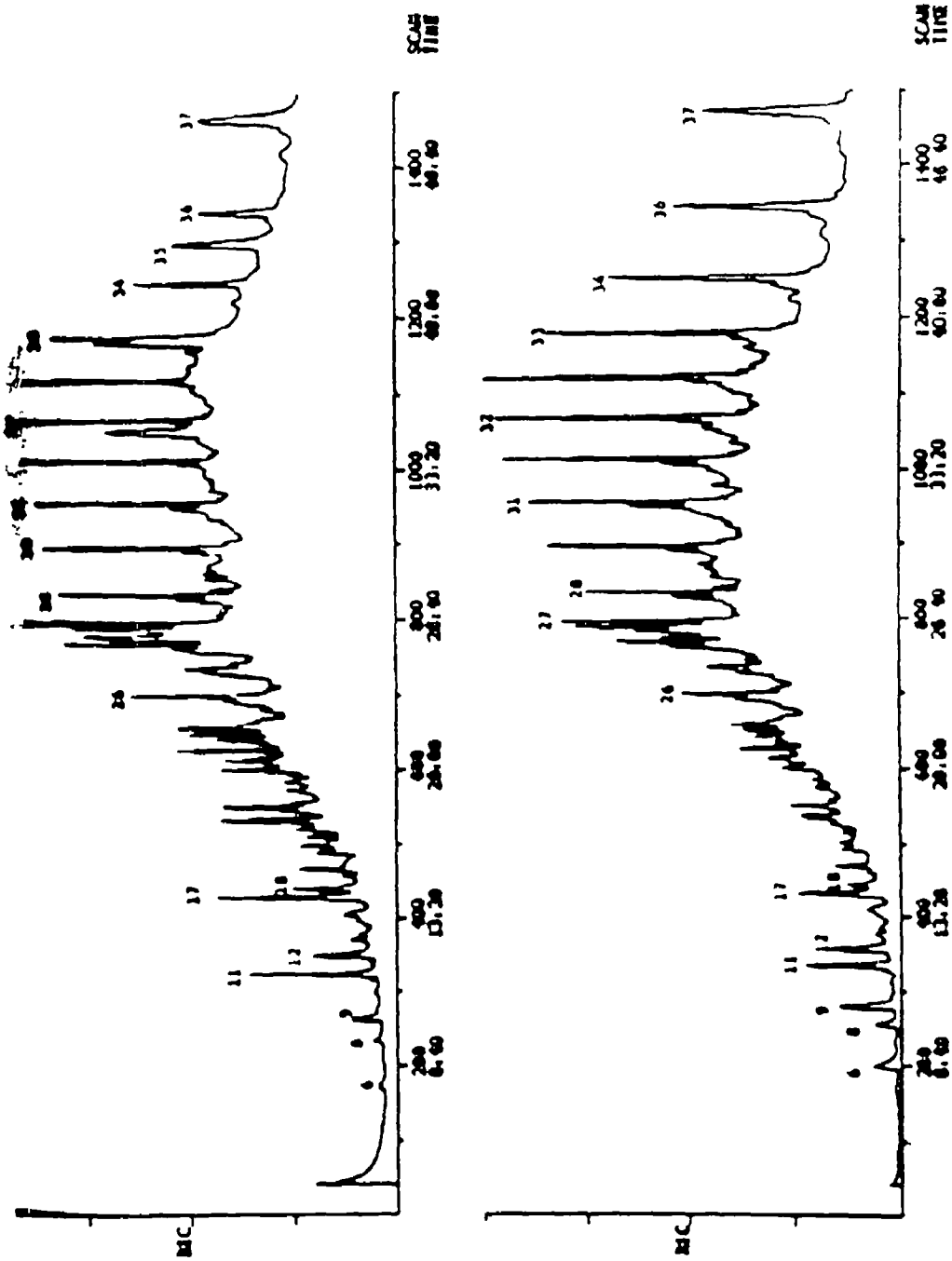


Figure 3. Chromatograms of Condensed Product Tars. Tar I (Top) Produced During Air Gasification, Tar II (Bottom) Produced During Oxygen Gasification.

TABLE

Component	Tar 1	Tar 2
NAPHTHALENE	502	612
C_1 - ALKYL	69	5.
C_2 - ALKYL	. 2	.
C_3 - ALKYL	1 3	44
C_4 - ALKYL	67	42
BIPHENYL	29	28
C_1 - ALKYL	005	064
TOTAL 2 RING PNA s	. 72	. 22
ACENAPHTHYLENE	0 89	ND
ACENAPHTHENE	53	11
C_1 - ALKYL	11	11
FLUORENE	52	61
C_2 - ALKYL	.36	25
PHENANTHRENE	1 *	1 .
ANTHRACENE	63	56
C_1 - ALKYL	95	71
C_2 - ALKYL	58	44
C_3 - ALKYL	48	24
TOTAL 3 RING PNA s	6 02	. 22
FLUORANTHENE	50	36
PYRENE	79	61
C_1 - ALKYL	35	18
C_2 - ALKYL	17	19
CHRYSENE/BENZANTHRACENE	58	29
C_1 - ALKYL	20	1
C_2 - ALKYL	078	13
TOTAL 4 RING PNA's	3 02	2 02
BENZO(a)PYRENE	12	004
BENZOPYRENE (ISOMERS	35	1.
TOTAL 5 RING PNA s	672	192
TOTAL PNA's	14 2	10 52

Organic Profiles of Condensed Product Tars

Component	Tar I	Tar II
PHENOL	1.2%	.2%
C_1 - ALKYL	52	.3
C_2 - ALKYL	89	.3
C_3 - ALKYL	75	84
C_4 - ALKYL	27	31
INDANOLS	61	54
C_1 - ALKYL	53	52
C_2 - ALKYL	62	52
NAPHTHOLS	20	1.1
C_1 - ALKYL	1.3	1.9
C_2 - ALKYL	1.2	1.5
TOTAL PHENOLICS	7.6%	10.5%
PYRIDINE	ND	ND
ALKYL PYRIDINES	ND	ND
ANILINE	ND	ND
BENZONITRILE	ND	ND
QUINOLINE	076	059
ALKYL QUINOLINES	NM	NM
INDOLE	052	079
CARBAZOLE	16	095
DIBENZOFURAN	33	29
DIBENZOTHIOPHENE	12	10
TOTAL HETEROCYCLICS	2.2%	4.2%
ALIPHATIC HYDROCARBONS	36	43
ALKYL BENZENES	2.0	2.0
SULFUR, S_8	ND	ND
TOTAL ORGANICS	58%	67%

ND = Not Detected

NM = Not Measured

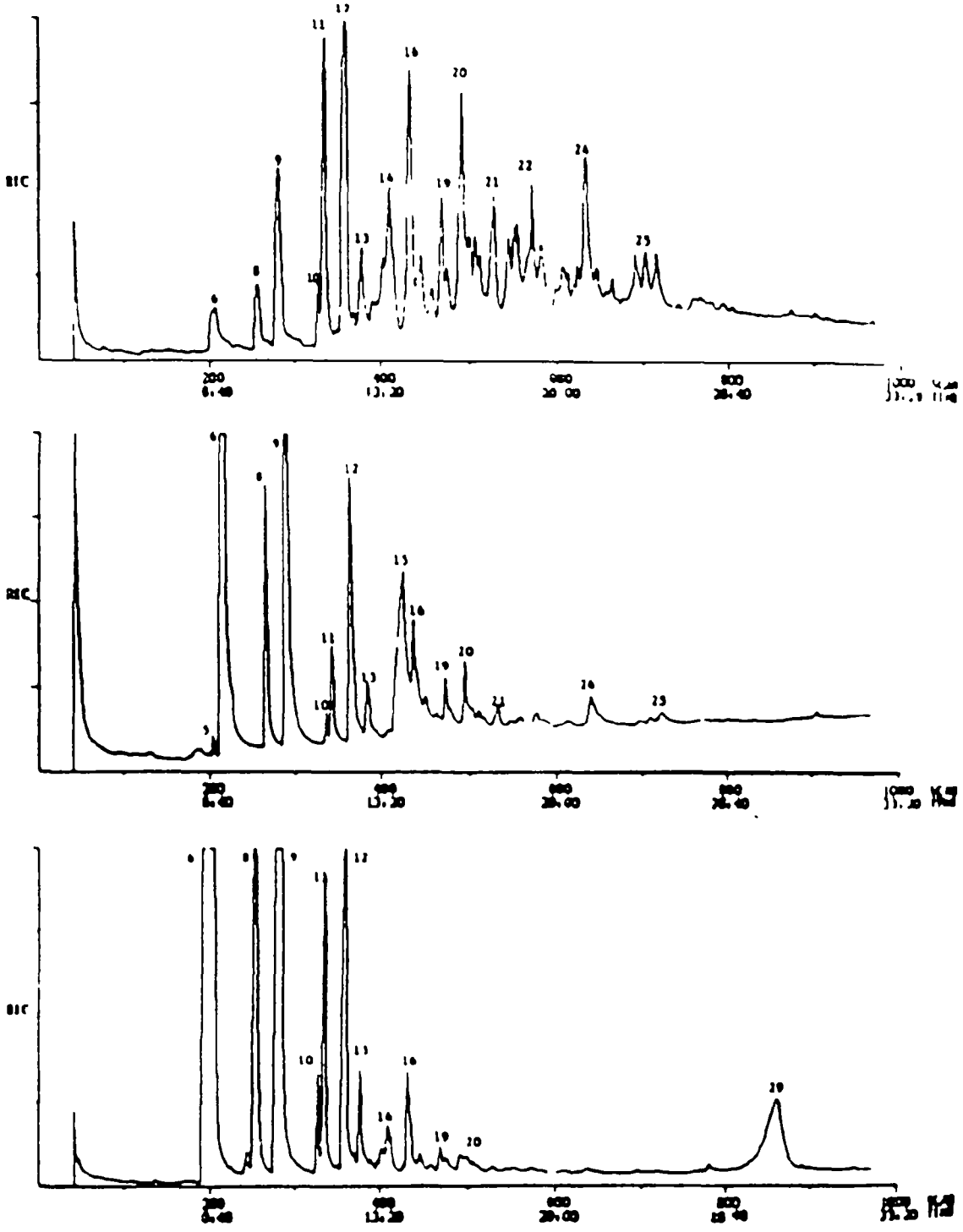


Figure 4.

Chromatograms of Water Equilibrated With Tar (Top), Condensed Product Water I (Middle), Condensed Product Water II (Bottom).

[5-261]

less than saturated. The water concentration of each phenolic species is proportional to the tar concentration. In fact, all phenolics have approximately the same distribution coefficient between the tar and water phases (≈ 620 mg phenols in oil/mg phenols in water) as shown in Figure 5.

Condensed Product Water Analyses

The RIC of two condensed product water samples are also shown in Figure 4 and are quantified in Table 4. The profile of organic compounds in these samples is very similar to that of the burn cavity groundwater immediately after gasification. (See Figure 2). However, the phenolic profiles of the condensed water are different than that of the water equilibrated with tar (Table 4). Phenol is the predominant phenolic compound in the condensed waters (and burn cavity groundwater), with decreasing amounts of heavier phenolics according to their molecular weight (and solubility). This relationship is demonstrated in Figure 6.

The water equilibrated with tar in the laboratory contained only minor concentrations of phenol compared to water samples taken in the field. These tars have probably been stripped of lighter phenolic compounds by contact with water prior to sampling. However, the tar and water condensates were sampled in the field at separate times and may not have been in equilibrium or contact together. A more comprehensive sampling and analysis program is needed to resolve this question.

Volatile compounds measured in condensed water II by a purge and trap technique are summarized in Table 5.
The volatile organics appear to be minor components of the condensed water. Perhaps these compounds are not efficiently condensed and are retained in the product gas.

Major GC peaks in all the samples analyzed (Figures 2, 3, 4 and 7) are identified in Table 6.

TABLE ...

Component	Water in Equilibrium with Tar ...	Condensed product water ...	Condens... or water
NAPHTHALENE	94 ppb	18 ppb	...
C_1 - ALKYL	160	10	...
C_2 - ALKYL	240	5	
C_3 - ALKYL	130	2	
C_4 - ALKYL	17	ND	...
BIPHENYL	10	1	
C_1 - ALKYL	9	ND	ND
TOTAL 2 RING PNA's	660 ppb	96 ppb	...
ACENAPHTHYLENE	18	2	
ACENAPHTHENE	93	10	...
C_1 - ALKYL	ND	2	ND
FLUORENE	78	5	
C_1 - ALKYL	18	1	ND
PHENANTHRENE	150	55	...
ANTHRACENE	41	3	
C_1 - ALKYL	88	2	...
C_2 - ALKYL	ND	ND	ND
C_3 - ALKYL	ND	ND	ND
TOTAL 3 RING PNA's	410	82 ppb	...
FLUORANTHENE	16	3	
PYRENE	13	4	
C_1 - ALKYL	4	ND	
C_2 - ALKYL	ND	ND	ND
CHRYSENE BENZANTHRACENE	6	5	...
C_1 - ALKYL	ND	1	1
C_2 - ALKYL	ND	ND	ND
TOTAL 4 RING PNA's	41 ppb	13 ppb	...
BENZO(a)PYRENE	2	2	2
BENZOPYRENE ISOMERS	5	7	...
TOTAL 5 RING PNA's	7 ppb	9 ppb	...
TOTAL PNA's	1100 ppb	200 ppb	...

[redacted] Profiles of Condensed Product Water Samples

[redacted] Water in Equilibrium with Tar

Component	Water in Equilibrium with Tar I	Condensed product Water I	Condensed product Water II
[redacted]	1 - ppm	350 ppm	50 ppm
C_1 - ALKYL	6 0	98	38
C_2 - ALKYL	15	40	19
C_3 - ALKYL	12	6 0	4 0
C_4 - ALKYL	- 8	4 5	0 76
[redacted]OLS	6 5	5 9	0 96
C_1 - ALKYL	11	6 2	0 72
C_2 - ALKYL	1.		
[redacted]OLS	11	8 0	0 54
C_1 - ALKYL	11	10	0.64
C_2 - ALKYL	1.6	2.6	0 32
[redacted] PHENOLICS	80 ppm	530 ppm	116 ppm
[redacted]	12 ppb	280 ppb	49 ppb
[redacted] PYRIDINES	1100	100	500
[redacted]	20	50	20
[redacted]	1	ND	-
[redacted]	1700	930	150
[redacted] QUINOLINES	1500	410	60
[redacted]	520	50	100
[redacted]	130	590	100
[redacted]	29	25	10
[redacted]	23	20	12
[redacted] HETERO-CYCLICS	[redacted] ppb	[redacted] ppb	[redacted] ppb
[redacted] HYDRO-CARBONS	NM	NM	NM
[redacted]	NM	NM	NM
[redacted], S_8	ND	ND	16 ppm
[redacted] ORGANICS	86 ppm	532 ppm	117 ppm

ND = Not Detected

NM = Not Measured

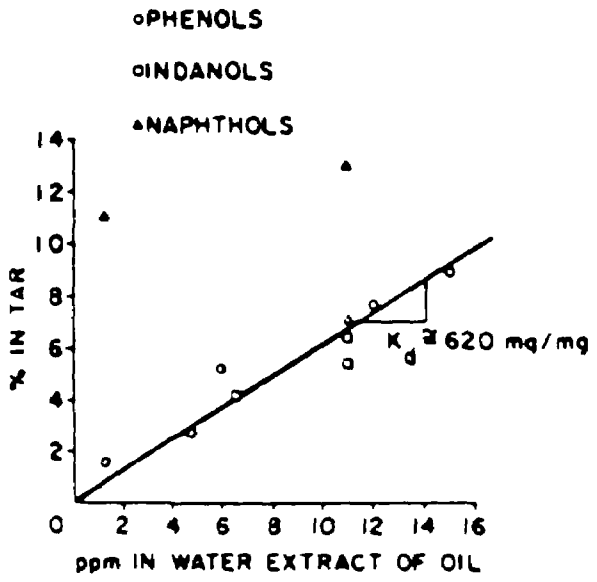


Figure 5. Equilibrium Distribution of Organics Between Tar And Water Phases.

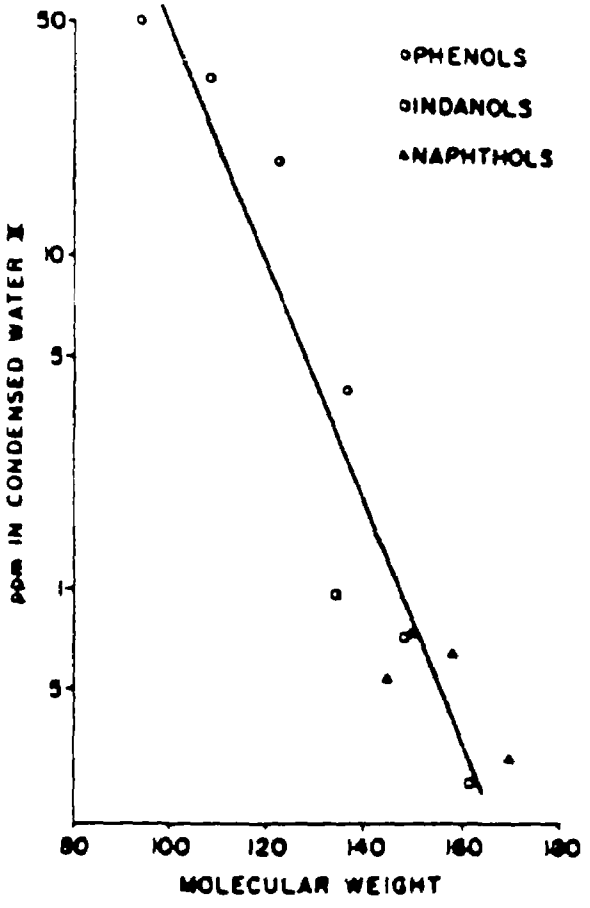


Figure 6. Relationship of Molecular Weight of Phenolic Materials to Concentration in Condensed Water.

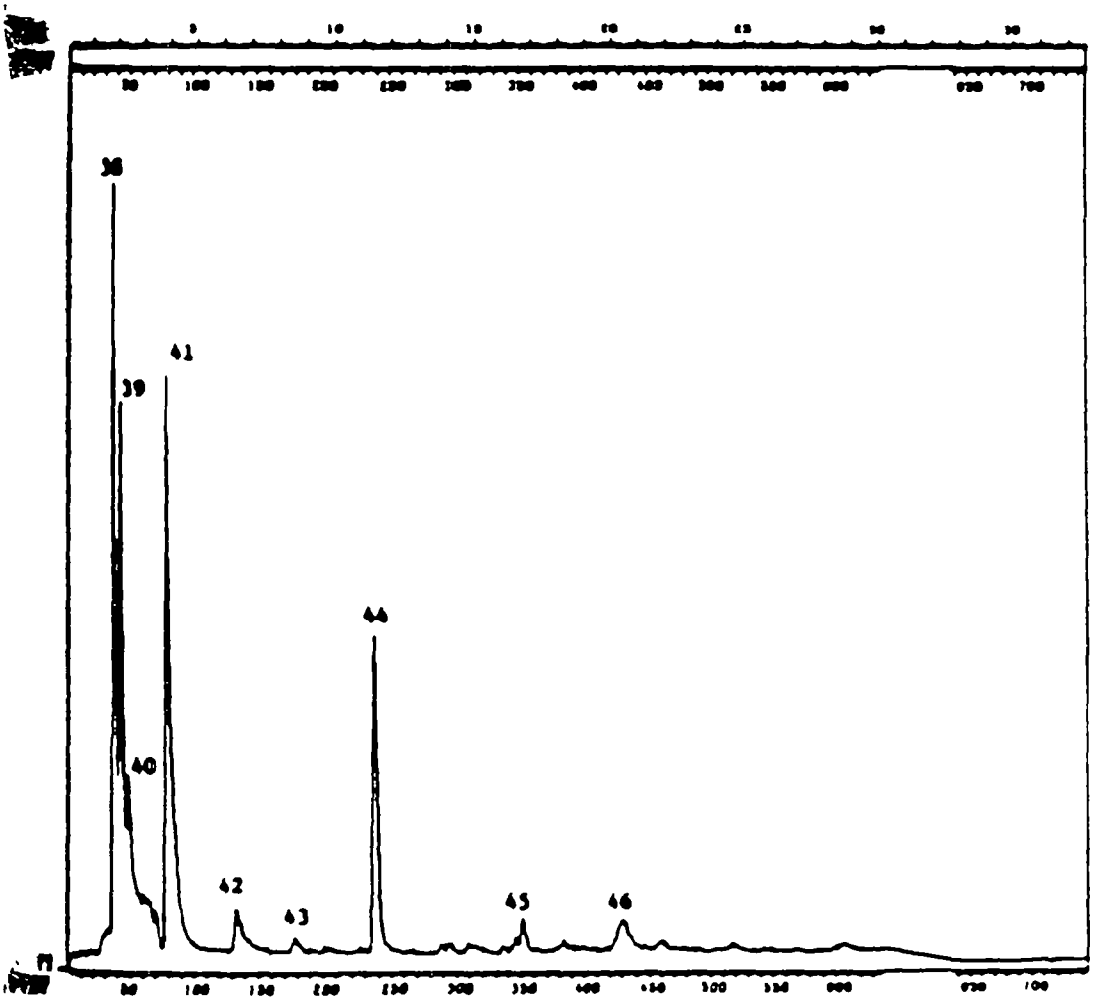
TABLE 5

Concentration of Volatile Organics in Condensed Water II.

Compound	Concentration, ppb
[illegible]tone	NM
[illegible]ylene Chloride (laboratory contaminant)	NM
[illegible]rahydrofuran	280
[illegible]tyraldehyde?	NM
[illegible]iophene	8
[illegible]zene	83
[illegible]lene	3
[illegible]yrene	31
[illegible]ylbenzene	2
[illegible]lenes	ND

- [illegible] Not Detected
- [illegible] Not Measured

[illegible]IC of this analysis is shown in Figure 7.



[illegible] 7. Chromatogram of Volatile Organic Compounds in Condensed Water II.

TABLE I

Chromatographic Peak No.	Compound Identified
1	Pyridine
2	2-Methylpyridine
3	3-Methylpyridine and 4-Methylpyridine
4	C_2 Alkylpyridine
5	Internal Standard (dichlorobenzene)
6	Phenol
7	Dihydroxybenzene (molecular weight 110)
8	o-Cresol
9	m-Cresol and p-Cresol
10	C_2 Alkylphenol
11	Naphthalene and C_2 Alkylphenol
12	C_2 Alkylphenol
13	C_2 Alkylphenol
14	C_3 Alkylphenol
15	Benzoic Acid
16	C_3 Alkylphenol
17	2-Methylnaphthalene
18	1-Methylnaphthalene
19	4-Indanol
20	5-Indanol
21	Methylindanol
22	Methylindanol
23	C_2 Alkylindanol

Identification of Major Chromatographic Peaks

24	Naphthol
25	Methyl Naphthols (3 Isomers)
26	n-Hexadecane
27	Phenanthrene
28	n-Octadecane
29	Sulfur, S_8
30	Phthalate ester
31	n-Eicosane
32	n-Docosane
33	n-Tetracosane
34	n-Pentacosane
35	Aliphatic hydrocarbon
36	n-Hexacosane
37	n-Heptacosane
38	Acetone
39	Methylene Chloride (laboratory contaminant)
40	Unknown
41	Isobutyraldehyde
42	n-Butyraldehyde? (molecular weight 72)
43	Chloroform
44	Benzene
45	Internal Standard (dichlorobutane)
46	Styrene

CONCLUSIONS

1. In field samples taken at two lignite gasification sites in Texas, phenolic materials (phenols, indanols, and naphthols) were shown to be predominant groundwater pollutants. Lesser amounts of polynuclear and heterocyclic aromatic hydrocarbons were also identified.
2. There may be substantial capacity for natural groundwater renovation following UCG. Adsorption on coal is a likely mechanism for immobilization of organics in groundwater. Other possible mechanisms can also be proposed.
3. Analysis of condensed product tar indicates a large amount of PNA are produced during gasification, however their potential for groundwater pollution is probably limited by their water solubility.
4. The condensed product water, while more concentrated in phenols, is similar in composition to groundwater sampled from the burn cavity.
5. More comprehensive study of tar and water condensates is needed to predict water solubilities of organics released to groundwater during gasification.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Department of Energy, Basic Resources, Inc. who funded this work. Furthermore, this work would not have been possible without the use of the GC-MS system, and cooperation which was generously provided by Dr. James Hudson, Department of Chemistry, University of Texas at Austin. Appreciation is expressed to Jerry Parr, Radian Corporation, Austin, Texas, who ran the volatile analysis.

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1. "Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants," U.S. Environmental Protection Agency, April, 1977.

2. E.D. Pellizzari, "Identification of Components of Energy-Related Wastes and Effluents" EPA report, EPA 600/7-78-004, Jan., 1978.

3. J.H. Campbell, E.D. Pellizzari, and S. Santor, "Results of a Groundwater Quality Study Near an Underground Coal Gasification Experiment (Hoe Creek I)" prepared by Lawrence Livermore Laboratories for the U.S. Department of Energy, under contract no. W-7405-eng-48, Feb., 1978.

SECTION 5.3.2

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	"Underground Coal Gasification (Experimental Technology)," Assessment of Class V Injection Wells in the State of Wyoming
AUTHOR: (OR INVESTIGATOR)	Western Water Companies
DATE:	September 1986
FACILITY NAME AND LOCATION:	U.S. Department of Energy Hanna area (Hanna Basin of Southcentral Wyoming) USEPA Region VIII
NATURE OF BUSINESS:	Coal Gasification

BRIEF SUMMARY/NOTES: Only four areas in Wyoming contain Underground Coal Gasification (UCG) experiments. The Hanna area was selected for a site assessment because it is a well documented UCB experimental area. A coal bed within the Tertiary Hanna formation (Hanna #1 coal bed) was utilized for the experiment.

The Hanna research facility consisted of five separate burn sites controlled from a central area. Seven gasification experiments were made using different well patterns, involving approximately 30 wells used either as injection or gas-recovery wells. Injected materials were limited to water, steam, air, oxygen, and propane.

