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June 1977

Ecological Research Series

IRRIGATION WASTEWATER DISPOSAL WELL STUDIES---SNAKE PLAIN AQUIFER

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

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IRRIGATION WASTEWATER DISPOSAL WELL STUDIES
SNAKE PLAIN AQUIFER

by

William G. Graham
Darrel W. Clapp
Thomas A. Putkey
Idaho Department of Water Resources
Statehouse
Boise, Idaho 83720

Grant No. R802931

Project Officer

D. Craig Shew
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate, and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

William C. Galegar
Director

ABSTRACT

Drain wells are used to dispose of excess irrigation and surface runoff water from approximately 320,000 a of agricultural land within the eastern Snake River Plain area of southern Idaho. The impact of this practice on the underlying Snake Plain aquifer, the primary source of potable water for approximately 140,000 people, was not understood. Thus, an investigation was initiated to evaluate the impact of irrigation disposal well practices on the water quality of the Snake Plain aquifer.

A study site was selected where the geology was determined to be characteristic of areas in the Snake River Plain where irrigation disposal wells are extensively used. Alternating permeable and dense basalt layers underlie the discharge site. The aquifer at the project site was defined as a leaky artesian groundwater system.

Initial quality of the artesian groundwater was found to be within Idaho drinking water standards. Pesticides, herbicides, and trace metal concentrations in the irrigation wastewater were within drinking water standards. Total and fecal coliform bacteria and sediment were the only contaminants found in irrigation wastewater in excess of drinking water standards.

Wastewater discharge to the disposal well resulted in the formation of a nonsymmetrical recharge zone. Rapid lateral movement of the discharge water through the recharge zone indicated that flow was through fractures and channels. Bacterial levels and turbidity within the recharge zone approached those of the discharged wastewater and were far in excess of drinking water standards.

Deep percolation of injected wastewater resulted in bacterial contamination of both the deep perched water zone overlying the confining layer and the artesian groundwater system. Suspended solids, as measured by turbidity, were filtered out by the percolation process.

This report was submitted in fulfillment of Grant No. R802931 by Idaho Department of Water Resources under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period November 19, 1973 to September 22, 1976; and work was completed as of September 17, 1976.

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ACKNOWLEDGMENTS

We gratefully acknowledge the U.S. Bureau of Reclamation for permitting the construction of project facilities on lands administered through their office and for water quality analyses performed in their regional laboratory. Especial thanks are given to Everett Williams, USBR, for his cooperation with the water quality analyses.

Our appreciation is also extended to the A & B Irrigation District for their cooperation in providing the project with a constant source of irrigation wastewater, storage space for equipment, and assistance in maintaining the project site.

SECTION 1

INTRODUCTION

Drain wells have been a common means of disposing of irrigation wastewater and natural runoff from agricultural land within the eastern Snake River Plain area of southern Idaho (1-2). This practice has been developed as a result of large areas with rolling topography and internal drainage patterns combined with a loess overburden of relatively low permeability. Agricultural land in areas of internal drainage would have been rendered unusable if a feasible means for disposal of wastewater had not been found.

The geology underlying the eastern Snake River Plain consists of a sequence of successive flows of basalt intercalated with sedimentary and unconsolidated pyroclastic interbeds. Many of the basaltic flows comprising this sequence are highly fractured and readily accept large volumes of wastewater. Where saturated, these permeable flows compose the Snake Plain aquifer, which underlie nearly all of the eastern Snake River Plain and provide the most prolific water-bearing sequence in Idaho (fig. 1). This aquifer is the primary source of potable water for approximately 140,000 (3) people in addition to supporting agriculture and fish propagation.

Department records indicate that up to 1300 km^2 (320,000 a) of agricultural land within the eastern Snake River Plain are drained by over 2000 disposal wells. Concentrated use of disposal wells occurs in Gooding, Lincoln, Jerome, and Minidoka Counties of south-central Idaho and Jefferson, Bonneville, and Bingham Counties of southeastern Idaho (fig. 1). These wells are typically 10-30 cm in diameter, 30-50 m in depth, and are capable of accepting flows up to 8 m^3/min.