Contaminants of concern are those produced by subsurface combustion of coal and the postburn leaching of the ash and spalled residue in the burn cavity. These contaminants include ammonia, boron, phenols, and sulfide. Other contaminants potentially present in trace quantities are complex organic compounds such as polynuclear aromatics, polycyclic organic chemicals, and thiols.

The Hanna #1 coal aquifer has suffered adverse impacts as a result of in situ coal gasification experiments. Contamination by a variety of organic pyrolysis product chemicals and elevated concentrations of ionic species native to groundwater have been demonstrated. The operator has made no efforts to restore groundwater quality.

CHAPTER 8

UNDERGROUND COAL GASIFICATION (Experimental Technology)

Introduction

Selection of Assessment Site

Since only four areas in Wyoming contain Underground Coal Gasification (UCG) experiments, all four were considered for this assessment. Two of the sites, ARCO's Rocky Hill #1 Area, and the DOE Hoe Creek area, are located in the Powder River Basin. Rocky Hill is 40 miles south of Gillette, Wyoming in Section 16, T44N, R71W. Hoe Creek is 20 miles south of Gillette, in section 7, 142N, R72W. The Hoe Creek site was dropped from consideration because of complications in evaluating the area since subsidence to the surface occurred after gasification. Two coal seams and an overlying aquifer contain waters which became intermixed after subsidence, and the resulting data have lesser meaning than data from other UCG experiments. The Rocky Hill #1 site was eliminated from consideration because much detailed information is still considered proprietary and is unavailable for this assessment.

Two sites in the south-central part of Wyoming were considered for assessment. They were the steeply-dipping bed (SDB) project, conducted on the west flanks of the Rawlins Uplift 4 miles west of Rawlins, Wyoming and operated by Gulf Research and Development Company, and the U.S. Department of Energy (DOE) Hanna area where a series of UCG experiments were conducted over a six-year period. The SDB area was rejected because it is devoid of subsurface aquifers which could be

contaminated by UCG development. The Hanna area was selected for site assessment because it is a well-documented UCG experimental area and information is available for assessing injection results. Figure 8-1 is a location map of the Hanna UCG area and the specific experimental sites.

Geology

Regional Geology

The Hanna UCG area is in the southeastern portion of the Hanna Basin. The Hanna basin of southcentral Wyoming is one of the deepest in the intermountain region. It is 40 miles long by 25 miles wide, and contains a sedimentary section that exceeds 30,000 feet in thickness.

Structure

The Hanna Basin and adjacent Carbon Basin are bounded by Laramide-aged uplifts: the Rawlins Uplift to the west, Medicine Bow Mountains to the south, the Saddleback Hills to the east, and the freezeout, Seminoe, and Shirley Mountains to the north. Numerous normal faults occur across the coal-bearing synclines of the basin. These faults trend northwest-southeast with cross-faulting common. Faults often occur quite closely together and vertical displacements vary from a few feet to several hundred feet. Zones of closely-spaced fractures are sometimes associated with these faults.

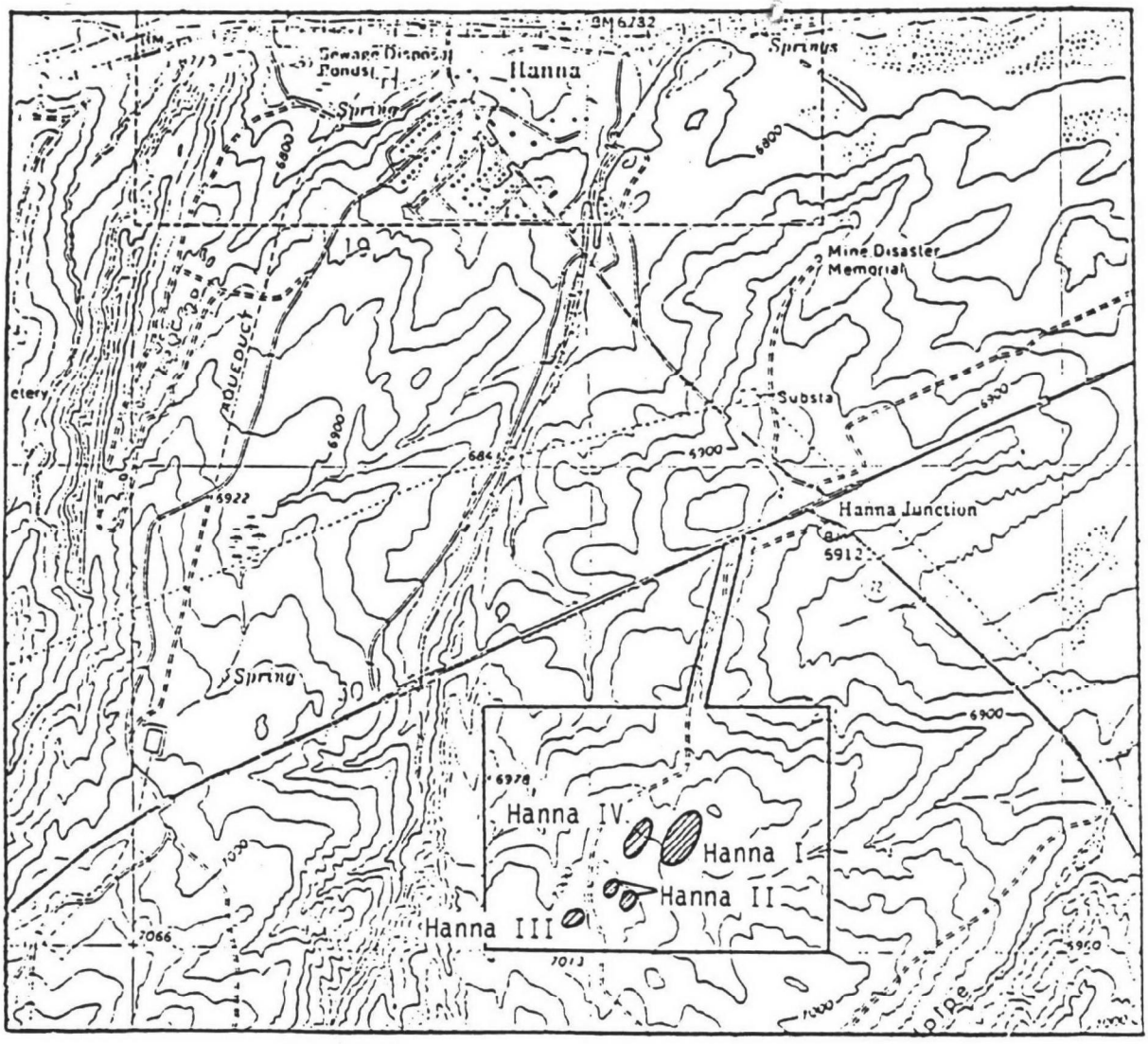


Figure 8-1. Hanna UCG R&D License Area and Experimental Sites (from WDEQ Files).

Stratigraphy

Three formations deposited during the development of the Hanna Basin are recognized in this region. These include the Upper Cretaceous Medicine Bow, Paleocene Ferris, and Paleocene-Eocene (Tertiary) Hanna Formations. Aggregate thickness of these deposits is approximately 21,000 ft. Each was deposited in the subsiding Hanna Basin in continental environments including alluvial fan, fluvial, and swamp settings. Coal beds are common in all three lithologic units, and many have been extensively exploited by both underground and strip mining (Glass, 1972; Glass and Roberts, 1980).

Site Geology

Structure

The experimental area is located southwest of the structural axis of the Hanna Basin. Rock units strike northwest and dip to the northeast at an average of 3°. Normal faults at the test site with displacements up to 50 feet disrupt the strata as illustrated by the Structural Contour Map and the cross-section shown on Figures 8-2 and 8-3. The fault system has created structural dips of up to 8° in part of the study area.

Stratigraphy

The Hanna UCG project utilized a coal bed in the Hanna Formation called the Hanna No. 1 coal bed which is 28 to 30 feet thick at the site. The lithology and stratigraphy of the portion of the Hanna

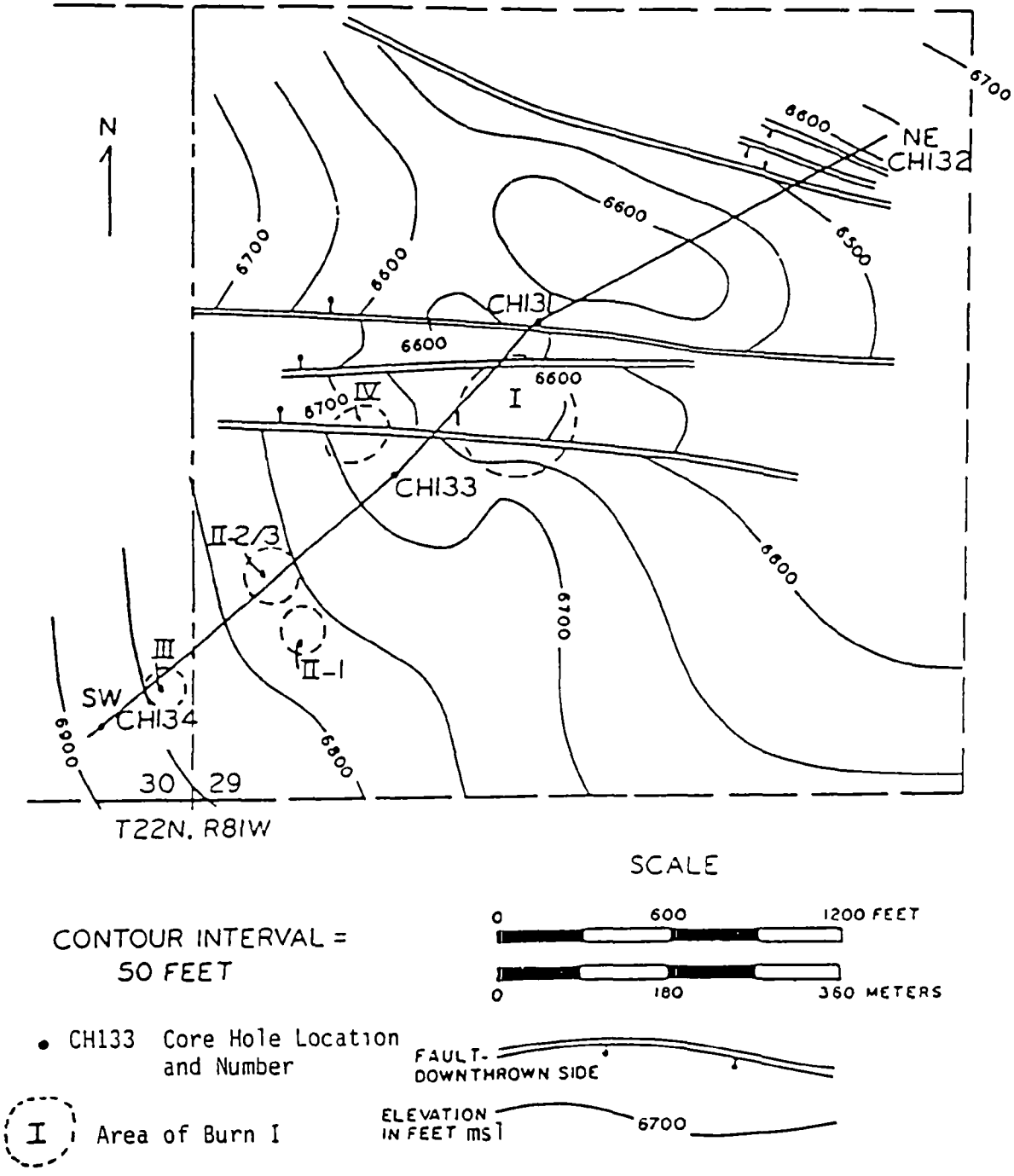
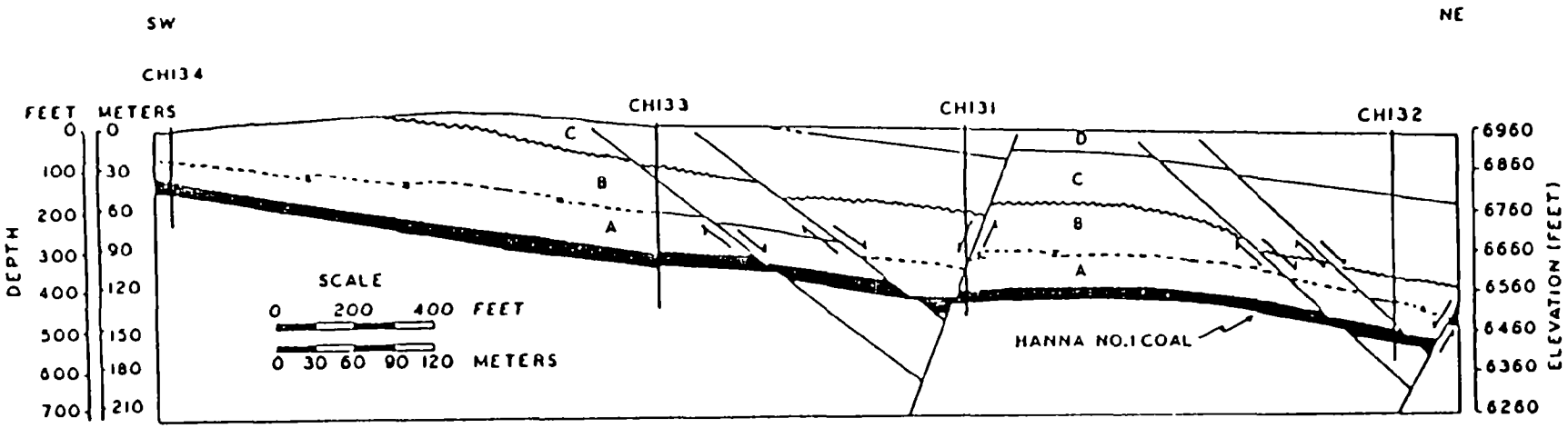


Figure 8-2. Structural contour map on top of the Hanna No. 1 coal bed (after Youngberg et al., 1981). Note: structural contours in feet above sea level. SW-NE line is surface trace of cross section shown in Figure 8-3.



A, B, C, D = Lithologic Units Shown on Figure 6-4.

Figure 8-3. Generalized northeast-southwest structural cross section of the Hanna UCG area (after Craig et al., 1982). (Location of section shown on Figure 8-2.

Formation within which the experiment was conducted is shown on Figure 8-4.

Hydrogeology

In 1980 a field program to evaluate the hydrogeology of the sites was begun. Twenty-two wells were completed as monitor wells and four holes were cored and geophysically logged. From this and previous core information, three aquifers were identified at the site: the upper overburden aquifer (unit C, Figure 8-3), the lower overburden aquifer (unit A, Figure 8-3), and the Hanna No. 1 coal seam aquifer (unit , Figure 8-3).

Structures within the upper overburden aquifer are primarily trough and planar crossbedding. These deposits are poorly to moderately sorted, with a mean grain size of 0.41 mm. The aquifer ranges in thickness from 0 feet at the outcrop area to 242 feet thick to the north.

The lower overburden aquifer ranges in thickness from 26 feet at the southeast corner of the study area to 100 feet at the Hanna II, Phases 2 and 3 site. This aquifer is separated from the Hanna No. 1 coal bed by 1 to 19 feet of shale.

The Hanna No. 1 coal seam aquifer was deposited in a swamp environment where peat accumulated and formed coal. This swamp was prone to overbank contamination which formed carbonaceous shales within the coal bed when sediment from the fluvial system inundated the swamps. The Hanna No. 1 coal seam is 22 to 34 feet thick at the gasification area and dips to the northeast (Schowengerdt, 1985).

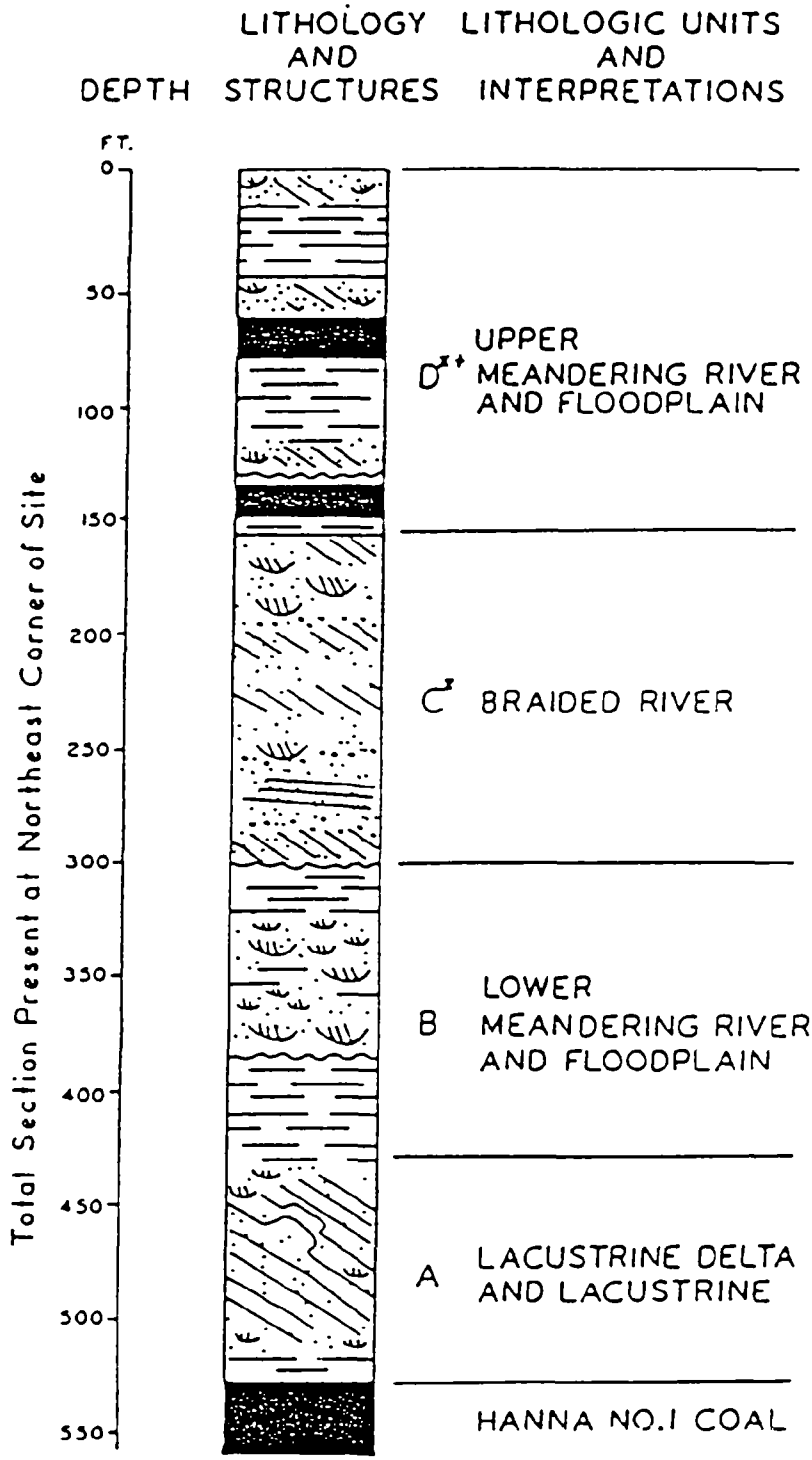


Figure 8-4. Subdivision of the overburden of the Hanna No. 1 coal bed at the Hanna UCG site (after Craig et al., 1982). *- Not present at Hanna UCG III +- Not present at Hanna UCG II or Hanna UCG IV.

Ground-Water Flow

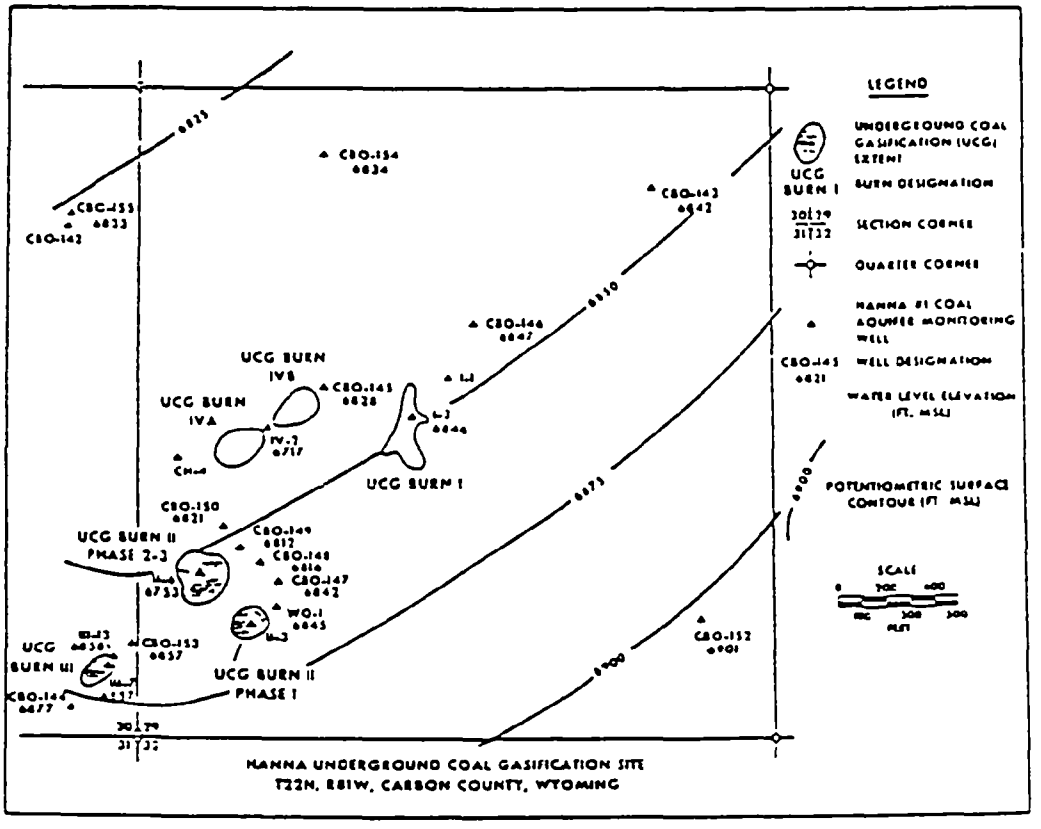
Pre-gasification data, although scarce, are available for comparison to post-gasification data. A preburn potentiometric surface map of the Hanna No. 1 coal seam is presented in Figure 8-5. In developing this figure, emphasis was placed on perimeter wells furthest from the burn site. The Hanna No. 1 coal potentiometric surface represents a flow pattern towards the north-northwest with apparent major recharge from outcrop areas and a possible minor recharge component from leakage of overlying strata.

Directional permeability measurements show three maximum trends, and the resultant vector of directional permeability is interpreted to be approximately N 30° E. Table 8-1 summarizes other hydraulic parameters for the three aquifers.

Ground-Water Quality

The water-quality monitoring program at the Hanna site proceeded in two major phases. Phase 1 included the preburn baseline and early postburn sampling at Hanna III during 1977 and 1978.

In 1977, a monitoring program was established for the Hanna III field test, including a limited-duration baseline sampling period. Sporadic collection of data at the remaining experimental sites continued through this period. The second phase of sampling occurred on a quarterly basis throughout the site from September 1980 to December 1982. Average concentrations of ground-water constituents obtained during the 1977 period are listed in Table 8-2.



Preburn Potentiometric Surface, Hanna #1 Coal Aquifer

Figure 8-5. Preburn Potentiometric Surface, Hanna No. 1 Coal Aquifer (from Schowergerdt, 1985).

Table 8-1. Hydraulic Properties of Aquifers at the Hanna UCG Site (after Youngberg and Santoro, 1981; and Schowengerdt, 1984).

Aquifer	Porosity	Storage Coefficient	Average Hydraulic Conductivity (ft/day)	Average Transmissivity (ft^2/day)	Average Ground-Water Velocity (ft/year)
Upper Overburden	0.19	0.003	0.037 (0.024 - 0.048)	4.3 (2.4 - 7.6)	1.6 (0.2 - 2.9)
Lower Overburden	0.15	0.003	0.012 (0.0016 - 0.027)	0.63 (0.06 - 1.6)	3.2 (0.3 - 8.1)
Hanna No. 1 Coal	0.03	0.001	0.03 (0.0011 - 0.16)	0.84 (0.019 - 7.8)	110 (0.23 - 393)

Table 8-2. Hanna III Water Quality Baseline.

Hanna III Water Quality Baseline

Parameter	Overburden Aquifer		Coal Aquifer	
	Average Concentration[1,2]	Number of Samples	Average Concentration[1,2]	Number of Samples
pH (standard units)	8.08	12	8.63	30
Water Temperature (°C)[3]	10	--	10	--
Total Dissolved Solids	2,561	12	1,223	30
Sodium	1,107	12	510	30
Bicarbonate	1,679	12	1,106	30
Sulfate	677	12	19	28
Sulfide	*	*	*	*
Ammonia-Nitrogen	1.66	12	1.15	30
Boron	0.07	12	0.04	18
Fluoride	1.22	12	1.86	30
Manganese	0.27	12	0.08	30
Phenols	--	--	--	--
Total Organic Carbon	14	12	41	30

[1] All values in mg/l, unless otherwise specified.

[2] All averages based on values reported above the detection limit. (1977 Data)

[3] Reported as 50°F (10°C) by downwell thermocouples.

* All values were reported below the detection limit or not detectable.

Ground-Water Use

Ground waters in the general area are used for municipal water supply, stock watering, and industrial purposes. Table 8-3 lists the water well permits registered with the Wyoming State Engineer which exist within approximately 1.5 miles of the permit area. These wells are shown on Figure 8-6 which gives their location and use. The location and volume of use of the municipal well for Hanna is not listed on the permit (Wyoming State Engineer). The principal industrial use is for placing a slurry of water and sand into an abandoned coal mine to prevent subsidence, using water from a water-filled void in that mine.

Description of Facilities and Operational History

The Hanna UCG research facilities consisted of five separate burn sites controlled from a central area. Seven gasification experiments were made using a variety of well patterns and involving approximately 30 wells used as either injection or gas-recovery wells.