Studies of irrigation return flows in areas of the Snake Plain aquifer indicate that sediment loads and bacterial concentrations in such waters present the most obvious threat to degradation of groundwater quality (4-5). Both Bondurant and Carter determined that the applied water in the Twin Falls tract has low ionic concentrations and that surface runoff water exhibits only a slight increase in nitrate ion and a decrease in orthophosphate ion as compared to the applied water. No information is currently available on the possible contamination of groundwater by the sediment and associated adsorbed chemicals present in irrigation wastewater injected into disposal wells.

In response to public concern for the protection of groundwater quality, the Idaho State Legislature assigned the responsibility for regulating the use of waste disposal wells to the Department of Water Resources. The lawmakers recognized that any practice or condition which potentially limits the usefulness of the Snake Plain aquifer has serious economic and public health

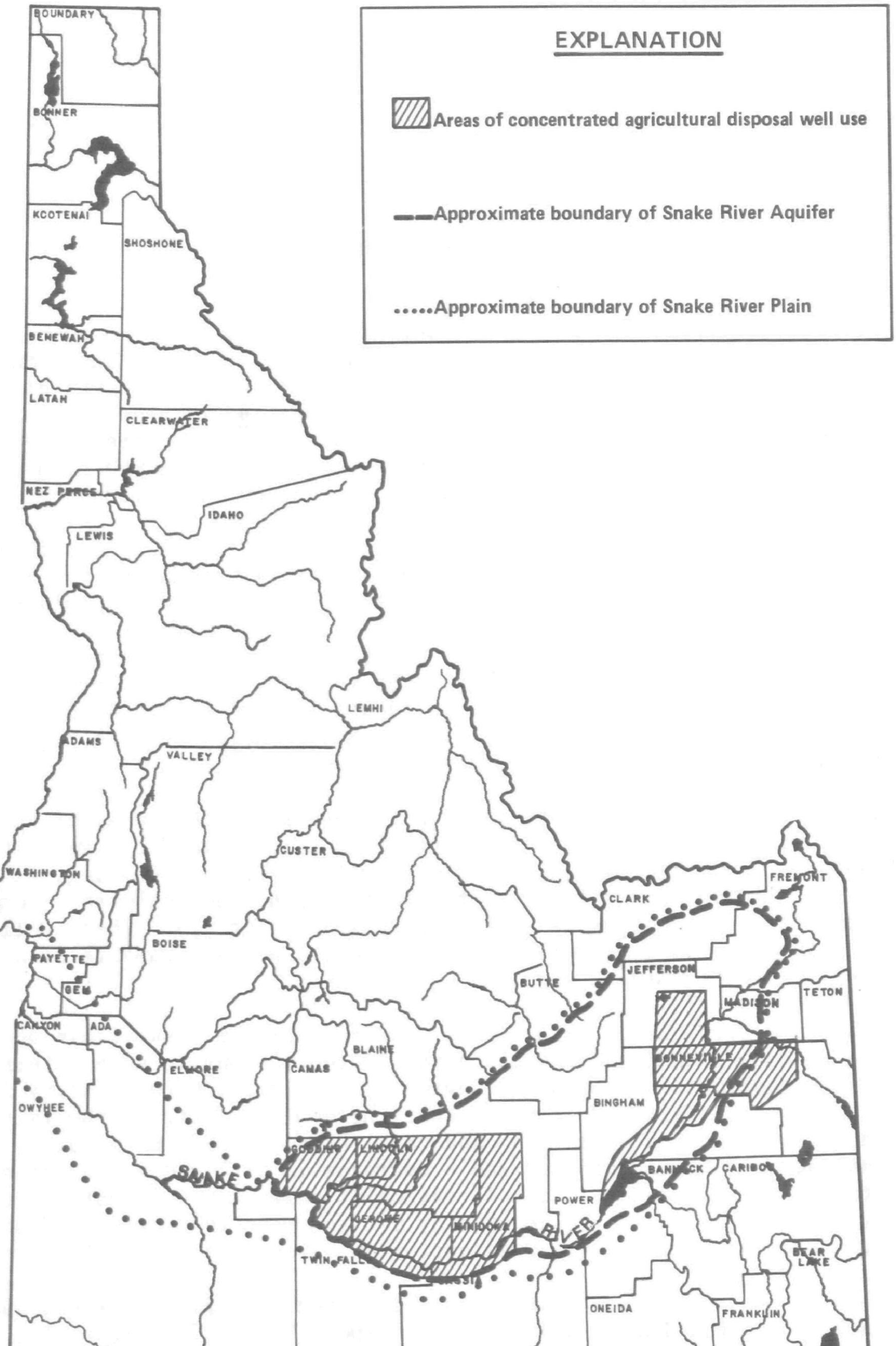

FIGURE I. Index map of Idaho exhibiting areas of concentrated agricultural disposal well use (adapted from Moreland, Seitz and LaSala, 1976) implications. They also recognized that continued use of disposal wells may be necessary to the economic survival of irrigated agriculture. Consequently, they provided that the present or future use of any waste disposal well used exclusively for the disposal of irrigation wastewater or surface runoff water should not be prevented where such disposal does not adversely affect domestic water supply. The lawmakers therefore charged the departments of Water Resources and Health and Welfare with establishing criteria and standards for the disposal of irrigation wastewater.

Adequate data were not available to evaluate the effect of injecting irrigation tailwater runoff into a basalt aquifer. Thus, there was an immediate need to collect this data. This study was designed to:

1) Further define the quality of irrigation wastewater.

2) Determine the areal extent of the saturated recharge zone resulting from discharges to the disposal well.

3) Determine the ability of successive basalt flows intercalated with unconsolidated interbeds to remove contaminants from irrigation wastewater.