Figures 8-7 and 8-8 show examples of the patterns of wells involved in underground coal gasification of the Hanna No. 1 coal bed (Covell et al., 1980). The series of experiments were chronologically designated as Hanna I through Hanna IV, and were developed from March 1973 through September 1979. For this report, attention has been focused on the Hanna III site because of its goal of measuring water quality effects of UCG in the coal seam and in an underlying aquifer. Two injection wells (1 and 2) shown on Figure 8-7 were spaced 60 feet apart and were aligned along the major fracture direction. Twelve observation wells were completed, four (wells 3, 4, 5, and 14) in the overlying aquifer and

Table 8-3. Water Well Permits Within a 1.5 mile Radius of the DOE Hanna UCG Permit Boundaries.

Permit Number	Location (S-T-R)	Owner	Use	Depth (ft)	Water Level (ft below surface)	Yield (gpm)
68966	NE/NW 18 22N 81W	Midwest Mining	MON	400	--	0
69232	NW/NE 18 22N 81W	Midwest Mining	MON	100	--	0
68967	NE/NW 18 22N 81W	Midwest Mining	MON	300	--	0
49243	NW/NW 18 22N 81W	J. Linden	STO	125	--	10
69233	NW/NE 19 22N 81W	Midwest Mining	MON	408	115	0
71818	SE/NW 19 22N 81W	McMurray Company	IND	150	--	125
71819	NE/NW 19 22N 81W	Eby Mine Company	IND	100	--	25
37156	SE/SW 31 22N 81W	Arch Minerals	MON	140	--	0
37157	SE/SW 31 22N 81W	Arch Minerals	MON	260	--	0
59634	NW/NE 32 22N 81W	Arch Minerals	MON	210	23.5	0
37158	SE/SE 33 22N 81W	Arch Minerals	MON	120	flowing	3-4 25-30 on pump

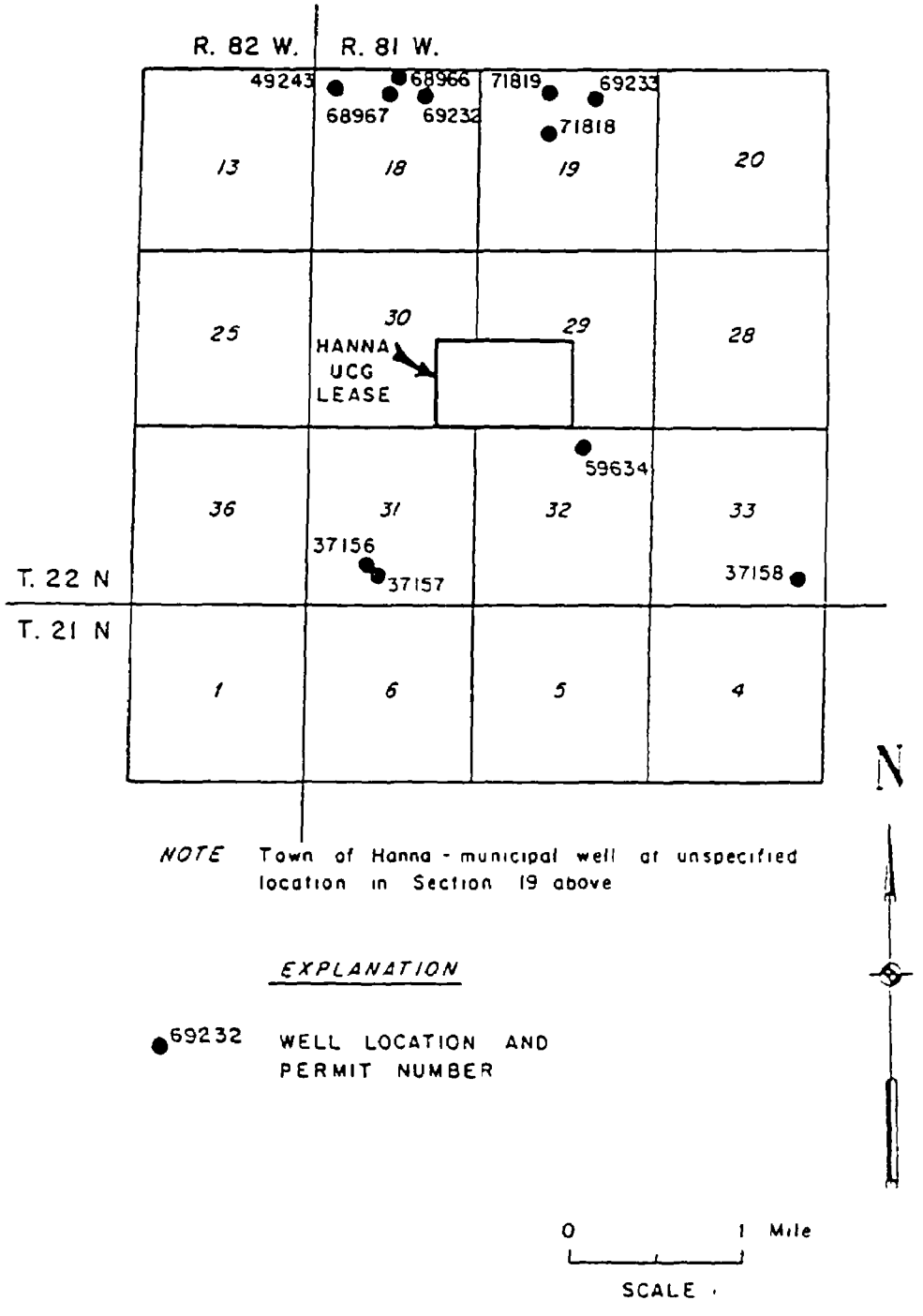


FIGURE 8-6 LOCATIONS OF PERMITTED WATER WELLS NEAR THE HANNA UCG PROJECT AREA

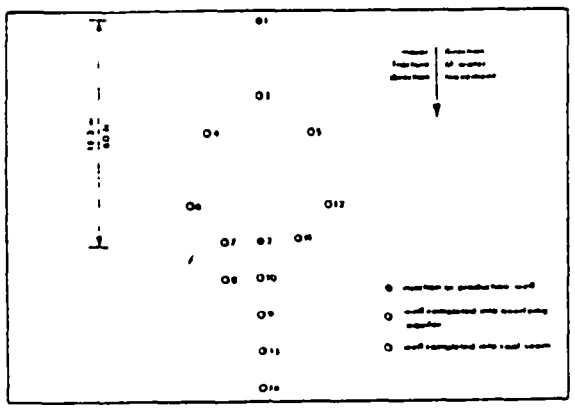


Figure 8-7. Well Pattern for Hanna III

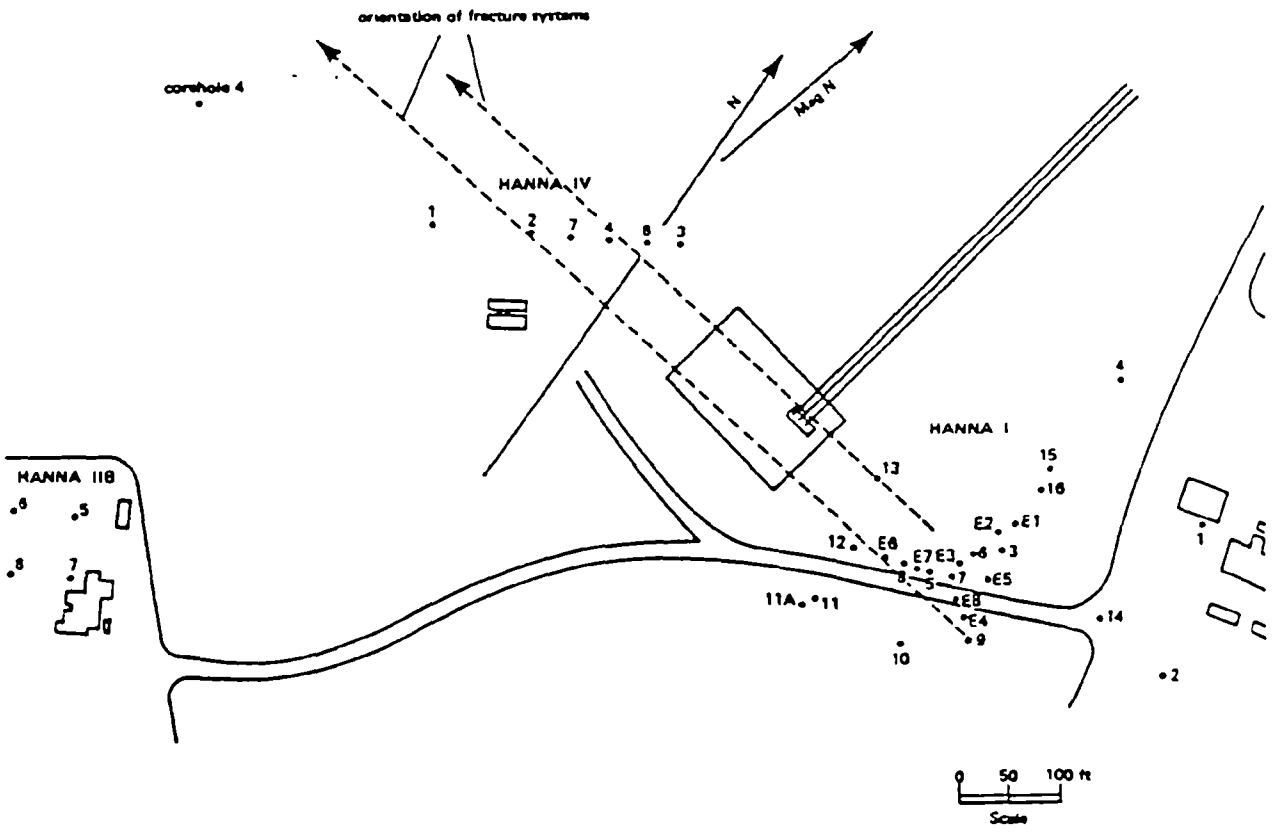


Figure 8-8. Hanna Well Pattern

eight (wells 6-13) in the coal seam. Injection wells were completed using high temperature-cement as exhibited in Figure 8-9. Observation wells were constructed as shown in Figure 8-10, and high temperature cement was not used.

Since 1974, various ground-water observation wells were installed, culminating in 1980 with a group of 22 new monitoring wells; 14 in the Hanna I coal seam, 4 in the upper overburden aquifer, and 4 in the lower burden aquifer. In all, sampling and testing was conducted in 31 wells. Figure 8-11 shows the locations of all observation wells used for hydrological evaluation over the life of the experiments. Each new well was cased with 5-inch steel pipe and left open hole throughout the entire aquifer.

Upon completion of the gasification experiments, most of the buildings and all of the surface installations were dismantled and moved. However, one building and all monitor wells were left intact. Restoration of the land-surface was completed.

Past and Present Ground-Water Impacts

Ground-Water Flow

A postburn potentiometric surface was developed for the Hanna No. 1 coal aquifer to evaluate the progress of water level recovery in the burn cavities after the Hanna III experiment. Figure 8-12 presents the water-level distribution at the Hanna site for August 15, 1983. The general trend closely resembles the pre-burn potentiometric surface (Figure 8-6) with one exception. The aquifer exhibits a cone of

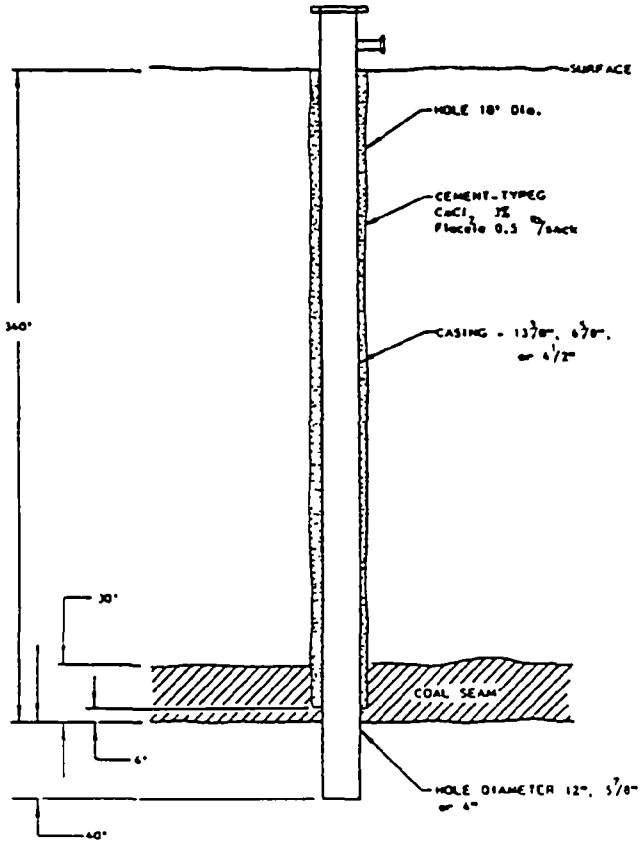


Figure 8-9. Typical Production or Injection Well Completion, Hanna IV Area (from WDEQ Files).

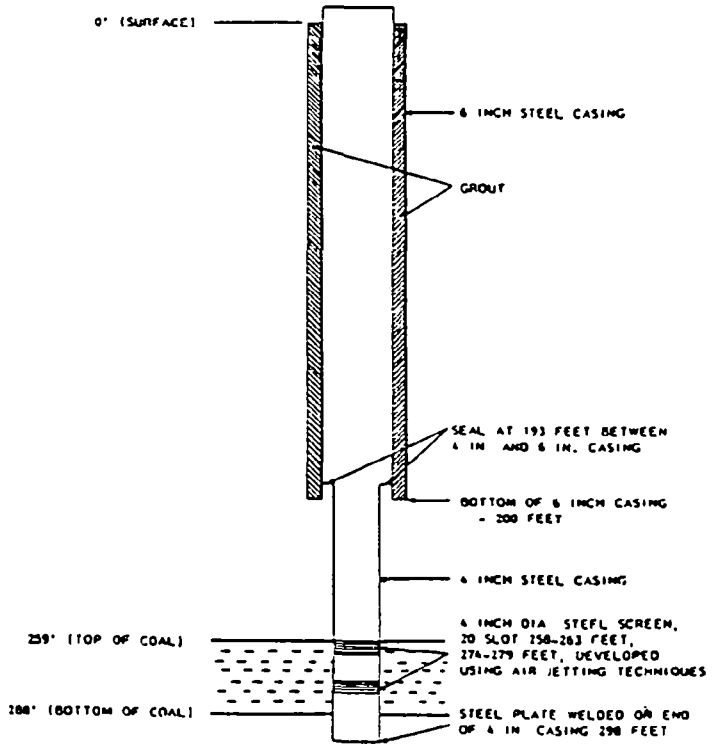


Figure 8-10. Typical Monitoring Well Completion, Hanna IV Area (from WDEQ Files).

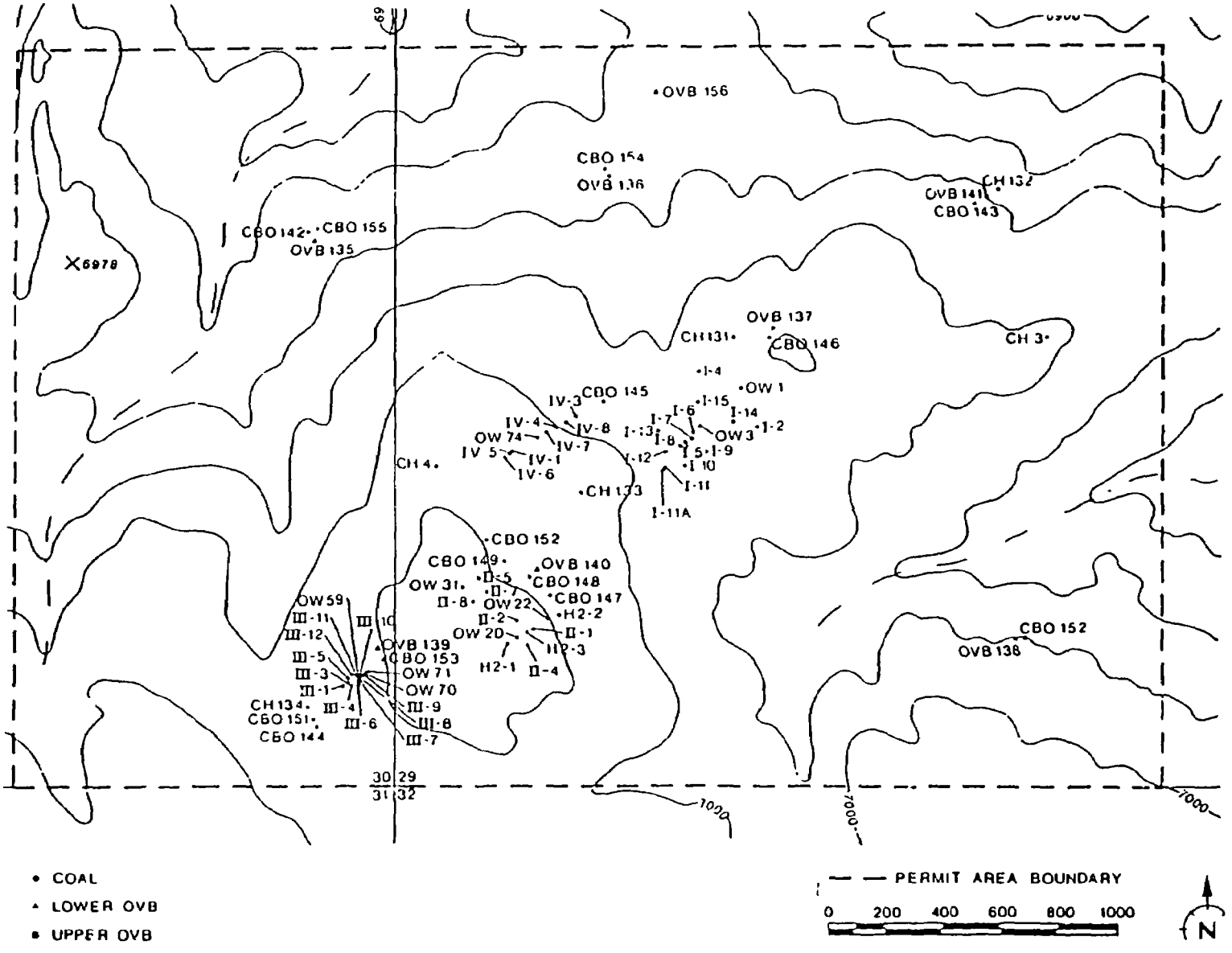
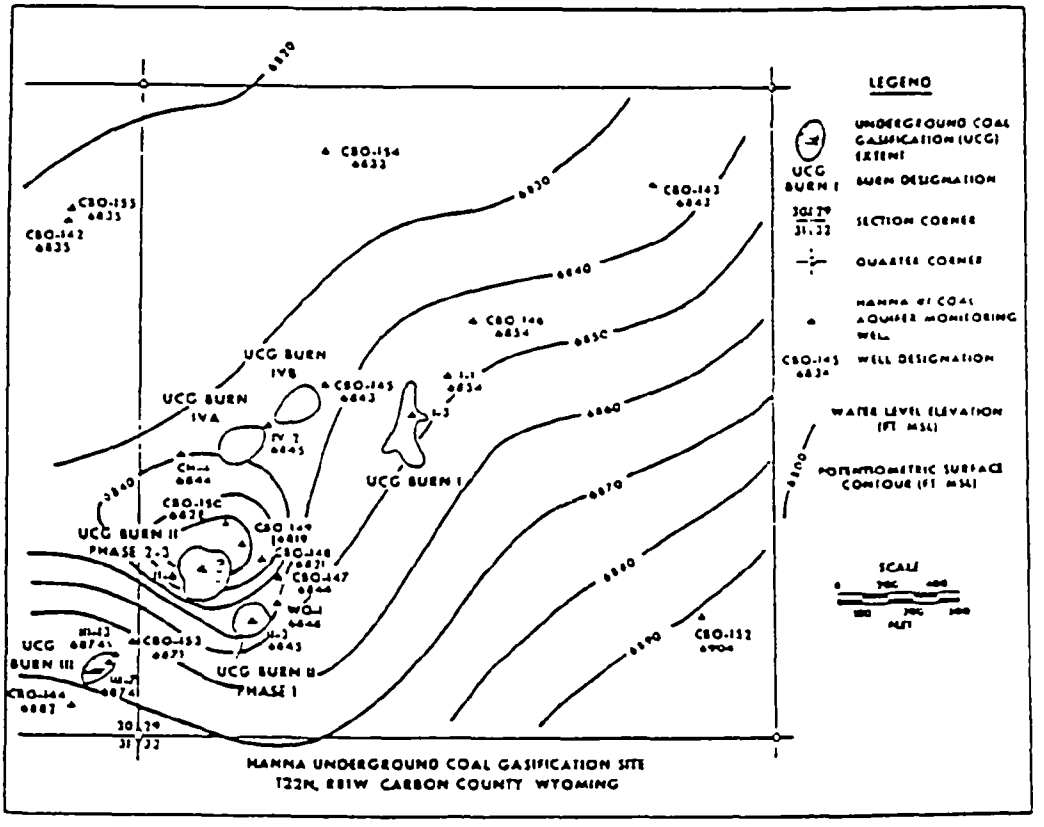


Figure 8-11. Locations of Wells Sampled for Water Quality, 1974 - 1983 (from WDEQ Files).



8/15/83 Potentiometric Surface, Hanna #1 Coal Aquifer.

Figure 8-12. 8/15/83 Potentiometric Surface, Hanna No. 1 Coal Aquifer (from Schowengerdt, 1985).

depression adjacent to the Hanna II burn, indicating that the aquifer recovering from that experiment.

Water Quality

The materials injected into the subsurface in UCG experiments are limited to water, steam, air, oxygen, and propane. The contaminants of concern are those produced by subsurface combustion of coal and the postburn leaching of the ash and spalled residue in the burn cavity. Contaminants produced as pyrolysis products and examined at the Hanna site include ammonia, boron, phenols, and sulfide. Dissolution of leachable materials from the coal ash and overburden materials after the experimental burn creates elevated concentrations of most major ionic constituents and some transition or heavy metals. The leachate products monitored at the Hanna site include bicarbonate, fluoride, manganese, sodium, sulfate, total dissolved solids, and total organic carbon. It should be noted that these are not the only contaminants which are likely to be released from in situ coal gasification cavities. Additional contaminants, which are likely to be found in microgram per liter concentrations, include complex organic compounds such as polynuclear aromatics (PNAs), polycyclic organic chemicals (POCs), and thiols. These chemicals are often referred to as the "tars and oils" when produced in above ground coal gasification facilities. They can render water unfit for domestic use even when present in small concentrations, due to the tastes and odors which they impart. Many of these chemicals also are significant health threats when ingested in low concentrations over long periods of time.

The initial post-gasification sampling phase began in June 1978, approximately 1 year after gasification, when water samples were obtained from 11 of the original 14 wells at Hanna III. Sampling continued through November 1978, with eight sets of samples collected. The second sampling phase began in September 1980, when samples were collected from 3 wells at Hanna III, and from approximately 30 additional wells throughout the site. This phase continued through December 1982, with a total of 10 samples collected on a quarterly basis (Cooke and Oliver, 1985).

Pyrolysis Products

Postburn data from the process and burn cavity wells display dramatic evidence of the release of pyrolysis products (sulfide, ammonia, and phenols, and boron) into the ground water by the UCG process (Table 8-4). Sulfide concentrations over 10 mg/L are common, with most values reported over 4 mg/L. Ammonia concentrations increased sharply immediately after gasification, from less than 5 mg/L to over 25 mg/L. Concentrations then decreased gradually to near baseline conditions.

Phenols were initially detected in burn cavity waters much later than the other pyrolysis products. The earlier experiments presently show the greatest concentrations of phenols (over 100 ug/L, compared to a 10 ug/L background), while the more recent experiments exhibit only moderate or no increases. At this time, it is difficult to determine the rate of decline of phenol concentrations in burn-cavity waters.

Table 8-4. Summary of Comparison of Preburn and Postburn Ground-Water Quality Parameters at the Hanna UCG Site[a].

Leachate Indicators	Preburn Concentration Coal (mg/L)	Preburn Concentration Overburden (mg/L)	Postburn Concentration (mg/L)	Comments
Total Dissolved Solids	1,220	2,560	3,000 - 5,000	Slow increase after burn ended, remains well above baseline.
Sulfate	19	680	400 - 3,500	Gradual increase after burn, then slow decrease began 1½ years after burn. Derived from gypsum dissolution.
Bicarbonate	1,100	1,680	100 - 1,700	Initial increase to 1,700 mg/L, then rapid decline to below preburn values (approximately 700 mg/L).
Sodium	510	1,100	800 - 1,200	Slow increase after burn.
Manganese	0.08	0.27	0.3 - 1.0	Sharp increase. Trace constituent in coal.
Fluoride	1.86	1.22	7 - 50	Gradual decrease to less than 10 mg/L except at one site.
Total Organic Carbon	41	14	20	Decrease in burn-cavity waters, no change away from burn cavity.

Table 8-4. Summary of Comparison of Preburn and Postburn Ground-Water Quality Parameters at the Hanna UCG Site[a] (cont'd).

Pyrolysis Products	Preburn Concentration Coal (mg/L)	Preburn Concentration Overburden (mg/L)	Postburn Concentration (mg/L)	Comments
Boron	0.04	0.07	1 - 5	Sharp rise, then gradual decrease to 1 to 2 mg/L. Major trace element in coal.
Sulfide	ND	ND	0.1 - <10	Sharp rise several months after burn, sustained peak, then rapid decrease to low (0.1 mg/L) value.
Ammonia-Nitrogen	1.15	1.66	5 - 35	Sharp increase, then gradual decrease to baseline concentrations in coal and 20 mg/L in overburden.
Phenols	<0.01	<0.01	<0.1	Concentration rise shown well after burn, rate of subsequent decrease undetermined.

[a] Based on values presented by Schowengerdt (1985).

ND = Not Detected.

Well III-4, the only well completed in the overburden aquifer but afterward exposed to a burn cavity by overburden subsidence, also showed the impact of pyrolysis products of gasification. Evidence of boron contamination was less dramatic in this overburden well than in those of the coal aquifer, reaching concentrations of only 500 micrograms per liter (ug/L) and then decreasing to Hanna III baseline values. Sulfide concentrations increased to above 10 mg/L, as in the coal aquifer, and remained elevated. Ammonia concentrations increased gradually from approximately 2 mg/L to over 35 mg/L and were last reported (1982) to have decreased to approximately 20 mg/L. Postburn data for phenols are inconclusive.

Leachate Products

Preburn and postburn leachate indicator parameters in ground-water samples from the Hanna III site are summarized in Table 8-4. The postburn concentration of total dissolved solids in the burn cavity ground waters increased from a preburn average of about 1,200 mg/L to a postburn average of 3,000 mg/L, with maximum concentrations of over 5,000 mg/L attained at Well Hanna III-7. After gasification, concentrations continued to increase slowly. Concentrations in the Hanna III wells remained above baseline when last reported in 1982.

Sulfate concentrations increased from a level of less than 50 mg/L to as high as 3,500 mg/L in Hanna III-7. Most other monitored wells exhibited a gradual increase in sulfide concentration with time.

Bicarbonate concentrations increased slightly from a baseline level of 1,100 mg/L to approximately 1,700 mg/L after gasification, and then

decreased rapidly to about 700 mg/L. Sodium concentrations increased gradually from approximately 500 mg/L to an average of 900 mg/L. A maximum concentration of 1,200 mg/L was attained at Hanna III-7. Manganese concentrations increased greatly after gasification to over 1,000 ug/L.

The ground waters also exhibited increases in fluoride concentrations after gasification. Well III-7 showed an initial increase to 7 mg/L followed by a gradual decrease to near baseline. At III-2, however, early postburn fluoride concentrations were observed upwards of 15 mg/L. Fluoride concentration in III-2 ground-water appears to have stabilized below 10 mg/L.

The concentration of total organic carbon in the cavity ground waters decreased from a level of approximately 45 mg/L to an average of 20 mg/L. All non-cavity wells showed no change in concentrations over time.

Well III-4 exhibited effects of leachate contamination similar to those of the wells originally completed in the coal. The total dissolved solids concentration of water from the well increased from approximately 1,900 mg/L to over 5,000 mg/L after gasification and in 1982 remained above 4,000 mg/L. Sulfate showed no apparent increase in concentration, while bicarbonate concentrations declined. Sodium concentrations increased from approximately 900 mg/L to over 2,000 mg/L with the rate of increase paralleling that of total dissolved solids. No increase in manganese concentration was observed. Fluoride exhibited a slight increase in concentration after gasification, peaking sharply at 25 mg/L during 1981, well above the baseline level of approximately

1.5 mg/L. Total organic carbon increased from approximately 15 mg/L to a peak of nearly 100 mg/L after gasification with a subsequent gradual decline (Permit 1 RD).

Plume Behavior

To exhibit the movement of pyrolysis products throughout the entire Hanna site over a 19-month period, boron and phenol concentrations were plotted over time by Schowengerdt (1985). These plots show that the plumes developed in all directions from the burn sites and were elongated only slightly in the downgradient (northwest) direction. Apparently, molecular dispersion or gaseous dispersion plays as significant a role in short-term migration as does advective transport.

Summary

An analysis of the impact of UCG processes on ground waters at the Hanna site is impeded by several flaws in the design and execution of the environmental monitoring program. Paramount is the lack of baseline data, especially for the wells outside the immediate areas of the burns. These wells showed many flat concentration versus time curves, though often at concentrations considerably above the reported Hanna III baseline data. Also common were single peaks of moderate intensity on otherwise flat curves. The potential impact of the addition of large volumes of foreign waters into the burn cavities is also very difficult to account for in the evaluation of general water quality character.

However, an analysis of cavity ground waters provides definitive qualitative evidence of the release of gaseous pyrolysis products and leachate development in the post-gasification environment.

Solubilized pyrolysis products were found in the gasification cavity. Greatly elevated levels of boron, sulfide, phenols, and ammonia were common in the coal cavities and in the exposed overburden above Hanna III. Several peripheral wells also exhibited increased concentrations of pyrolysis products. Maximum concentrations achieved for individual parameters are unknown due to the lapse of time between the completion of each experiment and the execution of each phase of the sampling program.

Increased concentrations of leachate products were ubiquitous in the gasification cavities. Total dissolved solids concentrations in the cavities rose two- to four-fold after gasification, and remain well above the presumed baseline. Increased concentrations of leachate components were also seen in several of the peripheral wells.

Past and Present Ground-Water Impacts

The Hanna No.1 coal aquifer has suffered adverse impacts as a result of the Hanna in situ coal gasification experiments. The ground water in the aquifer has become contaminated by a variety of organic pyrolosis product chemicals, and elevated concentrations of ionic species native to the water have resulted from the exposure of char and ash produced by the underground gasification. The operator of the Hanna gasification experiment has made no known efforts at ground water restoration.

At the present time, this contamination is not known to be having any effect upon the public health or welfare. Permitted wells downgradient from the experiment site are used only for monitoring purposes; there are no users of water from the coal aquifer in the area, ~~as the water's natural quality of the water is poor for most uses.~~ Contaminant plumes have been demonstrated to be moving away from the gasification area, however.

Prediction of Future Ground-Water Impacts

As mentioned, the Hanna site operator has made no effort to restore ground-water quality at the Hanna in situ coal gasification site. The operator may be required to make such efforts as part of future experiments, but it is not known if any restoration activities will be attempted for the purpose of removing ground-water contaminants resulting from past experiments. Potential future adverse environmental impacts resulting from the experiment are dependent upon the extent to which contaminants migrate to areas where they may be withdrawn by wells, or discharge to streams or springs.

The movement of ground water contaminant plumes, as established by earlier investigators, has been discussed briefly above. Those investigators have made no prediction of the ultimate fate of the ground-water contaminants, however. Mattox and Humenick (1980) described ground waters in the vicinity of an experimental burn in Texas as experiencing attenuation of organic contaminants to near background levels within one year after the burn. They attributed the attenuation

to adsorption of the organic contaminants onto the coal aquifer matrix and to biochemical conversion. These same mechanisms should influence the attenuation of organic contaminants at the Hanna site. Inorganic contaminants may slowly leach into the ground water for years and cause a very slow return to baseline conditions. Advective transport by the moving ground water is likely to be the most important means of migration, and precipitation, adsorption and ion exchange, along with dilution, will be the most important means of attenuation.

Restoration Techniques

Available aquifer-restoration techniques are limited to either ground-water sweeping similar to that employed at uranium ISL sites, or to physical containment of the burn-area ground water to prevent the migration of contaminants. Sweeping or flushing the area of the burn with ground water would entail the use of injection and recovery wells and above-ground treatment of the produced water prior to reinjection. Physical containment of the postburn ground water or isolation of the burn cavity and residuum from the ground-water system could entail conventional grout injection techniques on the periphery of the burn area or backfilling of the cavity with a low-permeability slurry.

On the scale commonly involved with experimental technology Class V well projects, either sweeping or isolation techniques would be economically and technically viable, because such projects are not profit oriented. In large-scale commercial applications, however, where large areas would be subjected to gasification, restoration by

ground-water sweeping would be the preferred alternative because the aquifer would be returned to a usable state rather than a nonproductive state as it would with the isolation alternative. The commercial ventures, however, would employ proven technology, and associated injection wells would not be covered by the Class V regulations.

Recommendations for Mitigation of Existing Ground-Water Pollution

It would be possible to improve the quality of ground water in the Hanna 1 coal aquifer, though it may not be possible to return the ground water to its preburn condition. A restoration program would have the beneficial effects of reducing the severity and areal extent of ground-water contamination, and reducing the likelihood that the contaminants may move large distances from the experimental area.

Restoration activities would probably have to be centered on removing contaminated ground-water from the gasification cavities. This could be accomplished using existing wells into the cavities, or using new wells developed expressly for this purpose. Water would have to be produced from the wells at a rate sufficient to develop local cones of depression at the cavities, in order to draw contaminated waters back into the cavities and ultimately out of the formation.

Hydrogeological investigations sufficient to define the appropriate pumping rates and locations would be necessary prior to initiation of pumping. It might be economically advantageous to pump contaminated ground water from wells outside the burn cavities, in addition to those in the cavities. Such wells could be located, or completed at depths so as to recover only the most heavily contaminated ground water.

Consideration would have to be given to adequate treatment of the contaminants at the surface. The polluted ground water could be placed into evaporation ponds lined with impermeable membranes, or treated by biological and/or chemical means to remove contaminants. It could then discharged to the surface or reinjected into the formation to effect a ground-water sweep.

Prevention of Ground-Water Pollution at Similar Sites

The first step needed to prevent long term ground-water pollution from occurring at sites similar to the Hanna in situ coal gasification site would be a requirement in the facility permit that ground-water restoration be performed. Such a requirement should be a feature of all permits for projects for in situ mineral recovery projects, regardless of size or ownership.

Restoration requirements should, of course, be base upon demonstrated techniques for achievement of the required restoration. To this end, applicants for permits for facilities such as the Hanna project should be required to present laboratory or pilot-scale test data supporting the viability their proposed restoration schemes.

In those situations where totally new mining and/or restoration technology is to be employed, WDEQ would be justified in limiting the size of proposed projects until restoration has been satisfactorily demonstrated. The agency has the authority to do this, and routinely does so for commercial uranium in situ mining sites.

SECTION 5.3.3

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	"Oil Shale In Situ Retorting (Experimental Technology)" Assessment of Class V Injection Wells in the State of Wyoming
AUTHOR: (OR INVESTIGATOR)	Western Water Companies
DATE:	September 1986
FACILITY NAME AND LOCATION:	Talley Energy Company Site (Sec. 17-T18N-R106W, Sweetwater County) and the DOE Rock Springs Site (Sec. 15-T18N-R106W, Sweetwater County), Wyoming USEPA Region VIII
NATURE OF BUSINESS:	Oil shale retoring

BRIEF SUMMARY/NOTES: During a span of ten years, eleven experiments were conducted at the Rock Springs site. The Tipton shale member of the Green River Formation was the unit in which all in situ experiments were conducted. The lithology and stratigraphy of this unit are nearly interchangeable between both areas.

Surface facilities consisted of air compressors, buildings containing control equipment, holding tanks, demisters, piping, wellhead, and repair and support equipment shops. Materials injected into the subsurface were: 1) explosives, including NGI, dynamite, and pelletized TNT; 2) water during hydraulic fracturing operations; 3) 10/20 and 6/8 mesh sand both during hydraulic fracturing and stemming in instrument wells; 4) propane for initial combustion; and 5) air injected into wells to sustain combustion during retorting experiments.

Observations of water quality from USGS records indicate that hazardous wastes from oil shale retorting experiments are generally located in wells at or very near the individual sites and that transport of such constituents has been at a relatively low rate. However, this data is not entirely consistent with DOE monitoring well data. The present study concludes that the Tipton Shale aquifer has suffered adverse impacts as a result of experimental retorting. Contaminants present as a result of organic pyrolysis include phenolic and polynuclear aromatic compounds.

CHAPTER 9

OIL SHALE IN SITU RETORTING (Experimental Technology)

Introduction

Two oil shale in situ retort sites were considered for assessment: the Talley Energy Company site, in Section 17, T18N, R106W, Sweetwater County, and the U.S. Department of Energy (DOE) Rock Springs site, in Section 15, T18N, R106W, also in Sweetwater County. Both experimental areas are included in the WDEQ/LQD Temporary Filing Number 1 1/222 permit. Initial work at the DOE site began in 1969 and continued over a span of 10 years. Eleven experiments were conducted within section 15. Although a considerable amount of retorting parameter data are available, hydrologic data are sparse because little ground-water monitoring was accomplished. The available data were screened and reduced by Smith and Weand (1977) and their reporting was concentrated on sites six and nine. None of their analyses included the parameters of ground-water flow; instead they concentrated on water quality.

All in situ oil shale retorting experiments were conducted in the Tipton Shale Member of the Green River Formation. A 40-foot zone of 22 gallons per ton oil shale at the top of the member was the primary target for the research. The lithology and stratigraphy of the Tipton Member in both areas is nearly interchangeable (Dana and Smith, 1972), the principal difference being the amount of overburden. This assessment discusses primarily the DOE site.

Since the Talley Energy area did conduct preliminary hydrogeologic investigations in the same aquifers used during the DOE experiment, some

discussion of their results is pertinent to the DOE experimental tract. In 1981, 1982, and 1983 the U.S. Geological Survey (USGS) undertook a ground water study of the general area where in situ retorting experiments had been conducted over a 10 year period from 1969 through 1979. The investigation included the drilling of 15 observation wells by the USGS and the use of 10 existing DOE wells. Although much of the data have not been placed in report form, one report on leachate transport has been generated and accepted for publishing in June 1986 (Glover, 1986).

Regional Geology of the Green River Formation

Regional Structure

The Green River Basin is located in the southwestern portion of Wyoming and extends into Utah. Contained within the basin are rock units of the Green River Formation. These units comprise oil shale, marlstone, claystone, siltstone and sandstone with minor thin beds of limestone and tuffs, and locally thick beds of trona or trona and halite. All were deposited in Gosiute Lake, which occupied the region during Eocene times.

The Green River Basin is an asymmetric structural basin whose deepest part is near the southern margin of the basin. Large scale faulting can be seen on the west, northeast and southern flanks of the basin and some small scale faulting is present southwest of Rock Springs. However, no faults are known to displace beds of the Green River Formation. In general the Green River beds are nearly flat, dipping less than one degree throughout the basin.

Stratigraphy

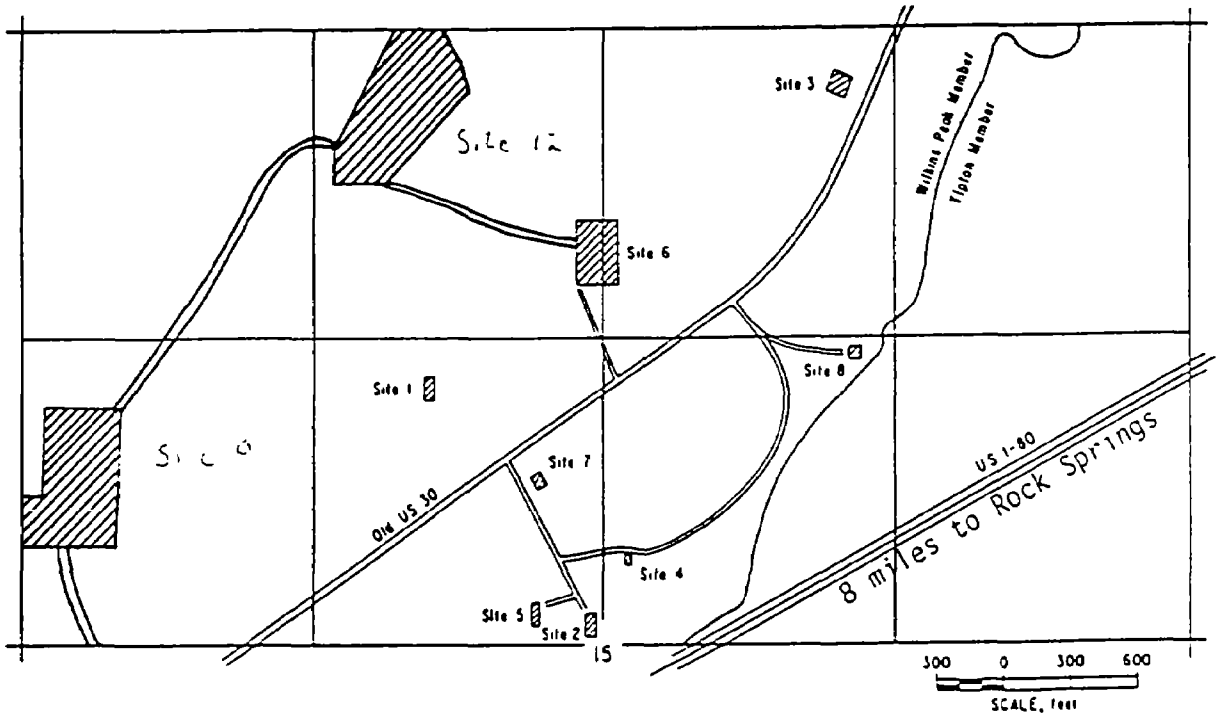
In most of the basin, the Green River Formation consists of the Tipton Shale Member, a basal oil shale unit; the Wilkins Peak beds; and the Laney Member, an upper oil shale and clastic unit (Culbertson, Smith, and Trudell, 1980). Of these, the Tipton is most important to this study because the in situ retorting experiments were conducted in its upper rich oil shale beds.

Site Hydrogeology

The 300-acre study area is located on the eastern flank of the Green River Basin, the extreme western slope of the Rock Springs Uplift (Figure 9-1). There are 11 sites in the study area from which experimental data are available. Geologic data to interpret the geologic framework of the study area were collected from test wells at each site.

Local Ground Water

Prior to the beginning of experimental activities at the DOE Rock Springs site, no hydrological testing was conducted to determine baseline conditions. Since no evidence of springs were found in or near the proposed site, the ground-water content of the subsurface was thought to be negligible. This assumption was further supported by the very low porosity and permeability of the oil shale. Furthermore, no significant faults and few fractures to act as ground water conduits exist at the site except for near-surface fractures produced by weathering.



Rock Springs Exploratory Sites, Sec 15, T 18 N, R 106 W.

Figure 9-1. Location of Oil Shale In Situ Retorting Sites Near Rock Springs (from WDEQ Files).

Three aquifers were found in the upper 200 feet of the Wilkins Peak and Tipton Members. These three aquifers were determined to be at depths of between 80 to 105 feet, from 120 to 140 feet, and between 160 and 180 feet at Site 9. Water was also found at a level of 300 feet from the surface at Site 6 and in a 900-foot Wasatch Formation well south of Site 9. Two of these aquifers lie above the oil-shale formation which was fractured and processed (burned). Leakage among the three aquifers before in situ processing of the oil shale is believed to have been minimal (Permit No. TFN 1 1/222).

At the DOE site, the USGS identified one aquifer in the Tipton Member of the Green River Formation (Glover, 1986). The Tipton aquifer is an 8-foot thick sandstone in the lower Tipton. The sandstone and its water are confined by overlying layers of oil shale and underlying strata consisting of a basal Tipton limestone and upper Wasatch shales and mudstones.

At the Talley Energy site, the USGS identified two aquifers; one in the uppermost Tipton (or lower Wilkin's Peak strata) at depths of 249 to 273 feet (above the target production zone), and the other in the middle Tipton at depths of 414-442 feet (below the target production zone) (Permit No. TFN 1 1/222). What water exists and does move in the subsurface, normally moves in the downdip and/or direction of decreasing gradient. Since the dip of the oil shale is west to southwest, the formation ground water is thought to move in that direction at a gradient less than the dip. An exception to this may be found in shallow alluvium, colluvium, and the weathered/fractured uppermost layers of bedrock at the site. Water level measurements made after the first successful experiment (Site 4) produced a variety of results in

comparatively closely spaced wells. These unconfined or semi-confined waters may migrate in directions other than downdip, probably towards local surface streambeds.

Thompson and Davis (1976) reported the results of tests conducted on 5 wells at the site. The transmissivity of the units penetrated ranged from 2.3 ft^2/day to 520 ft^2/day, hydraulic conductivity ranged from 0.01 ft/day to 5 ft/day, and storage coefficient ranged from 10^{-4} to 10^{-9}.

Ground-Water Quality

No baseline data are available for the DOE Rock Springs site because no hydrology studies were conducted prior to in situ retorting. However, studies were conducted in the same intervals at the Talley Energy site and water quality data are presented in Tables 9-1 and 9-2 for the upper and lower aquifers (Permit No. TFN 1 1/222).

In general these waters were found to be unacceptable for agricultural purposes due to naturally high concentrations of TDS and boron. In fact, the high TDS concentrations present difficult problems for nearly any potential use of this water. The water from tests in the upper aquifer (Wilkins Peak) is very poor quality, exceeding Class I, II and III standards in constituents including TDS, fluoride, chloride, ammonia, boron, cadmium, lead, manganese, and nickel. The water from the lower aquifer (Tipton) is much better water but exceeds Class I, II and III concentrations for fluoride and ammonia.

It should be noted in conjunction with these data that there were considerable differences in the water quality characteristics from one well to another, even though some wells were closely grouped. It is

Table 9-1. Baseline Water Quality in the Upper Aquifer, Talley Site (from WDEQ Files).

	Well 0-6		Well 0-5		Well 0-4		Average			Range	
Parameter[a]	4/11	4/13	4/11	4/13	4/11	4/13	0-4	0-5	0-6		
Na	11000	11000	23000	21000	11800	11500	11650	22000	11000	11000	230(
K	73	58	100	97	51	61	56	98	65	51	100
Mg	<0.1	<0.1	<0 1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	<0.1	<0.1	8.3	8.3	5.9	6.0	5.9	8.3	<0.1	<0.1	8.3
Total Cations	480.34	479 05	1003.4	916.33	514.86	502.08	508 47	959.8	480.15	479.95	100:
Cl	3900	3800	3700	3600	3600	3700	3650	3650	3850	3600	390(
Fl	52	52	91	95	58	46	52	93	52	46	95
Nitrate	<0 01	<0.01	0.02	0.02	0.02	0.02	0.02	0.02	<0.01	<0.01	0.0:
SO_4	493	617	130	110	1170	1730	1450	123	555	110	173(
CO_3	11200	10000	25200	22800	10900	10400	10650	23000	10600	10000	252(
HCO_3	930	3000	7300	6000	2800	2900	2850	6650	1965	930	730(
Phosphate	25	20	67	50	28	32	30	58	22	20	67
Total Anions	512.37	505 91	1073.77	968 77	539.06	538 02	538.50	1020.27	509.14	505.91	107:
NH_3	24	24	44	40	25	22	23	42	24	22	44
TDS	29500	28200	58700	52200	30100	29100	29600	55450	28850	28200	587(
Hardness	<0.1	<0.1	21	21	15	21	18	21	<0.1	<0.1	21
Total Alkalinity	19400	19100	48000	42000	20400	19700	20350	45450	19250	19100	4800
pH	9.97	9.88	10.01	10.00	9.93	9.93	9.93	10 00	9.92	9.88	10.0
Conductivity	31000	32000	49000	43000	34000	32000	33000	46000	33000	32000	490(

[a] Concentrations in mg/L except pH (std. units) and conductivity (umhos/cm).

Table 9-2. Baseline Water Quality in the Lower Aquifer, Talley Site (from WDEQ Files).

	Well 0-1		Well 0-2		Well 0-3		Average			Range	
Parameter[a]	4/11	4/13	4/11	4/13	4/11	4/13	0-1	0-2	0-3		
Sodium	510	550	430	410	640	640	530	420	640	410	640
Potassium	9 0	11.0	2.3	3.8	25	21	10.0	3.0	23	2.3	25
Magnesium	<0.1	<0.1	0.2	0.2	1.2	1.3	<0.1	0.2	1.2	<0.1	1.3
Calcium	6.1	6.0	2.9	3 3	6.4	6.1	6.0	3.1	6.2	2.9	6.4
Total Cations	22.71	24 40	18.91	18.10	28 9	28.79	23.60	18.45	28.85	18.10	28.9
Chloride	95	95	81	81	270	270	95	81	270	81	270
Fluoride	11	11	11	11	7.3	7.3	11	11	7.3	7.3	11
Nitrate	0.02	0.01	<0.01	0.01	0.04	0.01	0.02	<0.01	0.02	<0.01	0.04
Sulfate	44	27	1.8	<0.1	137	149	35	0.9	143	<0.1	149
Carbonate	140	160	130	140	190	220	150	135	205	130	220
Bicarbonate	860	880	840	850	850	840	870	845	845	840	880
Phosphate	<0 01	0.10	0.19	0.13	0 09	<0 01	0 05	0.16	0.05	<0.01	0.19
Total Anions	22.03	23.58	21.00	21.46	31.11	32.20	23.25	21.23	31.66	21.00	32.20
Ammonia	4.1	2.8	1.3	1.2	1.7	1.4	3.5	1.2	1.5	1.2	4.4
TDS	1420	1470	1230	1240	2000	1980	1445	1235	1990	1230	2000
Hardness	15	15	8.1	9.1	21	21	15	8.6	21	8.1	21
Total Alkalinity	940	990	900	920	1010	1060	965	910	1035	920	1060
pH	9.02	9.08	8.76	8.79	9 02	8.93	9.05	8.77	8.97	8.76	9.08
Conductivity	1800	1950	1700	1750	2900	2800	1875	1725	2850	1750	2900

[a] Concentrations in mg/L except pH (std. units) and conductivity (umhos/cm).

therefore apparent that the ground water quality in and around sites 6, 9, and 10 is quite variable and more difficult to assess than was anticipated by the operators.

Ground-Water Use

No water well permits are registered in the immediate vicinity of the DOE Rock Springs oil shale experimental area. A water well permit has been issued in the NW ¼ SW ¼ section 11, T18N, R106W for a future housing development consisting of a total of 478 proposed units (Wyoming State Engineer). The permit is for a well of a depth of 890 feet, far below the Green River formation. No other permits have been issued within a 1.5 mile radius of section 15. Section 11 is northeast and up dip from the experimental sites, and ground-water migration is not believed to be in that direction.