4) Determine water quality changes within the groundwater system resulting from the use of agricultural disposal wells.

The results will be used by Idaho departments of Water Resources and Health and Welfare to set standards regulating the use of irrigation disposal wells. Once the standards are set, the economics of meeting these standards can be developed.

SECTION 2

CONCLUSIONS

Coliform bacteria and sediment were the only contaminants found in irrigation wastewater in excess of Idaho's drinking water standards. The chemical quality of wastewater with respect to common ions surpassed that of groundwater. Pesticides, herbicides, and trace metal concentrations in the irrigation wastewater were within drinking water standards.

Discharge to the disposal well generated a nonsymmetrical recharge zone. The areal extent of the recharge zone increased during each successive discharge event. This data indicated that groundwater flow in the upper receiving system was through fractures and channels in the overlying basalt after the initial clay and rubble discharge zone had become saturated. Discharge water moved rapidly through the upper recharge zone, having traveled beyond 120 m within 4 days during the fourth discharge event.

Purification of wastewater moving both laterally through the recharge zone and vertically through the underlying basalt flows was limited. Bacterial levels in the recharge zone approximated those in the discharged wastewater and were far in excess of drinking water standards. Bacterial contamination of both the deep perched water zone and the confined aquifer during the discharge events was apparent. However, turbidity was reduced as the injected wastewater percolated downward through the basalt formations.

SECTION 3

RECOMMENDATIONS

From the results obtained in this project, it is evident that the use of irrigation disposal wells could lead to the contamination of domestic groundwater supplies. It is, therefore, recommended that frequent monitoring of the Snake Plain aquifer be conducted in areas of intensive disposal well use.

It is further suggested that future studies be conducted to:

1) Determine the technical and economic feasibility of removing bacteria and suspended solids from irrigation wastewater prior to subsurface injection.