Description of Facilities

In situ retorting was conducted at only four of the experiment sites at the DOE Rock Springs area: sites 4, 7, 9, and 12. At least 8 Class V injection wells were installed and used at these sites. Figure 9-2 shows the well pattern for the initial retorting experiment at site 4, with the No. 5 well as the air injection well (Carpenter, et al., 1972). Figure 9-3 shows the injection and production wells at site 9 where Well No. 1 was the air injection well. Figure 9-4 shows the well pattern at site 12. No figure is provided for site 7 because it was a short-term (8 day) experiment involving only two or three wells during combustion. Each surface facility consisted of air compressors,

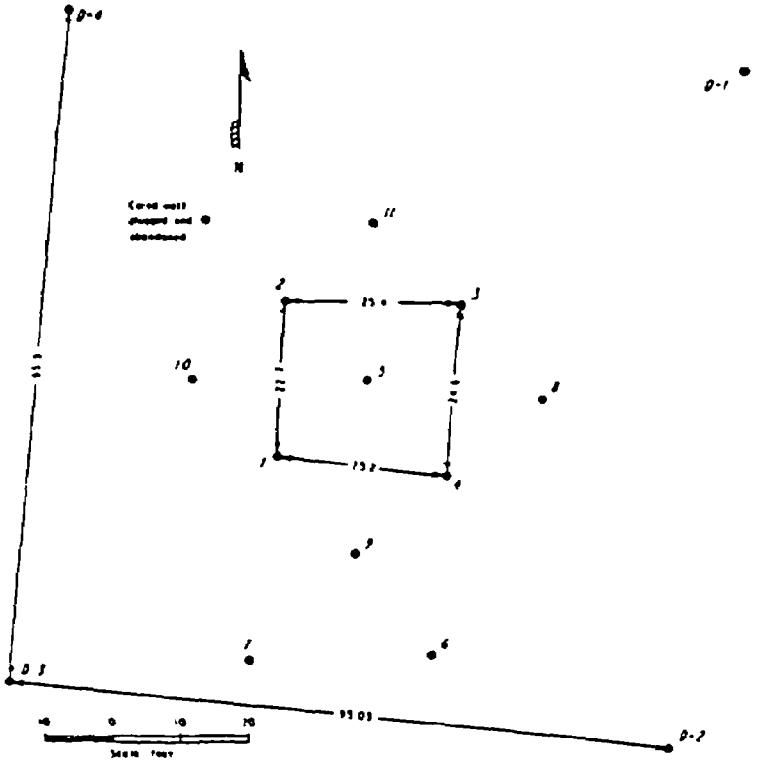


Figure 9-2. Well Pattern at the Site 4 Retorting Experiment (from Carpenter, et al., 1972).

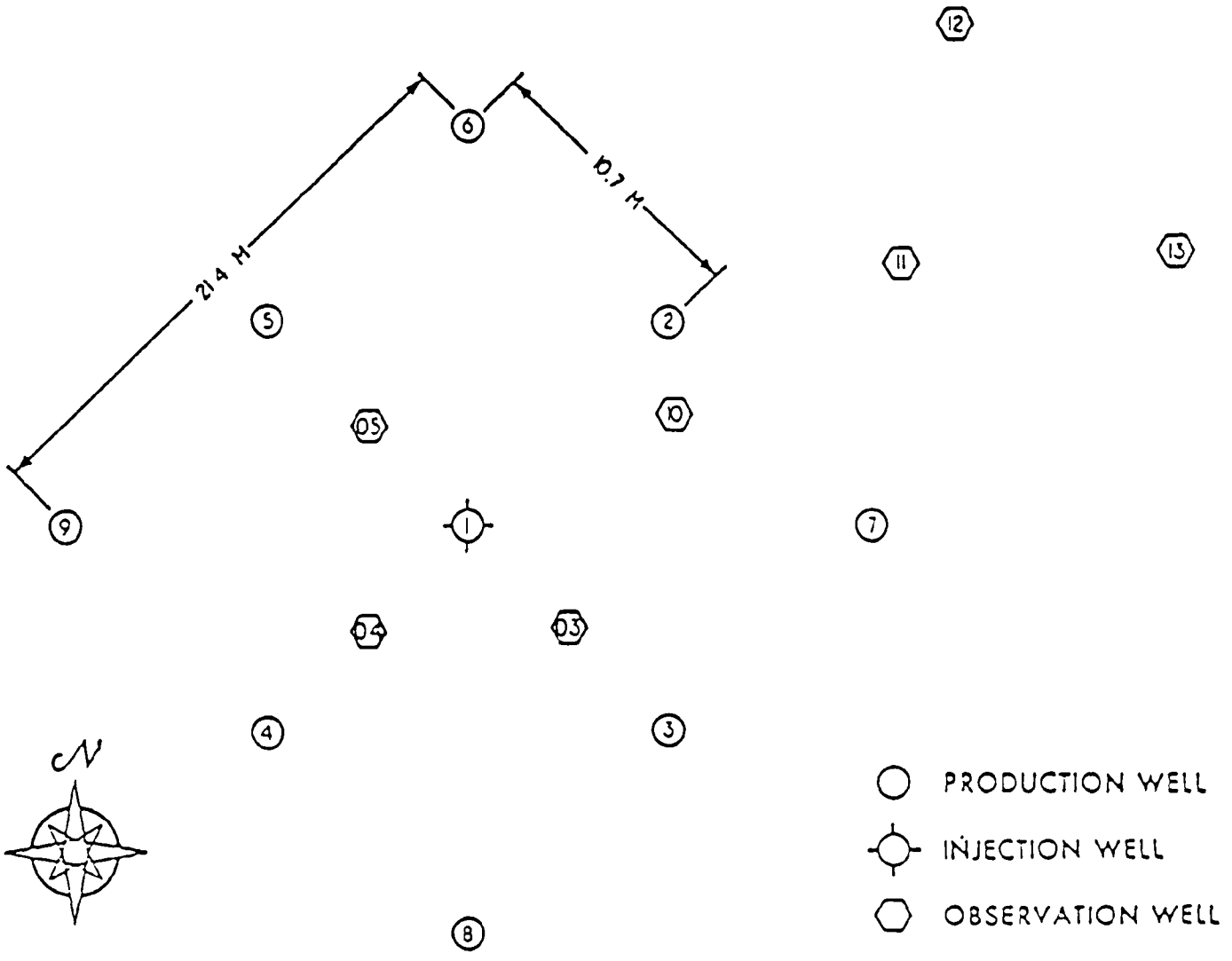


Figure 9-3. Well Pattern at the Site 9 Retorting Experiment (from WDEQ files).

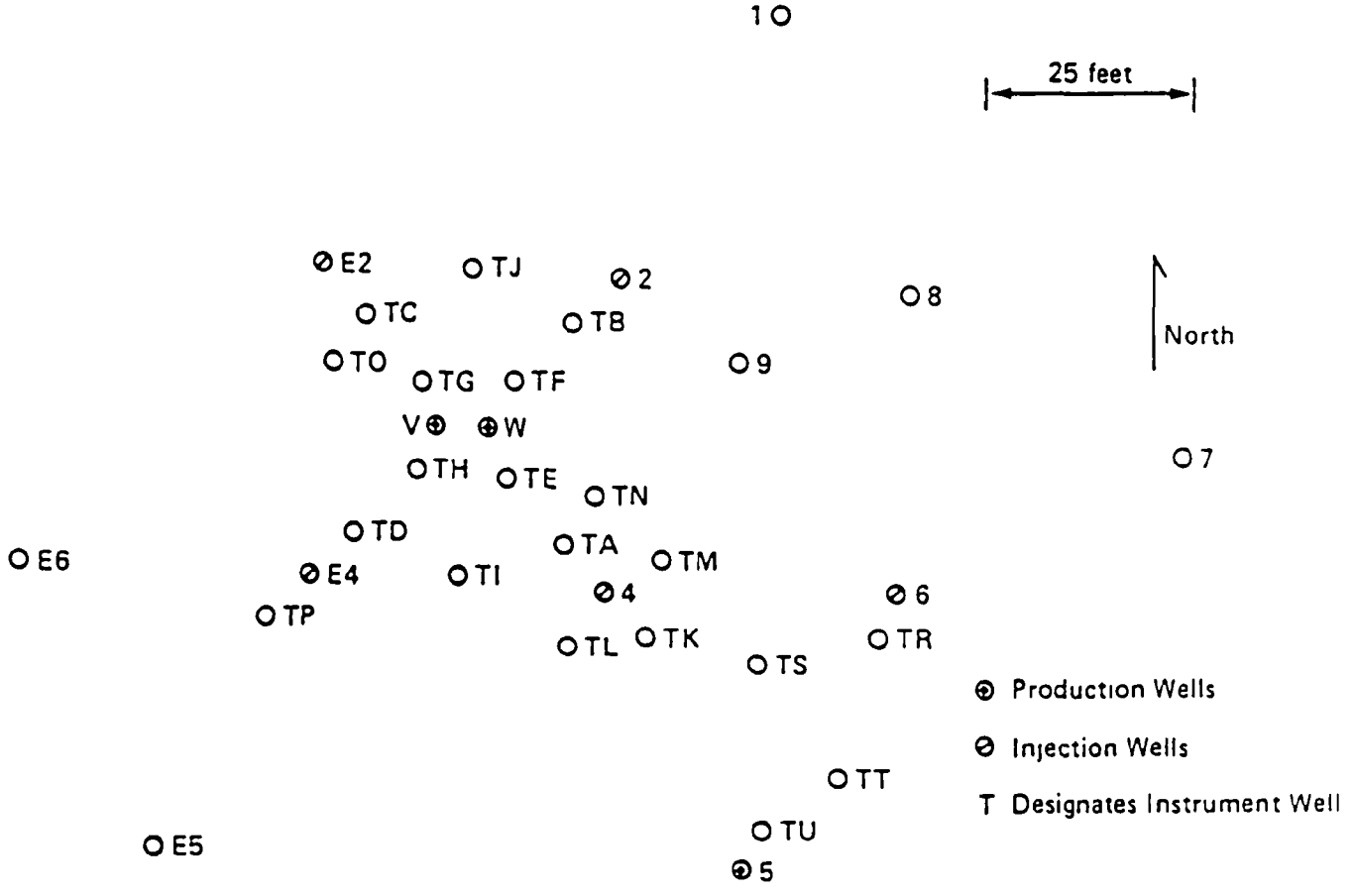


Figure 9-4. Well Pattern at the Site 12 Retorting Experiment (from Long, et al., 1980).

buildings containing control equipment, holding tanks, demisters, piping, wellhead, and repair and support equipment shops. During 1980 and 1981 all facilities were removed with the exception of the water monitoring wells.

Since the wells in each retorting pattern were involved with high temperature operations, the wells were completed by using high-temperature cement with 50% silica flour to cement the annulus from bottom to top. All production/injection wells used 7 to 8.6 inch steel casing and were cased to the top of the target production zone which was left as open hole. Observation wells constructed by DOE and Talley Energy used 4- to 6-inch steel casing. Details of construction for the USGS water monitor wells are not yet available.

Operational History

The DOE conducted operations at the Rock Springs site over a period of 10 years from 1969 to 1979. Although the DOE conducted 11 of 13 planned experiments associated with various phases of in situ research, only 3, (sites 4, 9, and 12) were successful in attaining subsurface retorting and are summarized here. Six other experiments (1, 2, 3, 5, 6, and 7) involving the use of injection wells for hydraulic and/or explosive fracturing were conducted between 1969 and 1977.

Materials injected into the subsurface were; 1) explosives, including NG (a liquid explosive), dynamite, and pelletized TNT; 2) water during hydraulic fracturing operations; 3) 10/20 and 6/8 mesh sand placed in the subsurface both during hydraulic fracturing and as stemming in instrument wells; 4) propane, for initial combustion for heating the oil shale; and 5) air, injected into wells to sustain

combustion during retorting experiments. During the experiments, about 190 quarts of liquid explosive and from 350 to 7500 pounds of pelletized TNT, each at different sites, were pumped into wells designed for fracturing of oil shale and wells designed for fracturing and retorting oil shale.

Hydraulic fracturing both with and without sand for propping fractures was conducted in the upper Tipton zones. Explosives were injected and detonated to increase fracture frequency at Site 4. The combustion phase of the test was initiated April 23 and was terminated on June 3, 1969, a period of 41 days. Approximately 30,200 gallons of oil was produced at Site 4,of which 8,000 gallons was recovered above ground (Carpenter, et al., 1972). The remainder was left in place underground.

The experiment at site 9 was a larger version of the Site 4 tests and was conducted at a greater depth. Subsurface fractures were created by both hydro/sand fracing and explosive fracturing. The experiment was run for a period in excess of 150 days in 1976, recovering 2,483 gallons of oil or about 1 percent of the oil shale reserves in the 40-foot Tipton zone (Long, et al., 1977) at Site 9.

At Site 12, a series of experiments were conducted between 1977 and 1979 in a 21 foot zone of the upper Tipton member that was hydraulically and explosively fractured. After 3 retorting attempts, combustion was achieved but could not be sustained beyond 10 days. No oil was recovered at the surface.

The most recent ground-water investigation, conducted by the USGS from 1981 to 1983, included water-quality analyses from 25 postburn observation wells downgradient from most of the experiment sites. Table

9-3 and Figure 9-5 provide locations and completion data for the 25 wells. Table 9-4 presents the ranges of common constituents and trace elements.

Some postburn water quality sampling was initially conducted prior to 1977. The available data for the DOE experimental oil-sale sites 6, 9, and 10 near Rock Springs were analyzed by Smith and Weand (1977). Most observation wells sampled at these three research sites showed very high TDS levels, with sodium usually representing over 98 percent of the cations. In most instances sulfate proved to be the most abundant anion, although carbonate and chloride levels were generally high also. No evidence indicates migration of the constituents into surface waters.

In studying contaminant transport in the DOE experiment area, the USGS selected thiocyanate as a non-hazardous indicator to detect migration away from the experiment sites. Thiocyanate was located as a plume migrating south and southwest to a distance of about 1/2 mile from site 9. It was predicted to discharge at the surface in late 1985 or early 1986 at a peak concentration of 45 mg/L. (Glover, 1986).

Observations of quality of water from USGS records indicate that hazardous wastes from oil shale retorting experiments are generally located in wells at or very near the individual sites and that transport of such constituents has been at a relatively slow rate. However, the quality analyses from the USGS and DOE monitoring wells vary greatly, affirming that transport may be occurring to the west or southwest.

The Tipton shale aquifer has suffered adverse impacts as a result of the Rock Springs in situ oil shale gasification experiment in that the ground water in the aquifer has become contaminated by a variety of

Table 9-3. Monitoring Well Completion Information, DOE Rock Springs Site (from WDEQ Files).

Well #	Owner	Depth	Completed Formation
9T-1	USGS	191	Tipton
9T-2	USGS	75	Tipton
9T-3	USGS	147	Tipton
9T-4	USGS	202	Tipton
9T-5	USGS	202	Tipton
9T-6	USGS	202	Tipton
9T-7	USGS	350	Wasatch
9T-8	USGS	450	Wasatch
9T-9	USGS	1020	Wasatch
9T-10	USGS	200	Tipton
9T-11	USGS	200	Tipton
9T-12	USGS	180	Tipton
9T-13	USGS	200	Tipton
9T-14	USGS	350	Wasatch
9T-15	USGS	160	Tipton
6-203	DOE	152	Tipton
9-11-01	DOE	227	Tipton
9-8	DOE	206	Tipton
9-4	DOE	170	Tipton
9-1	DOE	169	Tipton
9-D	DOE	900	Wasatch
9-E	DOE	174	Tipton
9-5	DOE	239	Tipton
12-4A	DOE	342	Tipton
12-4B	DOE	90	Wilkens Peak

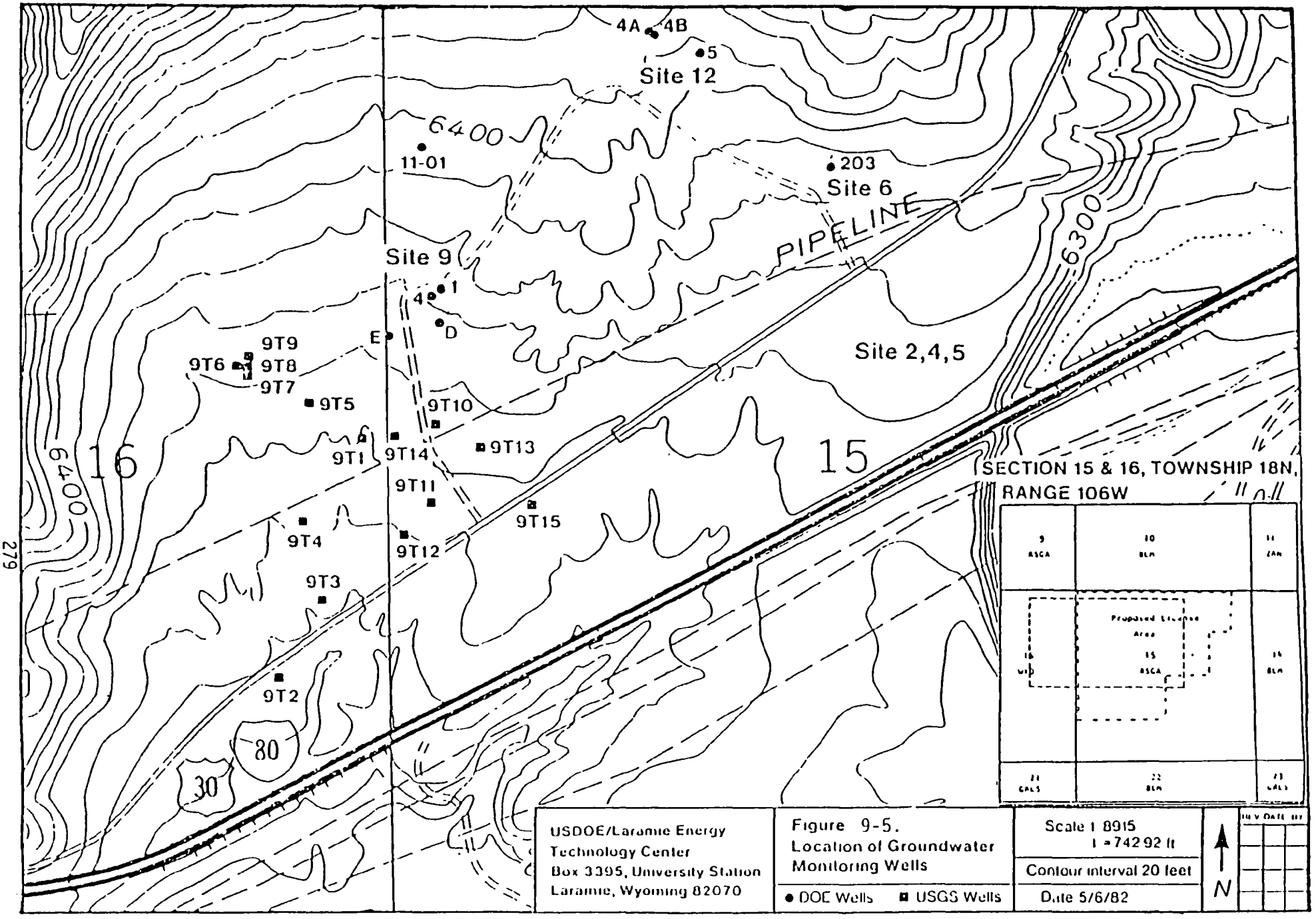

4A
4B
5
Site 12
6400
11-01
203
Site 6
PIPELINE
6300
Site 9
1
4
E
D
9T9
9T6
9T8
9T7
9T5
Site 2,4,5
9T10
9T1
9T14
9T13
16
15
6400
9T11
9T15
9T4
9T12
9T3
9T2
80
30
SECTION 15 & 16, TOWNSHIP 18N, RANGE 106W
USDOE/Laramie Energy Technology Center
Box 3395, University Station
Laramie, Wyoming 82070
Figure 9-5.
Location of Groundwater Monitoring Wells
● DOE Wells ■ USGS Wells
Scale 1 8915
1 = 742 92 ft
Contour interval 20 feet
Date 5/6/82
N

Table 9-4. Summary of Baseline Water Quality and Postburn Water Quality at the DOE Rock Springs Oil Shale In Situ Gasification Site (from WDEQ Files).

Parameter	Upper Aquifer	Lower Aquifer	Postburn Range
Conductivity (umhos)	32,000 - 49,000	1,750 - 2,900	1,610 - 5,400
pH (units)	9.88 - 10.01	8.76 - 9.08	7.8 - 12.0
TDS	28,200 - 58,700	1,230 - 2,000	875 - 50,600
Fluoride	46 - 95	7.3 - 11	0.3 - 130
Calcium	<0.1 - 8.3	2.9 - 6.4	0.2 - 29
Magnesium	<0.1	<0.1 - 1.3	<1 - 160
Sodium	11,000 - 23,000	410 - 640	360 - 18,000
Sulfate	110 - 1,730	<0.1 - 149	1.5 - 2,700
Chloride	3,600 - 3,900	81 - 270	38 - 7,900
Nitrate	<0.01 - 0.02	<0.01 - 0.04	
Ammonia	22 - 44	1.2 - 4.4	0.1 - 180
Arsenic	0.01 - 0.11	<0.01 - 0.04	<0.001 - 0.25
Barium	0.3 - 0.5	0.1 - 0.4	<0.1 - 0.43
Boron	8 - 11	0.9 - 1.4	0.9 - 840
Cadmium	0.06 - 0.11	<0.01	<0.001 - 0.005
Copper	0.2 - 0.5	0.3 - 1.4	0.002 - 0.055
Chromium	0.05 - 0.08	0.03 - 0.05	<0.001 - 0.015
Iron	0.6 - 3.5	4.8 - 12	
Lead	0.4 - 8.1	0.7 - 1.3	
Manganese	<<0.09 - 0.13	<<0.11 - 0.25	
Mercury	0.001	<0.001	
Nickel	0.3 - 0.7	<0.01 - 0.05	
Silver	0.03 - 0.06	0.01	
Zinc	0.2 - 0.9	0.8 - 4.9	

organic pyrolysis product chemicals. These chemicals include phenolic and polynuclear aromatic (PNA) compounds. Such chemicals generally render water non-potable when present in milligram per liter quantities, due to the tastes and odors they impart to the water. In addition, several of the PNAs are known or suspected carcinogens.

At the present time, this contamination is not known to be having any effect upon the public health or welfare. There are no direct users of water from the Tipton aquifer in the immediate area, as the water is naturally of very poor quality. The USGS is continuing to study the movement of contaminant plumes away from the gasification area.

Prediction of Future Ground-Water Impacts

The Rock Springs site operator has made no effort to restore ground-water quality at the Rock Springs in situ oil shale gasification site. There are no known plans to conduct any future additional experiments or ground-water monitoring or restoration activities, other than the USGS investigation, at the Rock Springs site. Potential future adverse environmental impacts resulting from the experiment will depend upon the extent to which contaminants migrate to areas where they may discharge to surface streams, most likely Bitter Creek. No contamination of Bitter Creek has been detected, but monitoring of the creek has not been regularly, or recently, performed.

The USGS thiocyanate contaminant plume study, when published, may reveal the extent of the threat of surface discharge of contaminants generated by the gasification experiment. Such studies, however, are

probably the only way to assess the threat posed to ground waters and to the public health and welfare by the contaminants generated in the Tipton shale aquifer by the experiment. Adequate modeling of the aquifer is not possible without far more data on the flow regime in the aquifer. The hydraulic characteristics of the aquifer appear to be very strongly dependent upon local fractures, and the aquifer as a whole shows characteristics too heterogeneous to be modeled using the limited data available.

Lacking any better method of predicting future impacts of the experiment, a worst case approach must be utilized. The assumptions assumed for this case are as follows:

1. Contaminated ground water in the Tipton Shale aquifer at the DOE Rock Springs in situ oil shale gasification experimental site will eventually discharge to Bitter Creek, via the alluvium beneath that stream.
2. The Tipton Shale will afford no natural attenuation in the concentration of the contaminants in the aquifer.
3. Movement of the contaminants through the aquifer is slow, as evidenced by the apparent failure of the contaminants to move more than approximately 1,000 feet from Site 9 to monitoring well 91-1, during the 84 months which elapsed between the Site 9 gasification experiment and the conclusion of USGS monitoring efforts. It is assumed that the rate of contaminant movement, and ultimate discharge from the aquifer, is 150 feet per year.

4. The wetted front of the contaminant plume is assumed to be 100 feet wide (the distance between wells 9-6 and 9-8); and 21 feet thick (the thickness of the experimental burn zone). This is an area of 2,100 square feet.
5. The fracture porosity of the Tipton Shale is 0.10. This figure is speculative, and has therefore been chosen to give a worst case result.
6. The concentration of methylnaphthalene in the contaminated aquifer water when it reaches Bitter Creek will be 3,000 ug/L.

Using these assumptions, a discharge of 0.001 cfs of contaminated water from the Tipton aquifer can be calculated. A value of 5 cfs has been assumed as the reasonable minimum flow in Bitter Creek at this location. This results in the conclusion that Bitter Creek, during periods of low flow, will be contaminated with 1.7 ug/L of methylpyridine resulting from the in situ oil gasification experiments. This does not pose an immediate threat to public health (particularly considering the poor quality of Bitter Creek water), but it would be a measurable adverse impact on the environment.

Recommendations for Mitigation of Existing Ground-Water Pollution

It is not certain that any measures can be taken to alleviate long term pollution of the ground waters affected by the Rock Springs oil shale in situ gasification experiments. Ground water in the affected aquifer(s) flows almost exclusively in the extensive fractures in the host rock, but the contaminants are probably spread throughout the affected portion of the formation. As a result, contaminants will

probably be released very slowly from the blocks of formation rock lying between the fractures. It does not appear that there is any practical way to remove all the contaminants from these blocks.

One alternative to prevent migration of the contaminants out of the experimental area would be the construction of barriers such as slurry cut-off walls or grout curtains to prevent the movement of uncontaminated ground water into this area. The practicality of this measure is open to question due to the difficulty of guaranteeing the performance of such a barrier over a long period of time.

Additional efforts to define the actual extent of contamination might be useful. Such activities could help determine if there is any risk to surrounding property owners or the public from surfacing pollutants.

Prevention of Ground-Water Pollution at Similar Sites

As stated in the case study for the Hanna in situ coal gasification experiment, ground-water restoration should be included as a requirement of all permits for projects for in situ mineral recovery projects, regardless of size or ownership. Such a requirement should be imposed regardless of any anticipated lack of ground water impact. In those situations where totally new mining and/or restoration technology is to be employed, WDEQ would be justified in limiting the size of proposed projects until restoration has been satisfactorily demonstrated.

In addition, permit applications should contain sufficiently thorough information to be able to determine not only the presence or

absence of ground water in a proposed in situ mining zone, but also the quantity and quality of such water.

Summary

Explosives and ignition agents, frac sand and air were injected into at least 8 Class V injection wells at the Rock Springs oil shale in situ retorting experiments conducted between 1969 and 1979. Injection was into oil shales in the Tipton Member of the Green River Formation, in an area that contains few, if any, productive aquifers. No baseline hydrologic information was collected prior to the experiments, and only sporadic monitoring was performed until the USGS conducted a 3-year study between 1981 and 1983.

The monitoring showed that at least two aquifers exist above the retorted zones. The upper aquifer contains very poor quality water having dissolved solids in the range of 28,000 to 59,000 mg/L. The lower aquifer contains water that contains 1,200 to 2,000 mg/L dissolved solids and generally meets Wyoming Class III water-quality standards. Neither aquifer has significant permeability, and neither is known to yield water to any permitted wells in the vicinity of the experiment site.

Retorting produces a variety of ground-water contaminants which include organic and inorganic pyrolysis products and leachate. The USGS investigation has shown that in the 7 years that elapsed between in situ retorting and the initiation of their monitoring, a contaminant plume has migrated little more than one-half mile from the retort sites. The aquifer in the intervening area has been contaminated, but was not

classified as a sensitive aquifer even prior to the experiments. The most significant threat appears to be contamination of surface waters and alluvial aquifers by discharge of contaminated ground water.

Review of other oil shale areas in Wyoming indicates that there are geologic and hydrologic settings similar to the Rock Springs site. Very little shallow ground water is present, and most of that is of very poor quality. Consequently, the impacts of in-situ retorting, particularly at the experimental scale to which Class V injection wells are limited, are not likely to be significant. Future experiments, however, should be required to include hydrologic investigations adequate to determine in detail the occurrence, quality, and movement of ground water prior to, during, and after the experiment is conducted.

SECTION 5.3.4

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Rio Blanco Oil Shale Company MIS Retort
AUTHOR: (OR INVESTIGATOR)	Rio Blanco Oil Shale Company
DATE:	September 30, 1983
FACILITY NAME AND LOCATION:	Rio Blanco Oil Shale Company Federal Prototype Oil Shale Lease Tract C-a Colorado, USEPA Region VIII
NATURE OF BUSINESS:	Oil Shale Retorting

BRIEF SUMMARY/NOTES: The company proposes to abandon the two modified in situ (MIS) retorts tracts in the following manner:

1. Pump existing water out of retorts
2. Allow retorts to flood completely
3. Recirculate water through retort to leach most of soluble material from the rubble
4. Pump all leachate from the retorts and product collection system
5. Flood retorts
6. Monitor groundwater in area around retorts until it has been determined than an unacceptable migration of harmful substances is not likely to be detected in the monitoring wells adjacent to the retorts.

RIO BLANCO OIL SHALE COMPANY

MIS RETORT ABANDONMENT PROGRAM

SEPTEMBER 30, 1983

RETORT ABANDONMENT PROGRAM

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RETORT ABANDONMENT PROGRAM

1.0 Introduction

The Rio Blanco Oil Shale Company (RBOSC) has developed a plan for the abandonment of the modified in situ retorts on Federal Prototype Oil Shale Lease Tract C-a. This proposal is submitted to the Bureau of Land Management, Branch of Oil Shale in accordance with the conditions of approval for the Revised Detailed Development Plan dated September 22, 1977.

1.1 Abstract

RBOSC proposes to abandon the two modified in situ retorts on Tract C-a in the following manner:

- Pump existing water out of retorts
- Allow retorts to flood completely
- Recirculate water through retort to leach most of soluble material from the rubble
- Pump all leachate from the retorts and product collection system
- Flood retorts
- Monitor groundwater in area around retorts until it has been determined that an unacceptable migration of harmful substances is not likely to be detected in the monitoring wells adjacent to the retorts

The criteria for cessation of monitoring are spelled out in the proposal.

1.2 Executive Summary

A plan for the abandonment of the modified in situ retorts on Tract C-a has been developed in accordance with the stipulations attached to the approval of the Revised Detailed Development Plan dated September 22, 1977.

Several retort abandonment scenarios were evaluated before selecting the proposed plan.

- o Flood retorts and monitor
- o Leach by circulation followed by flood retorts and monitor
- o Flood retorts, leach by circulation, pumpdown, flood, and monitor
- o Pumpdown, flood, leach by circulation, pumpdown, flood, and monitor
- o Continuous retort pumping
- o Grout retort rubble
- o Curtain grouting around retorts

Based on experience since the end of retort operation, laboratory research, and hydrologic modeling the Pump - Flood - Leach - Pump - Flood - Monitor option was selected for Tract C-a MIS retort abandonment. The grouting options are potential fallback solutions should the proposed monitoring program demonstrate the need for such action.

An extensive groundwater monitoring program is planned. Daily, weekly, and monthly sampling and analysis activities are an integral part of the monitoring program. Specific inorganic and organic substances have been selected as indicators of leachate migration from the retorts. Response and termination criteria are also presented.

SECTION 5.3.5

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	MIS Retort Abandonment Program - June 1986 Pumpdown Operation
AUTHOR: (OR INVESTIGATOR)	Rio Blanco Oil Shale Company, Inc.
DATE:	September 1986
FACILITY NAME AND LOCATION:	Rio Blanco Oil Shale Company Federal Prototype Lease Tract C-a Colorado, USEPA Region VIII
NATURE OF BUSINESS:	Modified In Situ (MIS) Retorting Technology

BRIEF SUMMARY/NOTES: In 1980 and 1981, Rio Blanco conducted two experiments using MIS retorting technology. This report summarizes the operations and results of the second pumpout phase of MIS retort abandonment, conducted in June 1986.

Retort water was discharged to evaporation ponds or storage tanks for subsequent transfer to evaporation ponds. Nearly 15 million gallons of fluid was pumped. No discharge to surface streams occurred. An extensive monitoring program was conducted for the pumpout operation to track operations and evaluate program effectiveness.

Maximum drawdown in the retort system was about 65 feet. Monitoring well data indicated that the pumpout operation resulted in significant improvement of water quality within the retorts. Specific conductance declined from 2600 to 1900 micromhos after pumpout. TDS levels declined, and pH values decreased from greater than 9 to 8.5. Dissolved organic carbon concentrations were also reduced. Water quality in near-retort monitor wells showed minimal effect from the pumping operation.

MIS RETORT ABANDONMENT PROGRAM
JUNE 1986 PUMPDOWN OPERATION

REPORT TO:
BLM/Oil Shale Projects Office

RIO BLANCO OIL SHALE COMPANY, INC.

SEPTEMBER 1986

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1. SUMMARY

In 1980 and 1981, Rio Blanco Oil Shale Company conducted two experiments using a modified in situ (MIS) retorting technology. These experiments were conducted on Federal Prototype Lease Tract C-a. This report summarizes the operations and results of the second pumpout phase of MIS retort abandonment, conducted in June, 1986. The first pumpout operation was completed in June, 1985 and was summarized in a report to BLM in September, 1985.

The initial MIS retort abandonment operations included complete flooding of the retort system for a period of approximately one year (May 1984 through mid-May 1985). The main objective of the program was to remove soluble materials from the retort system. In May 1985, the retort system was pumped to remove these saline waters to lined evaporation ponds. During the 1985 operation, the mine water system was pumped concurrently to protect the bulkheads which separate the mine and retort systems and to minimize the inflow of fresh ground water into the lower part of the retort system. From observations of ground water inflow and water levels during the 1985 pumpout, Rio Blanco concluded that the retort system could be pumped alone without incurring these problems.

Following the 1985 operation, the water levels in the vicinity of the MIS retorts returned to pre-pumping levels and remained as such until the June 1986 operation. During the 1986 pumpout, only the retort system was pumped, although capacity to pump the mine system was maintained for use if needed. All water pumped from the retort system was again discharged to lined evaporation ponds.

This report summarizes the 1986 pumpdown operation and evaluates the effectiveness of the operation for retort cleanup and abandonment. Previous data and reports to the U.S. Bureau of Land Management/Oil Shale Projects Office (BLM/OSPO) have evaluated pre-pumpdown conditions. Detailed monitoring data listings have also been submitted to the BLM/OSPO and are not included in this report.

Retort water was discharged to evaporation ponds or to temporary storage in tanks for subsequent transfer to the evaporation ponds. Nearly 15 million gallons were pumped from the retort system. No retort water was discharged to surface streams. Pumping of the mine water system to control water levels was not required.

An extensive monitoring program was conducted for the pumpout operation in order to track operations (e.g. water levels and flows) and to evaluate the effectiveness of the flooding/pumpout operation (e.g. water quality).

The retort system was pumped at a rate of about 420 gallons per minute for the first three days, starting on June 2, 1986. The pumping rate was then increased to about 1050 gallons per minute for the duration of the operation, which terminated on June 13. The water pumped from the retort system represents about 2 pore volumes and about 3 pore volumes for the MIS retorts alone. The retort system was pumped until the tanks were full and the evaporation pond system was filled to 90 percent of total capacity. Since the start of the abandonment program, approximately eight pore volumes have been pumped through the retorts and about 190 tons of dissolved salts have been pumped from the retorts into the evaporation ponds. An additional 245 tons of dissolved salts were pumped from the retort system prior to the 1985 pumping program.

Upper Aquifer well D-5 was also pumped (about 1.2 million gallons) during the pumpout operation to refill the west pond which is the domestic water source for the tract.

Because of the reduced pumping relative to the 1985 operation, the drawdown of the upper aquifer and the cone of depression were more limited. The maximum drawdown in the retort system was about 65 feet. As expected, the cone of depression was somewhat elliptical in shape and oriented to the northwest - southeast direction. The cone of depression did not extend significantly beyond the tract boundary.

As measured in the RAM-7 monitor wells, located within Retort 1, and in the discharges of retort pumps, the 1986 pumpout operation resulted in

significant improvement in the water quality within the retorts. In the RAM-7 wells (excluding RAM-7A which was plugged), the specific conductance declined from about 2600 micromhos per cm before the pumpout to about 1900-2000 after the pumpout. The TDS in RAM-7 was less than 1500 mg/l in post-pumpout samples. The pH also decreased to about 8.5 from 9 or more. The increasing trend in salinity observed in the retort system for a short period after the 1985 pumping operation has not yet been observed following the 1986 operation. Dissolved organic carbon concentrations were also reduced by the 1986 pumpout.

Water quality in near-retort monitor wells showed minimal effect from the pumping operation.

The 1986 pumpout operation was successful in simplifying the operations by pumping only the retort system. This resulted in greater ease of operation and no surface discharges or reinjection of mine water. Also significant progress was made in improving the water quality within the retort system.

SECTION 5.3.6

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Groundwater Pollutants from from Underground Coal Gasification (UCG)
AUTHOR: (OR INVESTIGATOR)	M. J. Humenick and C. F. Mattox
DATE:	December 18, 1977
FACILITY NAME AND LOCATION:	Not Applicable
NATURE OF BUSINESS:	Not Applicable

BRIEF SUMMARY/NOTES: This impact of UCB on local groundwater quality is addressed in this research. Soviet studies on large UCG projects indicate that groundwater contamination from these operations persists up to five years after the projects are terminated. Concentrations of organics, ammonia, sulfate, and TDS were found to exceed drinking water standards during a field study of Texas utilities. Apparently most inorganic contaminants are extracted by groundwater intrusion from the ash in the burn zone. The impact of groundwater quality as a function of time and distance from the burn is site specific. The rate of water transport is a function of local hydraulic gradients, strata permeability, and structure discontinuities. Conclusions of this study are:

1. The impact of UCG on groundwater is a function of the local subsurface environment, and can be minimized by careful site selection.

2. Major pollutants include polynuclear and phenolic organic compounds, ammonia, sulfate, calcium and hydroxide. The source of inorganic pollutants is primarily ash leachate, and the source of organics and ammonia is primarily condensed vapors.

3. Pulverized lignite appears to have a higher capacity for sorption of pollutants than either of the two clay seams.

4. Adsorption of organics by clay and lignite is an effective removal mechanism, however, some TOC may be nonadsorbable.

5. The transport of inorganic cations is strongly affected by ion exchange.

6. Anions exhibited less interaction with clay and lignite.

GROUNDWATER POLLUTANTS FROM UNDERGROUND COAL GASIFICATION

MICHAEL J HUMENICK and C FLETCHER MATTOX

The University of Texas at Austin Department of Civil Engineering, Austin TX 78712 U S A

(*Received* 18 *December* 1977)

Abstract—The purpose of this study was to determine the contaminants released to groundwaters as a result of the underground gasification of lignite, and determine the ability of surrounding strata to moderate the impact. Groundwater pollutants principally arise from ash leachate and condensed vapors in surrounding strata. Ash was found to yield sulfate, calcium, and hydroxide while condensed vapors contributed organics and ammonia as major changes to water quality. The organics consisted of mostly polynuclear aromatic hydrocarbons. Phenols were not major organic components. Lignite and clay strata were studied to determine their ability to sorb the groundwater contaminants. Both types of strata were effective in sorbing organics and ammonia. The behavior could be described by Freundlich isotherms. Divalent cations were released by ion exchange with monovalent cations. Anions had little affinity for the strata. Relatively little migration of ammonia and most of the organics was predicted as compared with calcium, sulfate, and some non-sorbable organics.

INTRODUCTION

The impact of underground coal gasification (UCG) on the local environment is potentially damaging. Of the possible impacts, the effect of UCG on local groundwater quality is addressed in this research because it is the least understood and, perhaps, the most significant concern in the process' implementation. Documentation exists in the literature and from current projects that pollutants are released to groundwaters when normal flow returns to a post gasification zone.

Soviet studies (Kononov, 1964) on large-scale UCG projects have revealed that groundwater contamination resulting from gasification persisted up to five years after production had ceased. There were other reports (Klimentov, 1963) stating that phenols were found within another aquifer in Russia which extended over an area of 10 km^2.

During a small field study of Texas utilities in 1976 it was found that after gasification and intrusion of groundwater back into the burn cavity, water samples taken from the cavity contained an array of pollutants which are summarized in Table 1. Of concern were the high concentrations of organics, ammonia, sulfate, and total dissolved solids (Edgar *et al.*, 1977). All of these parameters exceed concentrations acceptable for drinking water supplies. While the increase in overall mineralization was approximately tenfold, excessive release of trace metals did not occur. Laboratory studies by several investigators on representative media similar to that remaining underground after gasification have indicated the source of these pollutants (Campbell & Washington, 1976; Humenick, 1976; Henry, 1976). Apparently most of the inorganic contaminants are extracted by groundwater intrusion from the ash in the burn zone after gasification. Organics and ammonia are deposited in the surrounding strata by condensation from cooling gases during gasification.

After determining the type and amount of pollutants released to groundwater by UCG it is then necessary to determine their fate. The pollutants will exhibit chromatographic transport away from the burn cavity in the direction of ground water flow.

Table 1. Water quality changes after gasification

Parameter	Before, mg l^{-1}	After mg l^{-1}
Ca^{2+}	20	200
Mg^{2+}	5	15
Na^{+}	100	300
HCO_3^-	300	500
CO_3	2	0
SO_4^{2-}	4	1150
H_2S	0·02	0·4
Cl^-	30	40
F^-	0·1	0·7
NO_3^-	—	2·0
NH_3	1·0	100
TDS	350	2300
Phenols	0·1	2·0
TOC	20	200
Volatile dissolved solids	—	300
CN^-	—	<0·01
CNS^-	—	<0·5
CH_4	0·42	0·16
pH	—	7·6
As	—	<0·01
Ba	—	<1
Cd	—	<0·01
Cu	—	<0·1
Cr (total)	—	<0·05
Mn	—	0·07
Hg	—	0·002
Se	—	<0·01
Ag	—	<0·05
Zn	—	<0·1
B	—	0.3

Table 2. Water used in sorption studies

	Preparation	NH_3-N	TOC
Type I Water	100% Burn cavity water	50mg l^{-1}	47mg l^{-1}
Type II Water	88% Burn cavity water 12% Condensate 250 mg l^{-1} NH_4Cl	200mg l^{-1}	174mg l^{-1}
Type III Water	85% Burn cavity water 15% Condensate	170mg l^{-1}	287mg l^{-1}

The impact on groundwater quality as a function of time and distance from the burn's site specific. The rate of water transport is a function of local hydraulic gradients, strata permeability, and structural discontinuities. The chromatographic nature of migration is determined by the adsorption–desorption, precipitation–dissolution and ion exchange reactions with the strata. In addition other mechanisms such as filtration, chemical reactions and anaerobic biochemical activity will influence pollutant transport. A significant body of literature from related fields is already available that is concerned with the transport of inorganic materials such as ammonia, sulfate, most other common anions and cations along with heavy metals (Grove & Wood 1977, Wood 1977, Pinder 1973, Lai & Jurinak 1972). However little information is available on the sorption effects towards the type of organics that will be released.

This paper investigates the physical and chemical phenomena which will affect the transport of UCG pollutants in the underground environment.

METHODS AND MATERIALS

To evaluate the behavior of organics and ammonia in the surrounding strata, actual groundwater samples from a UCG site were used in the study. Gross organic concentrations were determined by total organic carbon (TOC) analysis, while specific organics were identified by gas chromatography–mass spectrometry (GC–MS). Ammonia was determined via the Technicon Autoanalyzer.

Inorganic materials released during UCG were evaluated by a laboratory procedure. Residues from the gasification process were simulated by preparing representative samples of coal char and ash. All media were prepared from pulverized lignite which passed a 16 mesh screen. Ash was prepared by heating the pulverized coal to about 700°C in an open furnace for 12 h. Char was prepared through pyrolysis in a nitrogen atmosphere at 700°C for about two hours. These residues were then contacted with a water approximating the local natural groundwater quality. The contacting was performed batchwise with varying amounts of residue in 250–500 ml of water. The samples were placed on a shaker table at 20°C for 72 h. The samples were then filtered and the filtrate analyzed for major inorganic ions and TOC.

To evaluate the sorptive capacity of the surrounding three strata were tested: clay above the lignite, clay below the lignite and lignite. In each case increasing amounts of media were allowed to equilibrate with a sample of contaminated groundwater. Again samples were shaken for 72 h at 20°C, then filtered and analyzed for inorganic ions and TOC.

Sorption experiments were performed on three different types of contaminated groundwater, two of which were prepared in the laboratory to evaluate a wide range of concentrations for ammonia and TOC. These samples were prepared by spiking water taken from a burn cavity with condensate from the product gas. The composition of three types of water is shown in Table 2.

All samples of coal, clay and contaminated water used were obtained from Texas Utilities lignite mines and gasification site near Fairfield, Texas. All chemical analysis except GC–MS were performed in accordance with the 14th edition of Standard Methods or approved EPA methods.

RESULTS

Sources of pollutants

A GC–MS analysis performed by the EPA lab in Houston, Texas provided a qualitative measure of the types of organic pollutants released during gasification. Figure 1 shows a GC–MS trace of a sample taken from an uncontaminated observation well.

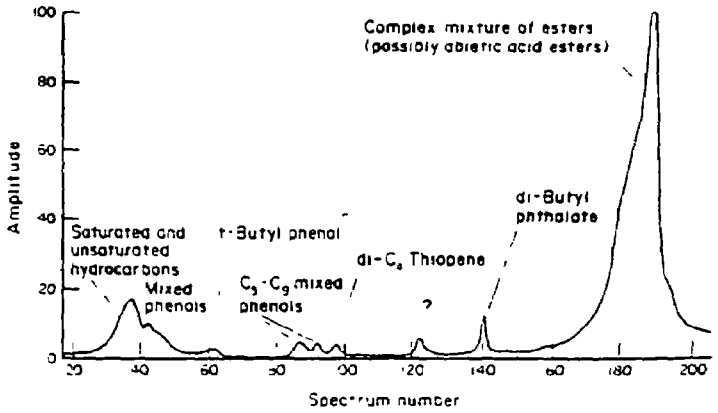

Fig. 1. GC–MS analysis, baseline contamination.

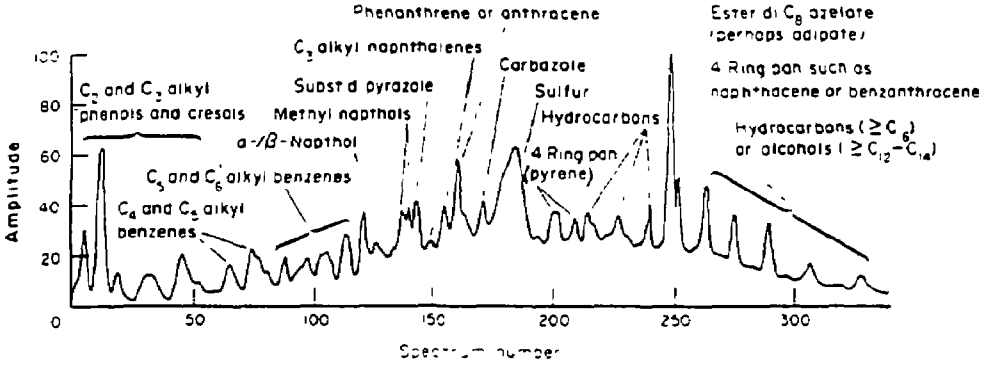

Fig. 2. GC–MS analysis contamination after gasification

These organics may represent baseline levels prior to gasification. The relatively high proportion of phenols in this sample is indicative of nearby lignite deposits. Figure 2 is a GC–MS trace of a groundwater sample taken directly from a burn cavity. The organics in this trace are identified by broad classes of compounds and undoubtedly many more specific compounds could be identified with increased GC resolution. A large proportion of the burn cavity organics are polynuclear aromatic hydrocarbons (PAH). Phenols constitute only a small portion of the total organics in the burn cavity.

The nature of the inorganic pollutants from the leachate of the gasification residue was studied through extraction experiments summarized in Table 3. Ash was the major source of inorganic pollutants, primarily sulfate, calcium and hydroxide. Compared to the ash, char and coal had little effect on the groundwater quality. It should be noted that under conditions of the laboratory experiments, a significant amount of TOC was released from the lignite which explains why the baseline water quality included fairly high organic concentrations.

The data shown in Table 3 indicate a decrease in calcium and sulfate with increasing amounts of ash. A similar trend with calcium and alkalinity is seen in the char extractions. Precipitation of calcium sulfate and calcium carbonate may explain these phenomena. It should also be re-emphasized that the prepared gasification residues contribute insignificant amounts of ammonia and in the case of char and ash little TOC. Thus the major source of ammonia and TOC must be condensed gases produced during gasification.

Sorption capacity of strata

Organics. Sorption isotherms for organics were prepared from batch equilibrium data in three separate tests. Tests I, II, and III were performed using different proportions of burn cavity water and above-ground condensate as indicated in Table 2. All tests showed the surrounding media to have capacity to sorb organics. Figures 3–5 show the data plotted as Freundlich isotherms.

It is apparent that the sorption characteristics of the organics in Test III were significantly different

Table 3. Leachate extractions of gasification residues

Residue gm l^{-1}	pH units	Alkalinity mg l^{-1} $CaCO_3$ total	Alkalinity mg l^{-1} $CaCO_3$ phenophthalein	$SO_4^{=}$ mg l^{-1}	Cl^- mg l^{-1}	Na^+ mg l^{-1}	Ca^{++} mg l^{-1}	Mg^{++} mg l^{-1}	K^+ mg l^{-1}	NH_3-N mg l^{-1}	TOC mg l^{-1}
						Ash					
192	10 1	144	96	1450	60	42 4	564	1 0	4 7	0 34	6 3
94 1	9 7	104	64	1700	48	37 0	585	2 4	3 8	0 17	6 3
54 7	9 1	48	20	2020	48	34 6	660	1 8 8	3 2	0 20	6 9
blank	7 8	184	0	25 5	34	33 4	22 4	23 8	2 5	—	6 9
						Char					
75 7	9 6	31	10	50	184	25 8	20 2	3 2	—	0 14	6 9
37 8	9 7	65	15	42	88	31 1	9 4	17 4	—	0 15	6 9
18 5	9 15	104	7	37 5	65	32 0	6 4	23 2	—	0 11	7 6
blank	8 45	196	5	30	33	31 7	19 0	26 6	—	0 12	12
						Lignite					
68 1	6 55	144	0	420	44	44 4	85	62	—	2 2	107
35 0	6 75	131	0	220	67	38 4	67 5	39	—	1 4	60
17 6	7 1	127	0	110	37	34 5	26 5	24	—	0 4	35
blank	8 45	196	5	30	33	31 7	19 0	26 6	—	0 12	12

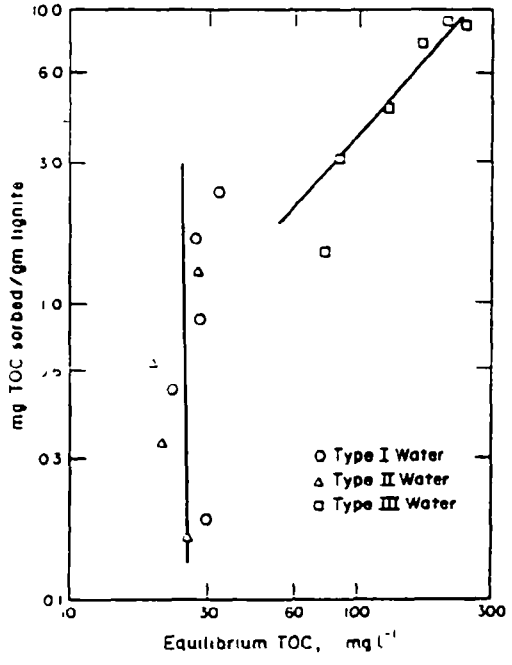

Fig. 3 TOC isotherm lignite

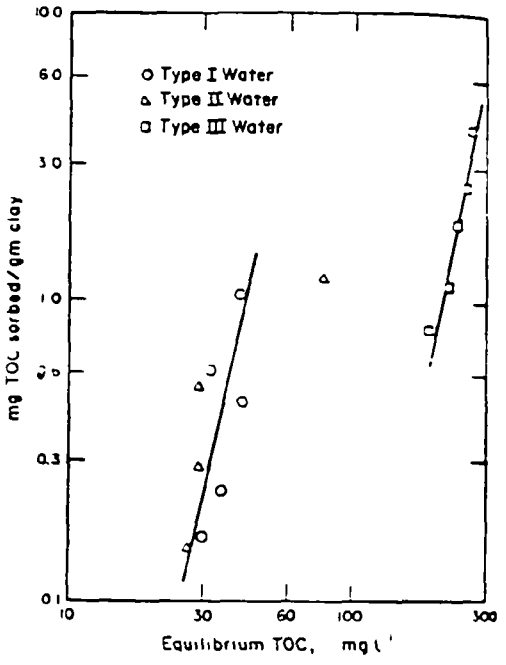

Fig. 4 TOC isotherm clay above lignite

than those in Tests I and II Type III water (used in Test III) contained the largest fraction of condensed organics and the data indicate these compounds may be less adsorbable than those found in the burn cavity Analysis of the lignite isotherm and the clay isotherms for Type III water indicates lignite was a more efficient sorbent than either of the clays, which are almost identical

A fraction of the organics may be nonadsorbable. For example, Fig. 3 shows that none of the tests were able to lower the equilibrium TOC concentration below about 25 mg l^{-1} Future work is directed toward identifying the specific organics which are not sorbed

Inorganics Although accurate characterization of ion exchange behavior requires the determination of selectivity coefficients for the exchanging ions, the distribution of solute species between solid and aqueous phases can also be described by the use of sorption isotherms. For the purposes of the paper, adsorption isotherms were used to approximate and identify the ion exchange behavior

Table 4 summarizes the results from one of the sorption experiments on Type II water The data indicate that cation exchange occurs with all strata The divalent cations, calcium and magnesium, are released from the solid phase concomitant with an uptake of monovalent cations (sodium potassium, and ammonia) from the liquid phase Of special significance is the uptake of ammonia by lignite and clay Freundlich-type isotherms for the uptake of monovalent cations are shown in Figs 6–8 for Type I and II waters.