2) Define the ability of indicator bacteria to denote the presence of pathogenic bacteria and viruses in groundwater.

SECTION 4

DESCRIPTION OF RESEARCH SITE AND CONSTRUCTION OF FACILITIES

Site Selection

The site selected for this project was approximately 40 km east of the city of Twin Falls in south-central Idaho on land held by the U.S. Bureau of Reclamation under a reclamation withdrawal (fig. 2). This site was most suitable for the purposes of this study because:

1) Geological formations at the site were thought to be characteristic of the basalt formations in those areas of the Snake River Plain where extensive use is made of wells to dispose of irrigation wastewaters.

2) It was isolated from all other disposal wells.

3) No domestic wells were located in the immediate vicinity of the project site.

4) A drainage ditch maintained by the A & B Irrigation District of Rupert, Idaho, traversed the site and provided a continuous supply of wastewater from over 12 km^2 of agricultural land during the irrigation season.

5) The area was easily accessible.

Construction of Facilities--1974 through 1975

A diversion ditch (30 m long and 1.5 m deep) was excavated to deliver wastewater to a holding pond (7.3 m wide, 8.5 m long, and 2.7 m deep) prior to their entering the disposal well (fig. 3). A concrete diversion dam and headgate at the diversion point allowed regulation of the rate of diverted water, and a Parshall flume with a water level recorder was installed in the diversion ditch to provide for continual measurement of the discharge flow rate. The inlet pipe to the disposal well was placed in the holding pond (1 m above bottom of the pond), and a screening structure (1.2 m square) was erected around the inlet. A platform with a ladder leading to it was built around the screening structure to enable water sampling at the inlet point.

A shallow disposal well, 20 cm diameter, was constructed 5.2 m from the settling pond with a 20 cm pipe as a connector entering the well 3.0 m below ground surface. The well was drilled to a depth of 38.1 m and terminated in a clay and rubble interbed. It was cased into the first hard basalt zone (8.2 m), and a surface seal was provided in accordance with Idaho minimum well