Inorganic anions exhibited less interaction with the media than the cations Chloride and sulfate concentrations remained essentially constant throughout all tests. These ions may be considered conservative solutes, and therefore will have relatively high groundwater mobility

Alkalinity species (bicarbonate and carbonate) decreased with increasing ratios of media to water, especially lignite These data are explained by the probable precipitation of calcium carbonate, neutralization of alkalinity by surface acidic groups on lignite, and some ion exchange

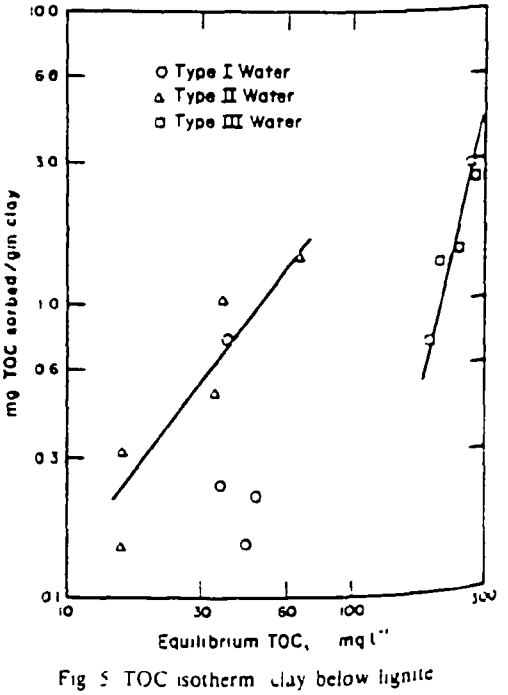

Fig. 5 TOC isotherm clay below lignite

Table 4 Test II isotherms

Sorbent gm l	pH units	Alkalinity mg l^{-1} $CaCO_3$	SO_4 mg l^{-1}	Cl mg l^{-1}	Na mg l^{-1}	Mg mg l	Ca mg l^{-1}	K mg l^{-1}	NH_3-N mg l^{-1}	TOC mg l^{-1}
				Clay seam below lignite						
1030	7 9	424	438	195	142	770	101	207	34	161
507	7 8	520	430	240	145	660	616	254	58	161
278	8 0	472	430	260	153	616	416	270	78	346
132	8 05	520	415	220	164	456	334	285	92	357
73 5	8 05	626	428	380	175	380	590	311	136	679
0	8 35	718	365	220	185	158	220	377	208	176
				Lignite						
896	7 7	326	400	225	122	625	198	167	30	268
447	8 0	306	400	180	129	485	125	197	48	214
222	7 9	298	410	205	137	376	930	218	68	196
109	7 7	356	410	270	173	286	710	260	96	286
57 5	7 85	416	410	200	164	228	566	290	122	—
0	8 2	662	365	200	182	158	260	367	200	184
				Clay seam above lignite						
972	8 05	270	423	395	128	660	102	173	32	268
502	8 2	364	438	185	129	635	740	218	42	286
264	8 1	406	405	210	142	560	866	245	126	286
129	8 25	530	443	210	175	508	394	295	108	429
75 0	8 30	514	405	200	167	396	424	295	136	304
0	8 3	728	388	•	182	166	237	372	192	163

• Value suspect, probable analytical error

Groundwater mobility of solutes

The distribution coefficient, k_d, is a useful parameter in comparing the relative groundwater mobility of various solutes. The distribution coefficient is defined as the ration of the solute in the solid phase to that in the liquid phase

$$k_d = \frac{\text{mg solute adsorbed/kg media}}{\text{mg l}^{-1} \text{ solute in solution}}$$

The higher the distribution coefficient, the less mobile the solute. In general, the distribution coefficient is a function of the nature of the solid and solute and the equilibrium concentration of the solute.

Figure 9 shows the distribution coefficients for the data taken in this work. In all cases pulverized lignite is a more efficient sorbent than the clay. This does not imply pollutant migration is greater in clay for two reasons. First, clay is a much more effective hyd-

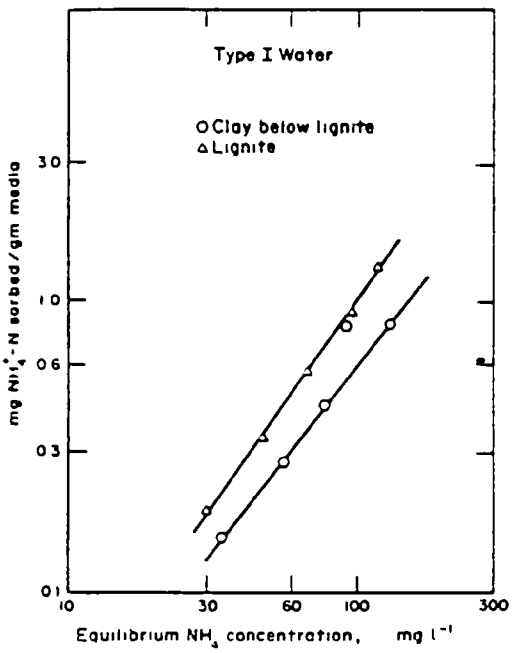

Fig. 6 Ammonia isotherm.

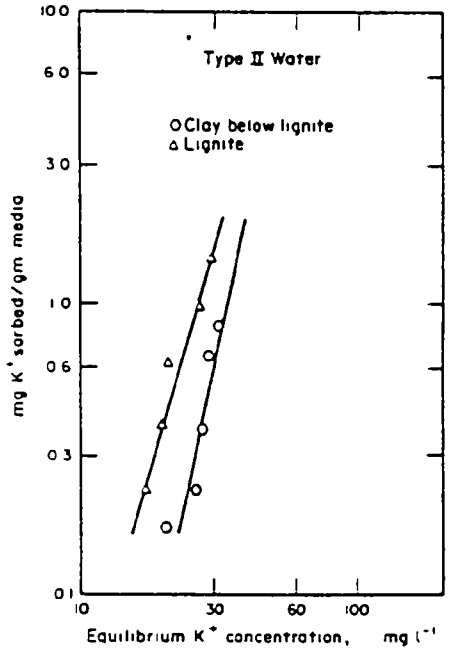

Fig. 7 Potassium isotherm

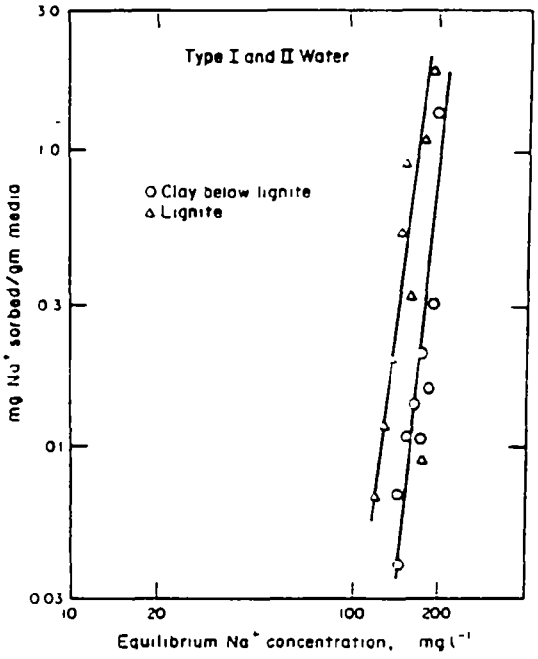

Fig. 8. Sodium isotherm

rological barrier than lignite. Groundwater velocities are greater in the more permeable lignite strata. Second, lignite surface area available for sorption is increased through pulverization, while that of the clay is unaffected by laboratory preparation. Field surface area must be correlated to laboratory surface area before rates of pollutant migration in lignite strata can be predicted.

It is also apparent that organics were among the least mobile solutes studied, while conservative anions such as chloride and sulfate and the divalent cations calcium and magnesium are among the most mobile solutes.

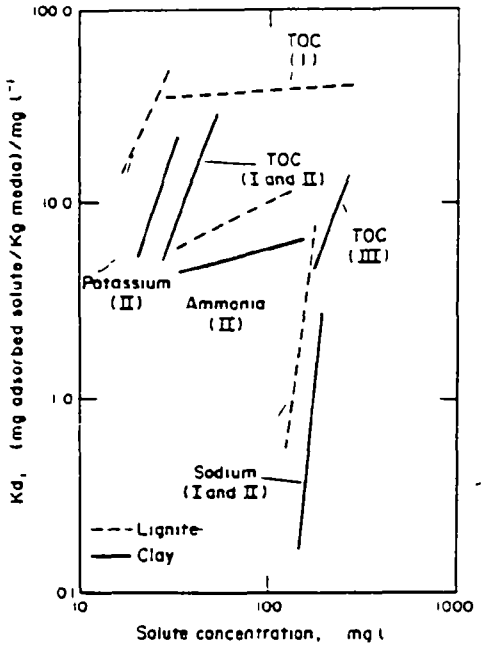

Fig. 9. Distribution coefficients for TOC, ammonia, potassium and sodium.

CONCLUSIONS

1. The impact of UCG on groundwater quality is potentially damaging. It is a function, to a large extent, of the local subsurface environment, and can be minimized by careful site selection.

2. Major groundwater pollutants resulting from UCG include polynuclear and phenolic organic compounds, ammonia, sulfate, calcium and hydrogen. The source of inorganic pollutants is primarily the leachate, while the source of organics and ammonia is primarily condensed vapors.

3. For all all solutes studies, pulverized lignite has a higher capacity for sorption of pollutants than either of the two adjacent clay seams.

4. Adsorption of organics by clay and lignite is an effective removal mechanism, however some TOC may be nonadsorbable.

5. The transport of inorganic cations is strongly affected by ion exchange. Divalent cations were consistently released from clay and lignite and replaced by monovalent cations. Ammonia was significantly sorbed by lignite and clay.

6. Anions exhibited less interaction with clay and lignite. Chloride and sulfate may be considered conservative ions with respect to sorption. Alkalinity decreased upon contact with lignite, and to a smaller extent with clays.

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Section 5.4

Spent Brine Return Flow Wells Supporting Data

SECTION 5.4.1

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	From Final Design for Arkansas' Class V Injection Well Inventory and Assessment
AUTHOR: (OR INVESTIGATOR)	Arkansas Department of Pollution Control and Ecology (ADPC&E)
DATE:	September 1985
FACILITY NAME AND LOCATION:	Arkansas, USEPA Region VI
NATURE OF BUSINESS:	Not Applicable

BRIEF SUMMARY/NOTES: Brine disposal injection wells are those used to inject spent brine into the same formation from which it has been withdrawn after extraction of the halogens. These wells comprise the majority of potential Class V wells in Arkansas. Seventy wells of this type are inventoried for Arkansas, and all are located in the southern counties of Columbia and Union. Four major companies own and operate all the wells.

The Arkansas Oil and Gas Commission (AO&GC) dictates construction requirements for these wells, and the State has concluded that these requirements are adequate. Most wells have approximately 60 feet of conductor casing, 500 to 1000 feet of surface casing, 8000 feet of long string casing, and 2000 to 8000 feet of injection tubing. Tubing is either set with a packer and fluid-filled annular space, cemented, or set with no packer with an open annular space. Most wells are open hole completions.

New brine disposal wells should be constructed with slight modification of AO&GC specifications, according to ADPC&E. To ensure protection of USDW, wells must be constructed so as to prevent fluids from escaping into untargeted formations through leaks in tubing, packer, and casing, or due to faulty cement. New construction requirements are specified in the report.

The study indicates that because of the structural simplicity of the area in which injection of brines is occurring and that the integrity of the confining beds is very good, the potential impact of these wells on USDW is negligible if wells are constructed and operated properly. At the present time, ADPC&E is planning a more comprehensive sampling of Class V waste streams and also a more complete development of background data on chemistry of the original brines and injection formations.

TYPES OF CLASS V INJECTION WELLS WITH POTENTIAL FOR USE IN ARKANSAS

Brine Disposal Injection Wells

Brine disposal injection wells are wells used to inject spent brine into the same formation from which it was withdrawn after the extraction of the brine's halogens. Brine disposal injection wells comprise the majority of Class V wells with potential for use in Arkansas. Therefore, most of the emphasis of this inventory assessment is devoted to Class V brine disposal wells. Please bear in mind during the review of this assessment that the authority over Class V brine disposal injection wells is dominated by the AOSGC and that this report consists largely of suggestions as to how the ADPC&E feels that all aspects of Class V brine disposal injection wells should be regulated.

Seventy Class V brine disposal injection wells exist in Arkansas, all of which are located in Columbia and Union Counties in south Arkansas. The ownership and operation of these wells is divided among four companies. These companies are: Arkansas Chemicals, Incorporated; Dow Chemical USA; Ethyl Corporation; and Great Lakes Chemical Corporation. Arkansas Chemicals Incorporated owns and operates three Class V brine disposal injection wells in the Newell Field of Union County. Dow Chemical USA is responsible for eleven Class V brine disposal injection wells in the Kilgore Lodge Field of Columbia County. Ethyl Corporation is responsible for twenty-seven Class V brine disposal injection wells in the Kerlin Field of Columbia County. Great Lakes Chemical Corporation is responsible for twenty-nine Class V brine disposal injection wells between its three plants. Great Lakes South Plant operates six wells in the Catesville field of Union County. Great Lakes El Dorado Plant is responsible for thirteen wells in the El Dorado South field of Union County and Great Lakes West Plant is responsible for ten wells in the Wilks, Garner Creek and Schuler Fields of Union County.

Potential Non-brine Class V Injection Wells

Class V Injection wells with potential for use in Arkansas are listed below:

1. Air conditioning return flow wells - wells used to return to the supply aquifer the water used for heating or cooling in a heat pump;

   a. Open-loop - water for the system is exposed to the atmosphere and potentially mixed with foreign substances between the supply and return wells;
   b. Closed-loop - water for the system is not exposed to the atmosphere and not mixed with any foreign substances between the supply and return wells;

2. Cooling water return flow wells - wells used to inject water previously used for cooling;

   a. Open-loop - water for the system is exposed to the atmosphere and potentially mixed with foreign substances between the supply and return wells;
   b. Closed-loop - water for the system is not exposed to the atmosphere and not mixed with any foreign substances between the supply and return wells;

3. Drainage wells - wells used to drain surface fluid, primarily storm runoff, into a subsurface formation;

4. Dry wells - wells used for the injection of wastes into a subsurface formation;

5. Recharge wells - wells used to replinish the water in an aquifer;

6. Sand backfill and other backfill wells - wells used to inject a mixture of water and sand, mill tailings or other solids into mined-out portions of subsurface mines whether what is injected is a radioactive waste or not;

7. Subsidence control wells - wells used to inject fluids into a non-oil or gas producing zone to reduce or eliminate subsidence associated with the over draft of fresh water. These wells are not used for the purpose of oil or natural gas production;

8. Radioactive waste disposal wells - wells used for the injection of radioactive wastes;

9. Experimental wells - injection wells used in experimental technologies; and

10. Injection wells for in situ recovery of lignite, coal, tar sands and oil shale.

These definitions, for the most part, were derived from 40 CFR 146.05(d).

The Department has recently received requests for permission to operate several types of Class V wells other than brine disposal injection wells. The Arkansas Electric Cooperatives Incorporated received a state water permit to construct and operate two closed-loop cooling water return flow wells in the first half of 1985. A schematic diagram of this type well system is found in Figure 3. The ADPC&E also received a request in January, 1985 for permission to reenter an abandoned oil production well and convert it to a drilling fluid disposal well. This type of well would be classified by the Department either as a Class V experimental or dry well, or some sort of Class II injection well. The person making this request has not made any further attempts toward obtaining a permit since his meeting with the Department in January, 1985. The ADPC&E received another request from an oil company for permission to inject the contents of the reserve pit for a deep well drilled for gas production which resulted in a dry hole. The Department granted this company permission to inject the drilling fluid from the reserve pit into a particular formation in the well after a geologic evaluation of the request was completed. The company agreed to plug the well after injection according to the plugged regulations of the AO&GC. This type of well is also classified by the ADPC&E as either a Class V experimental or dry well, or some sort of Class II injection well.

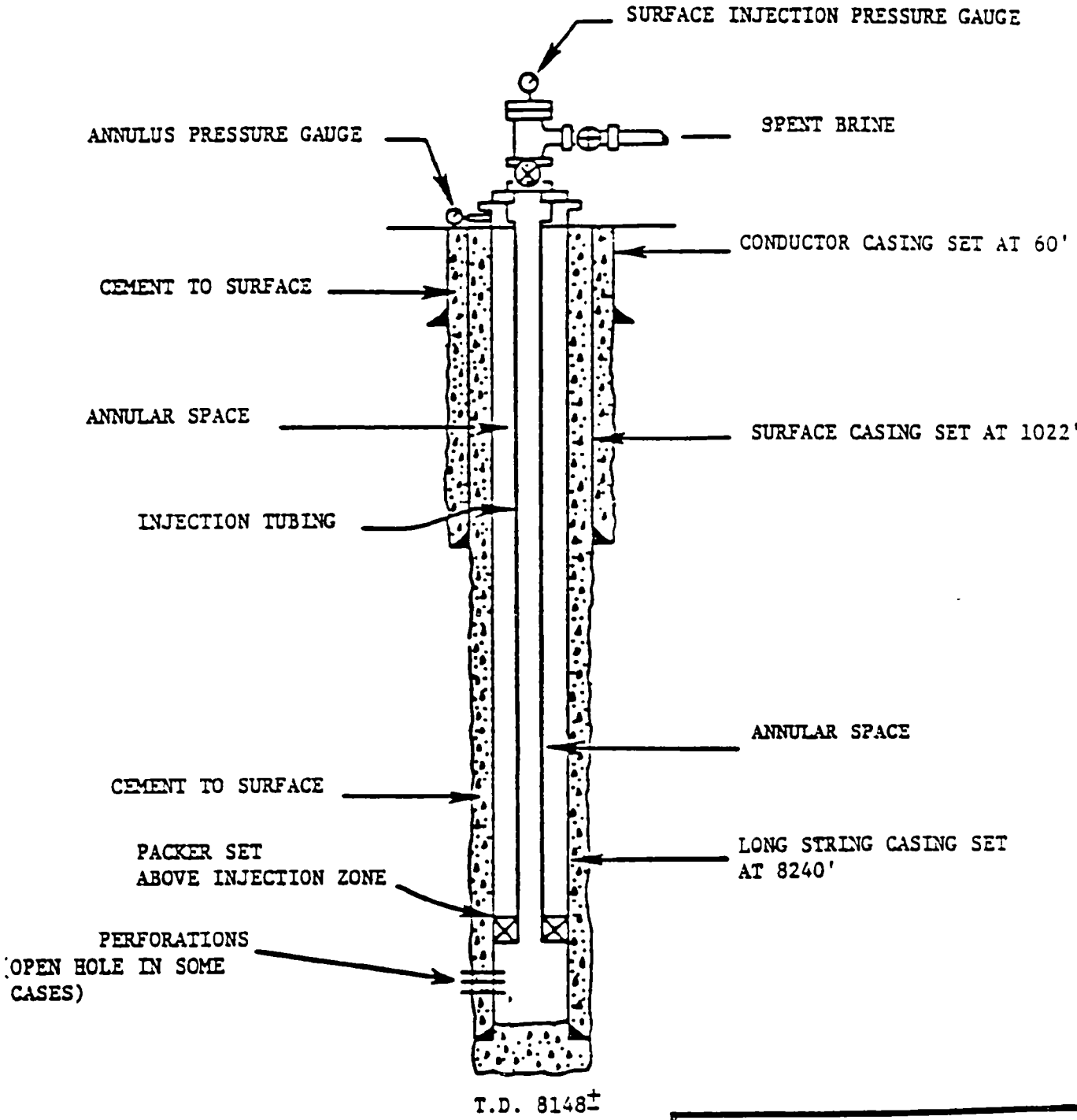
The ADPC&E has questioned the Arkansas Department of Health concerning cesspools and other devices that receive waste. The ADPC&E learned that the Health Department does not allow this type of injection well, nor does it permit septic system wells injecting waste from multiple dwelling or business establishments or community septic tanks. This inventory also revealed that although there is potential for the operation of the following wells in Arkansas, there are no known radioactive disposal wells, surface drainage wells, or aquifer recharge wells operating in the State of Arkansas.

It is the intent of the ADPC&E UIC Program to continue its efforts to identify and maintain an inventory of all Class V disposal wells in order to assess and prevent potential threats to groundwater in Arkansas.

EVALUATION OF CONSTRUCTION FEATURES

Existing Brine Disposal Injection Wells

The existing Class V brine disposal injection wells have been constructed using the construction requirements of the AO&GC. The construction of these wells, based on the available data, appears to be adequate. No cement logs were available, however, the records on the wells which were reviewed at the AO&GC, primarily well completion reports, were complete and contained a considerable amount of detailed construction, cementing, casing and plugging information. A representative example of a Class V brine disposal injection well, Great Lakes' SWD #9-1, is illustrated in Figure 1. The diagram illustrates typical construction specifications for existing brine disposal wells. Most of the wells have approximately 60



EXISTING CLASS V BRINE DISPOSAL INJECTION WELL

GREAT LAKES CHEMICAL CORPORATION

SWD #9M

SCALE NONE FIGURE 1

feet of conductor casing, 500 to 1000 feet of surface casing, 8000 feet of long string casing and 2000 to 8000 feet of injection tubing. In several instances, approximately 4000 feet of intermediate casing were set with about 4000 feet of liner set from just above the base of the intermediate casing through to the bottom of the well.

Tubing is either set with a packer and fluid-filled annular space, cemented in place by circulating cement to the surface, or set with no packer and with an open annular space. Several wells have been completed by perforation of the injection zone; however, most of the brine disposal wells are open hole completions.

New Brine Disposal Injection Wells

The ADPC&E suggests that new Class V brine disposal injection wells shall be constructed using a slight modification of the AO&GC construction requirements for Class II wells. Figure 2 is a generalized illustration of the construction requirements for new Class V brine disposal injection wells. For all new Class V brine disposal injection wells, the following construction requirements should apply.

To ensure the protection of USDWs, injection wells must be constructed in a manner to prevent injected fluids from escaping into untargeted formations through leaks in the tublar goods, packer, well casing, inadequate cement or faulty applications of cement.

The construction requirements included in this section apply to all new Class V brine disposal injection wells under the UIC program.

1) The proposed injection formation must be separated from USDWs by one or more confining zones which meet the approval of the Director.

2) Casing and cement for the proposed well must be designed to protect USDWs, thus it is necessary to consider:

   a) the depth of the well;

   b) anticipated maximum and average operating pressures;

   c) bottom hole temperature and pressures;

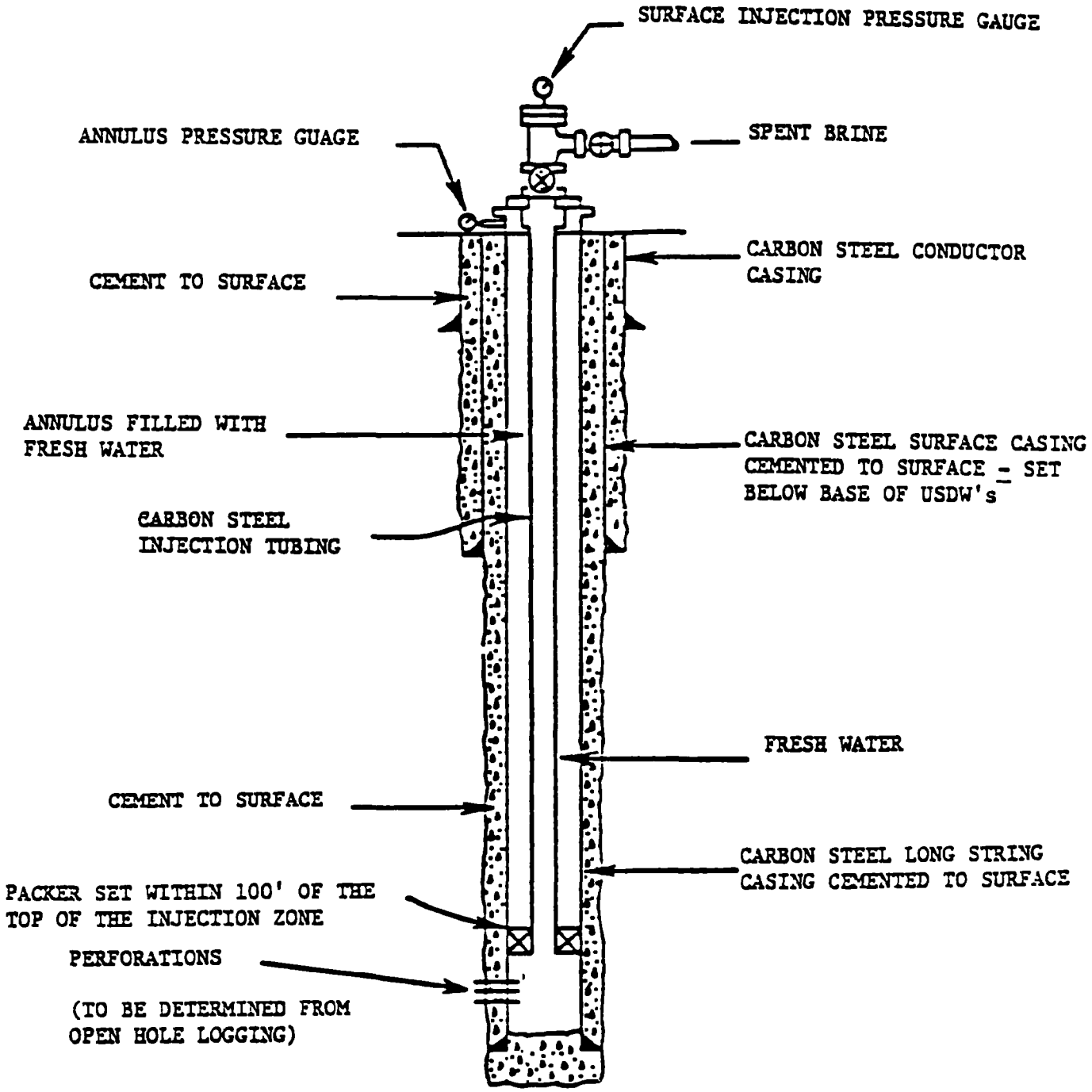
   d) the hole size;

   e) corrosivity of injection fluids and formation fluids;

   f) lithology of injection and confining zone strata;

   g) types and grades of cement to be used; and

   h) the expected life of the project.



CONSTRUCTION REQUIREMENTS FOR NEW CLASS V BRINE DISPOSAL INJECTION WELLS

SCALE NONE FIGURE 2

The casing above the injection zone shall be sufficiently cemented by circulating cement with returns to the surface.Good quality cement is imperative to assure against fluid migration into untargeted zones. The quality should be sufficient to withstand the maximum operating pressure and should be resistant to degradation by native formation fluids and the injection fluids.

On all newly drilled or converted, and all existing Class V brine disposal injection wells, injection must be through tubing set on a packer unless exception is granted by the Director. Packers shall be set no higher than 100 feet above the top of the injection zone.

Well use may not begin until an appropriate permit is issued. After permit issuance, any proposed change or alteration to construction plans and specifications described in the application must be approved by the Director before being incorporated. Also, all phases of well construction and testing must, if possible, be supervised by a qualified person who is knowledgeable and experienced in practical drilling engineering and who is familiar with the special conditions and requirements of injection well construction. Also, during the drilling and completion of Class V brine disposal injection wells, appropriate logs will be obtained and tests conducted as set forth in the mechanical integrity guidelines.

Consequences of Injecting into the Intended Injection Zone

The principal Class V brine disposal injection formation is the Smackover Limestone. The Smackover ranges in depth from about 7000 to 9000 feet in South Arkansas. The Smackover is the formation from which the original brine is extracted. Once the bromine is stripped from the brine, the remaining brine is injected via Class V brine disposal injection wells back into the Smackover. There are some Class V brine disposal injection wells which inject the spent brine into formations other than the Smackover Limestone. The other formations currently used as Class V brine disposal injection zones are, from deepest to shallowest: the James Member (limestone) of the lower Glen Rose Formation, the Tokio Formation (sandstone), the Blossom Formation (sandstone lateral equivalent of the Brownstown Marl), and the Graves Member(sandstone) of the Ozan Formation. Figure 4 illustrates the subsurface stratigraphy and the unit thicknesses of Mesozoic and Cenozoic strata of Columbia and Union Counties in south Arkansas. Figure 4 also classifies the strata as either injection formations, confining formations, or both. Wells which are injecting into formations other than the Smackover Limestone are in violation of 40 CFR 146.05 (e) (14). Subsequent to the completion of this report, and in accordance with Part 2.G. of the 1982 Amended Memorandum of Understanding between the ADPC&E and the AO&GC, the ADPC&E will inform the AO&GC of the wells that have been found to be operating in violation of 40 CFR 146.05 (e) (14) as this is a matter which falls under the jurisdiction of the AO&GC. The ADPC&E will also inform the AO&GC of all the available options.

Seventy Class V brine disposal injection wells are known to exist in Arkansas. Five of the seventy have been plugged and abandoned. All but five of the remaining sixty-five Class V brine disposal injection wells listed in Appendix A inject only into the Smackover Formation. Ethyl Corporation is responsible for three of the five wells and Great Lakes Chemical Corporation is responsible for the remaining two.

Two of Ethyl Corporation's wells, BDW (L.E. Christie) #6, which injects into the Tokio Formation, and BDW #13, which injects into the Tokio Formation, the James Member of the lower Glen Rose Formation, and the Smackover Formation, are currently being considered for a permit to operate as Class I waste disposal injection wells. BDW #6 injects a sludge of tail brine solids once every two or three years. This well will not be issued a permit to operate as a Class I well and will ultimately have to be plugged and abandoned. BDW #13 is presently operating as a Class V brine disposal injection well pending its being permitted as a Class I waste disposal injection well. Ethyl's BDW #3 is said to have been plugged and abandoned, but the records at the AO&GC, as illustrated in Appendix A, show that the well has only been plugged back from its original Smackover completion to a much shallower depth. The formation to which BDW #3 was plugged back to is unknown at this time, however, the depth indicated, 4150 feet, is approximately where one would expect the Tokio Formation or the James Member of the lower Glen Rose Formation to be.

Age		Group	Formation	Member	Maximum Thickness	Union County Thickness	Columbia County Thickness	Confining Zone	Injection Zone
Cenozoic	Tertiary	Claiborne	Cockfield (Sand)		200'	100'			
			Cook Mtn. (Clay)		150'	100'			
			Sparta (Sand)		900'	600'			
			Cane River (Ss & Cl)		700'	300'	140'		
			Carrizo (Sand)		400'	?	?		
		Wilcox	(Sand & Clay)		1000'	500'	700'		
		Midway	(Clay)		600'	400'	450'	✓	
Mesozoic	Cretaceous	Upper	Arkadelphia Marl		150'	150'	150'	✓	
			Nacatoch (Sand)		600'	200'	250' - 385'		✓(Class I
			Saratoga Chalk		150'	40'	140'	✓	
			Marlbrook Marl		200'	80' - 200'	130' - 180'	✓	
			Annona Chalk		100'	50'	100'	✓	
			Ozan (Sand & Clay)	Meakin					✓(Class I
				(Shale)				✓	
				Graves	300'	200'			✓
			(Blossom) (Sand & Clay)					✓	✓
			Brownstown Marl		250'	150'		Brownstown Marl	(Blossom)
			Tokio (Sand)		350'	200'			✓
			Woodbine (Clay)		250'	150'		✓	
		Trinity	Glen Rose	Upper Glen Rose (Marine Shale & Limestone)		0' - 350'	0' - 500'+	✓	
				(Massive Anhydrite) Ferry Lake Anhydrite		0' - 500'	0' - 340'	✓	
				Rodessa or Lower Glen Rose	or Bexar Sh / James Ls	0' - 900'			
						0' - 1100'	750' - 1100'	✓ Bexar Sh.	✓ James Ls.
			Hosston (Shale & Sandstone)		2500'	400' - 1900'	900' - 1900'	✓	
	Jurassic	Cotton Valley	Cotton Valley (Sh., Ls. & Ss.)		1400'	1600' - 2550'	1500' - 2500'	✓	
			Buckner (Sh. & Anhy.)		275'	60' - 190'	100' - 260'	✓	
			Smackover (Limestone)		900'	680' - 925'	455'+		✓
			Eagle Mills (Ss., Sh., Salt & Anhyd.)		1250'	1000' - 1290'+			

FIGURE 4

Great Lakes Chemical Corporation owns two Class V brine disposal injection wells which are not completed for injection into the Smackover Formation. One of Great Lakes' West Plant wells, Belinger Estate #1, injects into the Graves Member of the Ozan Formation, the Blossom Formation, and the Tokio Formation. Another of Great Lakes' wells which is located at the El Dorado Plant, SWD #8, is a dual completion and injects into the Meakin and Hogg Members of the Ozan Formation and into the Smackover Formation.

The geology of the area in which all Class V brine disposal injection activity occurs is relatively simple. The lack of structural and stratigraphic complexity in the geology of south Arkansas makes the area very favorable for UIC practices. Figure 5 shows the major regional structural geologic features in relation to the area in which all Class V brine disposal injection activity occurs, the area around El Dorado and Magnolia, Arkansas.

The integrity of the confining beds is very good. The confining beds are dominated by very slightly porous and permeable sediments. The confining beds are characterized by occassional porous and permeable lenticular bodies of rock which are neither laterally nor vertically extensive. Some thick (200- feet), regionally extensive, porous and permeable beds do exist in the succession of sediments above the Smackover, but they are all well confined by sediments of low porosity and permeability, the most abundant sediments of this succession.

The Midway Group consists of 400 to 600 feet of low permeability gray and blue clays. The lower 50-75 feet of the unit consists of calcareous clay and marls in Union County and interbedded sandstone and limestone in Columbia County. The Midway Group is the thickest and most important of the confining zones as it forms the main basal confining bed for fresh groundwater aquifers in Union and Columbia Counties. The Midway separates underground sources of drinking water from aquifers which may be used for underground injection because the water contained within them is not of useable quality. The ADPC&E voiced it's agreement with the AO&GC in June, 1984 that no underground injection of any kind will be allowed above the base of the Midway Group in south Arkansas unless it is specifically approved on a case-by-case basis by the Director.

As long as the Class V brine disposal injection wells are mechanically sound, the potential impacts of the injection fluid on nearby underground sources of drinking water are negligible or nonexistent.

The Sparta Formation is the principal source of municipal and industrial water supply in Union and Columbia Counties. The base of the Sparta Formation is approximately 1,500 feet above the top of the Midway Group. There are approximately 6,000 feet of sediments separating the top of the Smackover from the base of the Midway Group. A total of approximately 8,000 feet of sediments separate the top of the Smackover Limestone and the base of the Sparta Formation in the areas where Class V brine disposal injection occurs.

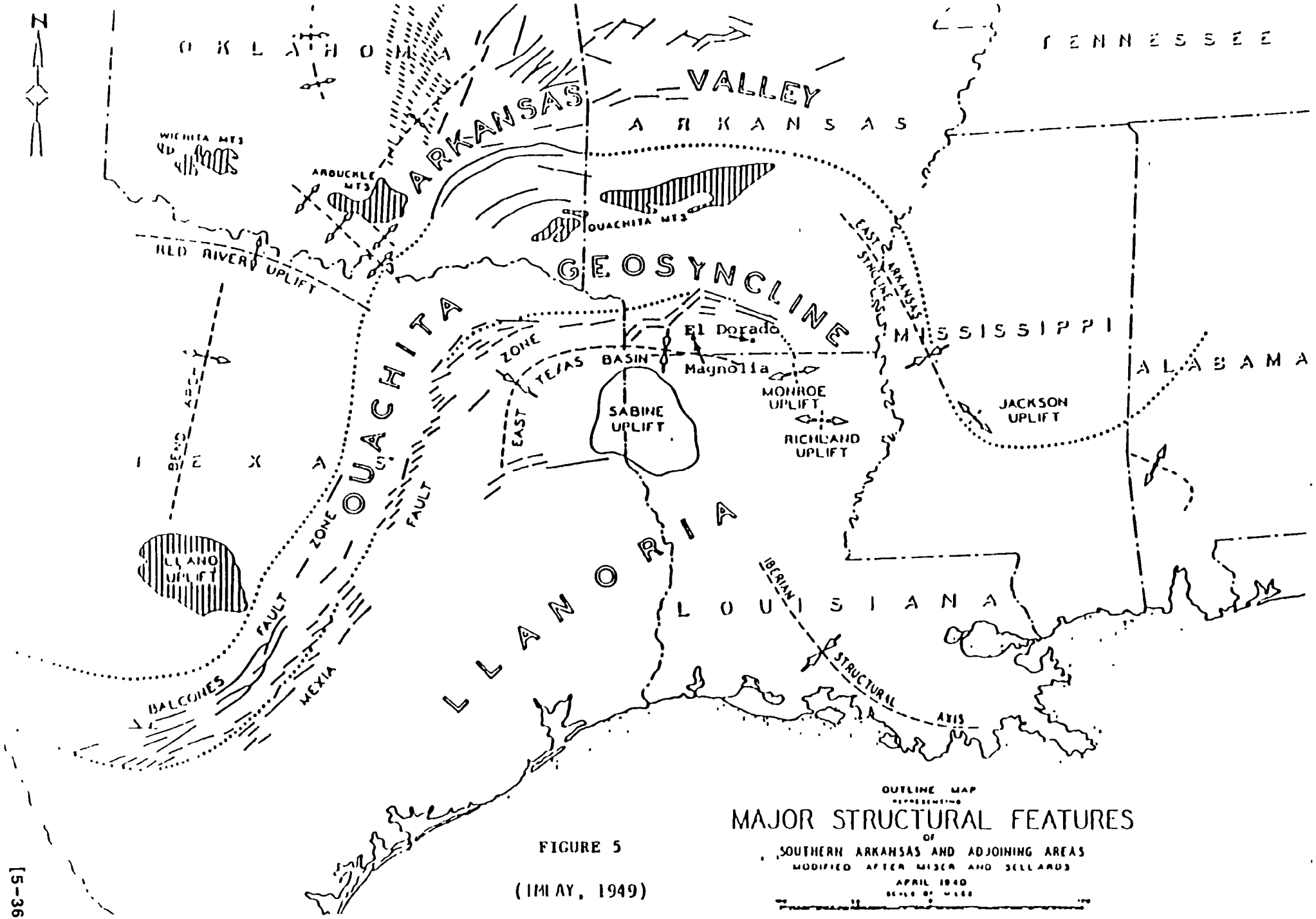


FIGURE 5

(IMIAY, 1949)

OUTLINE MAP

MAJOR STRUCTURAL FEATURES

OF

SOUTHERN ARKANSAS AND ADJOINING AREAS

MODIFIED AFTER MISER AND SELLARDS

APRIL 1940

The closest Class V brine disposal injection zone to the base of the Sparta Formation is the Meakin Member of the Ozan Formation. Approximately 2,200 feet of sediments separate the top of the Meakin from the base of the Sparta in Union and Columbia Counties. Nearly 45% of these sediments act as low porosity and permeability confining zones. The Meakin lies approximately 850 feet below the base of the Midway Group in Union and Columbia Counties. Over 50% of the sediments between the top of the Meakin and the base of the Midway Group act as low porosity and permeability confining zones.

At the present time, no pressure build-up calculations have been done for the Class V brine disposal injection wells. This is due to the lack of available pressure information at the time that the data for this report was collected. The ADPC&E would like to compile this pressure build-up information in the future either as an addendum to this report or just as suplementary information to help the Department secure a better grasp on Class V brine disposal injection well operations in Arkansas.

On October 1 and 2, 1984, Wayne Thomas, ADPC&E Petroleum Technician, collected samples of the spent brine at the Class V brine disposal injection well operation bromine plants in southern Arkansas. The sample collection locations and the chemical analyses of the samples (performed at the ADPC&E chemistry lab in Little Rock) may be found in Appendix C. The geochemical reactions between injected wastes and formation fluids have not yet been determined for the following reasons:

1. It is not certain whether or not the samples collected on October 1-2, 1984 contained a complete representation of the volatile organics which were originally sent to the pre-injection brine storage basins. There is a possibility that some volatile organics were volatized upon entering the storage basins or while being stored in the basins.

2. The ADPC&E has not yet acquired any background chemical analyses on the formation fluids of the injection zones.

3. The ADPC&E has not yet acquired any background chemical analyses on the original brine.

4. The ADPC&E plans to do a more comprehensive sampling of the Class V brine disposal injection well waste streams and also to develop background data on the chemistry of the original brine and of the injection formations. This also may be either an addendum to this report or just supplementary information to give the Department more control over the Class V brine disposal injection well program.

SECTION 5.4.2

TITLE OF STUDY: **(OR SOURCE OF INFORMATION)**	Memorandum to Wayne Thomas, Petroleum Technician for the Arkansas Department of Pollution Control and Ecology (ADPC&E)
AUTHOR: **(OR INVESTIGATOR)**	Jay Justice, Hazardous Waste Chemist (ADPC&E)
DATE:	January 17, 1985
FACILITY NAME AND LOCATION:	Arkasnas, USEPA Region VI
NATURE OF BUSINESS:	Results of Analysis of Samples Taken October 1-2, 1984 at the Bromine Plants in Southern Arkansas

BRIEF SUMMARY/NOTES: Results are presented for samples of brine injection fluids at six facilities. Analyses are grouped into four categories:

1. Volatile Organics (Method 8240)
2. Base/Neutral Extractables (Method 625)
3. Acid Extractables (Method 625)
4. Heavy Metals (Methods 7130, 7190, and 7420)

ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

MEMORANDUM

TO: Wayne Thomas, Petroleum Technician

FROM: Jay Justice, Hazardous Waste Chemist

DATE: January 17, 1985

SUBJECT: Results From Analyses on Samples Taken October 1-2, 1984 at the Bromine Plants in Southern Arkansas

The analyses that were done on these samples can be grouped into the four catagories listed below:

1) Volatile Organics (Method 8240 [1])
2) Base/Neutral Extractables (Method 625[2])
3) Acid Extractables (Method 625[2])
4) Certain Heavy Metals (Methods 7130[1], 7190[1], 7420[1])

The results of these analyses are as follows:

Great Lakes - South Plant
Sample Labeled "Tail Brine After Treatment"

1) Volatile Organics - none detected - less than 50 ppb
2) Base/Neutral Extractables - none detected - less than 200ppb
3) Acid Extractables - one compound detected - not halogenated: estimate concentration to be in order of 250 ppb - 750 ppb
4) Heavy Metals -
   Cadmium - less than 0.5 ppm Copper - 2.5 ppm
   Chromium - 2.5 ppm Lead - 12.5 ppm

Great Lakes - Marysville Plant
Sample Labeled "Tail Brine After Treatment"

1) Volatile Organics - none detected - less than 50 ppb
2) Base/Neutral Extractables - none detected - less than 200 ppb
3) Acid Extractables - none detected - less than 200 ppb
4) Heavy Metals -
   Cadmium - less than 0.5 ppm Copper - 3.5 ppm
   Chromium - 2.0 ppm Lead - 19 ppm

Great Lakes - Main Plant
Sample Labeled "Tail Brine From Bromine Tower"

1) Volatile Organics - none detected - less than 50 ppb

[5-367]

2) Base/Neutral Extractables - none detected - less than 200 ppb
3) Acid Extractables - seven compounds detected; three of these compounds were brominated; estimate concentration of each compound to be less than 250 mg/l.
4) Heavy Metals -

Cadmium - less than 0.5 ppm	Copper - 2.5 ppm
Chromium -less than 2.0 ppm	Lead - 17.5 ppm

In addition this sample contained what I believe to be elemental bromine.

Dow Chemical - Magnolia
Sample Labeled "Pump Discharge to Reinjection Field"

1) Volatile Organics - none detected - less than 50 ppb
2) Base/Neutral Extractables - none detected - less than 200 ppb
3) Acid Extractables - Four compounds detected; two of these were brominated; estimate concentration of each compound to be less than 250 ppb.
4) Heavy Metals -

Cadmium - less than 0.5 ppm	Copper - 2.5 ppm
Chromium - 4.5 ppm	Lead - 9.5 ppm

Ark Chem Inc.
Sample Labeled "Tail Brine From Pumping Station to Reinjection Field"

1) Volatile Organics - none detected - less than 50 ppb
2) Base/Neutral Extractables - none detected - less than 200 ppb
3) Acid Extractables - none detected - less than 200 ppb
4) Heavy Metals -

Cadmium - less than 0.5 ppm	Copper - 1.5 ppm
Chromium - 5.0 ppm	Lead - 17.5 ppm

Ethyl Corporation - Magnolia
Sample Labeled "Tail Brine From Pump Station to reinjection Field"

1) Volatile Organics - compounds present included dibromochloromethane [3] and bromoform [3]; estimate concentration of each compound to be less than 100 ppb.
2) Base/Neutral Extractables - 5 compounds detected; none of these compounds were brominated; estimate concentration of each compound to be less than 250 ppb.
3) Acid Extractables - Nine compounds detected; seven of these compounds were brominated; the compound with the highest concentration was Bromoform [3]; estimate concentration to be less than 250 ppb.
4) Heavy Metals -

Cadmium - less than 0.5 ppm	Copper - 1.5 ppm
Chromium - 4.5 ppm	Lead - 12.5 ppm

[1] Test Methods for Evaluating Solid Waste Physical/Chemical Methods SW - 846 2nd Ed.

[2] Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater EPA - 600/4-82-057

[3] Tentatively identified, not confined with standards

JJ/jtb

cc: Cheryl Terai
A.L. Sparks

APPENDIX C

Results From Analyses of Brine Disposal

Injection Well Injection Fluid

PLUGGING DETAILS

Company	Well Name	Plugging Date	Plugging Details	
DOW	J.O. DeLoach #1	6/27/83	Production Plug Fresh Water Plug Surface Plug	8130'-8400' 654'-1050' 5 sacks
Ethyl	BDW #3	4/20/74	PBTD Plug	4150'-4720'
	BDW #35	3/8/82	Hole Filled with Water Plugs	7492'-8000' 4148'-4278' 11' plug in top of 10 3/4" casing
	BDW #41	2/17/83	Hole Filled with Water Plugs	8204'-8590' 17' plug in top of 5 1/2" casing
Gulf (El Dorado Plant)	SWD #3	11/12/80	1500 sacks Halliburton Lite - top @900', 20 yards of wash rock on top of cement, 9 5/8" rubber plug on top of rock, 5 sacks cement plug from top of rubber plug to surface. Top of well is sealed by a welded metal plate.	

APPENDIX B

Class V Brine Disposal Injection Well Plugging Details

SECTION 5.4.3

TITLE OF STUDY: (OR SOURCE OF INFORMATION)	Development of a Two Aquifer Contaminant Plume: A Case History
AUTHOR: (OR INVESTIGATOR)	P.L. Campbell and J.V. Kinsella, D'Appolonia Waste Management Services, Baton Rouge, Louisiana
DATE:	Not Available
FACILITY NAME AND LOCATION:	Not Applicable
NATURE OF BUSINESS:	Not Applicable

BRIEF SUMMARY/NOTES: This paper examines the consequences of injection well failure on surrounding aquifers and remedial methods available.

Waste fluids were being injected into a saline aquifer at depths from 1900 to 2400 feet when a casing rupture was detected at a depth between 140 and 212 feet. Injection fluid was noted at the surface 100 feet from the injection well.

Investigation revealed that injection fluids had leaked into a system of fine to medium sands underlying a laterally discontinuous clay layer. The fluids migrated upward until the clay layer was encountered, then migrated horizontally to a point where the clay layer pinched out. Contaminants migrated through the natural break into shallower sands, and a two-aquifer plume developed. Plume, geometry, migration rate, and the ongoing cleanup efforts are reviewed.

Development of a Two Aquifer Contaminant Plume: A Case History

Pressley L. Campbell and John V. Kinsella
D'Appolonia Waste Management Services, Baton Rouge, Louisiana

Deep well injection of hydrocarbon waste streams is a common form of waste disposal. This paper examines the consequences of injection well failure on surrounding aquifers and the methods used to remedy the situation.

The project site is underlain by a complex sequence of alluvial sands, silts and clays. Waste fluids are injected into saline aquifers via several wells at depths ranging from 1,900 to 2,400 feet below ground surface. A ruptured casing leak from one of the wells was identified at a depth between 140 and 212 feet below ground surface. The leak was discovered when injection fluid appeared at the ground surface approximately 100 feet from the well.

A hydrogeologic investigation program was initiated to determine the extent of contamination of near surface aquifers. The shallow subsurface geology consists, from the surface downwards, of approximately 30 feet of gray silty clay overlying 25 - 30 feet of fine silty sand (40-foot sands). Underlying the 40-foot sands is a clay layer that is laterally discontinuous and varies in thickness from 0 - 5 feet. Fine to medium grained sands, up to 100 feet in thickness, underly the clay (100-foot sands). The 40 and 100-foot sands constitute the near surface aquifers and act as one hydraulic unit where the intermediate clay is absent.

The investigation revealed that waste fluid had leaked into the 100-foot sands and travelled vertically upwards under pressure until it encountered the intermediate clay layer. Contaminants then migrated horizontally beneath the clay until they reached a point where the clay layer pinched out. Contaminants migrated through this natural break into the 40-foot sands. A two aquifer contaminant plume subsequently developed. This paper discusses the plume geometry, rate of migration and ongoing cleanup effort.

Biographical Sketches

Dr. Campbell holds three degrees in Civil Engineering (Water Resources) from Carnegie-Mellon University. He has more than ten years experience in eight states completing multidisciplinary projects in hazardous waste disposal, water resources, hydrology, hydrogeology, computer programming and client-agency liason. Dr. Campbell was the lead engineer in the analysis, design, construction and operation of over 20 waste disposal facilities.

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Mr. Kinsella has a B.A. (Geology) from Trinity College Dublin and an M.Sc. (Hydrogeology) from the University of London. He has over six years experience working on a variety of hydrogeological projects ranging from water resources studies to computer modeling of groundwater contamination.

Mailing Address/Phone Number
D'Appolonia Waste Management Services,
A Division of IT Corporation
8116 One Calais Avenue
Suite 2D
Baton Rouge, Louisiana 70809
504/769-9700