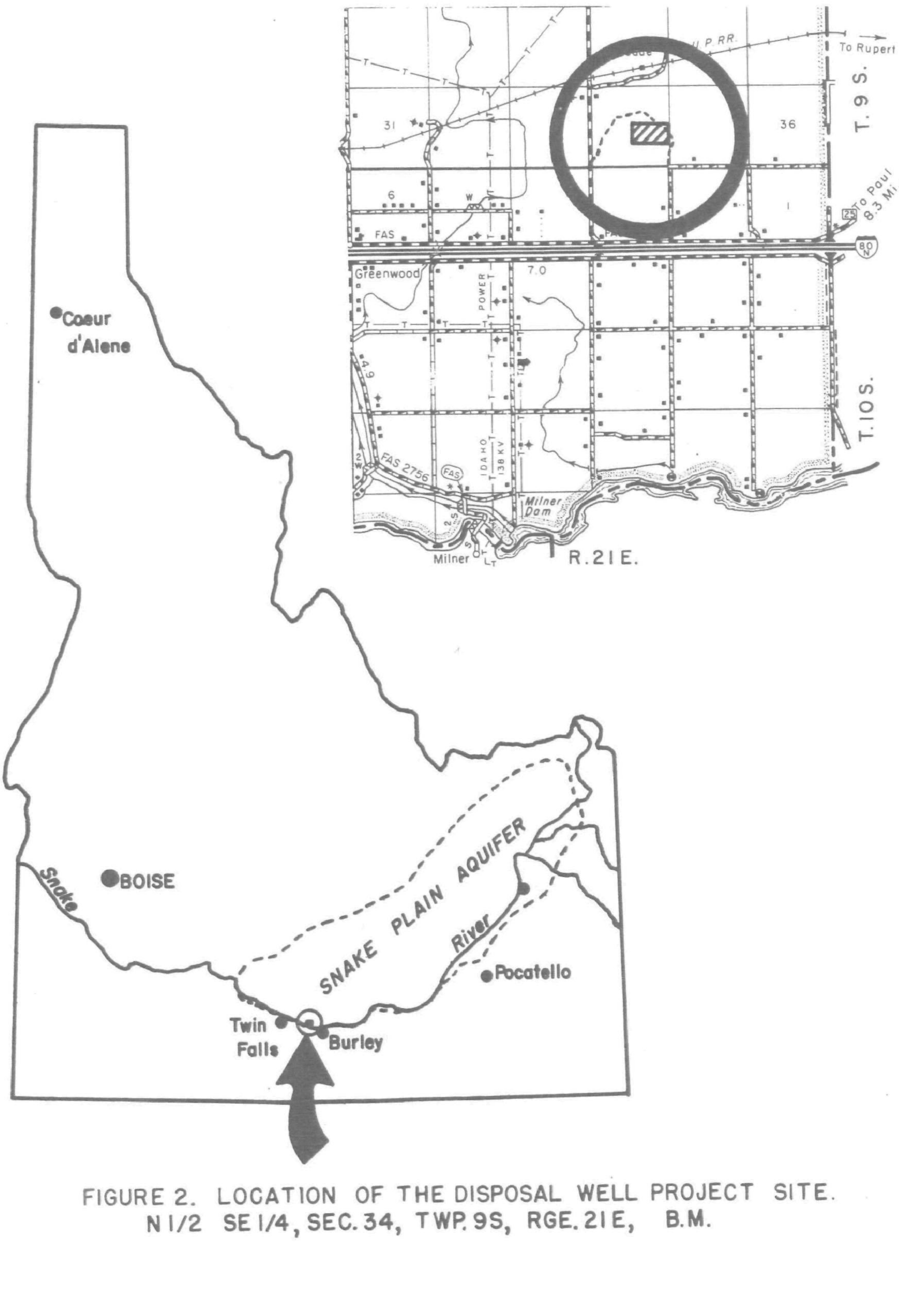

FIGURE 2. LOCATION OF THE DISPOSAL WELL PROJECT SITE.
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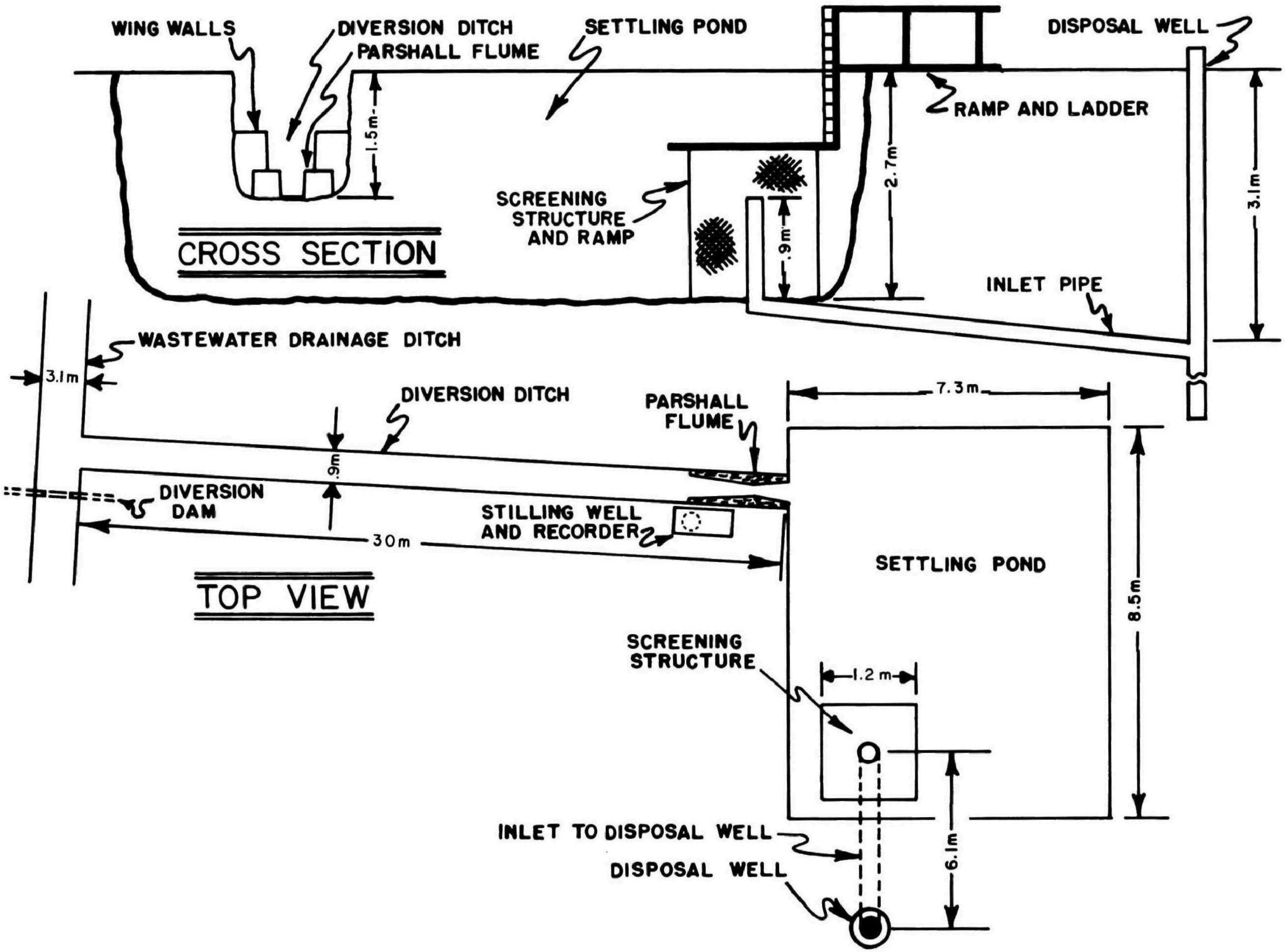

FIGURE 3. SITE FACILITIES FOR THE DISPOSAL WELL PROJECT.

construction standards. This construction was typical of irrigation disposal wells.

In geological formations such as those underlying the project site, the possibility existed that the wastewater might follow an irregular pattern of movement for some distance through fractured basalt formations or enter the deep aquifer in a direct path by way of interconnected fractures, thus avoiding detection through a predetermined deep monitoring well network. It was therefore decided to construct the monitoring well network in two stages.

Accordingly, two deep wells (DW1 and DW2) were constructed 15.2 m and 30.5 m distant from the disposal well along the theoretical downgradient direction of water movement (8). These wells were drilled using air and hydraulic rotary methods to a depth of 102.4 m, thus penetrating 6.1 m into the aquifer, the top of which was approximately 96 m below land surface. The wells were cased their entire length and were sealed from 1.5 m above the bottom of the confining layer to land surface to prevent perched water from moving through the annular space into the regional aquifer (see table 1 for construction features). Standing water in both wells was at 82.3 m below land surface indicating an artesian aquifer with a hydraulic head of 13.7 m. A water level recorder was placed over well DW1 to measure changes in depth to water in conjunction with subsequent discharge events.

TABLE 1. CONSTRUCTION FEATURES OF DEEP MONITORING WELLS (all wells 12.7 cm ID)

Well Number	D*	Total Depth (m)	Depth of Casing (m)	Perforation Zones (m)	Depth to Packer (m)
DW1	15.2 (50)	102.4	102.4	95.4- 99.4 101.5-102.4	90.5
DW2	30.5 (100)	102.4	102.4	95.4- 99.4 101.5-102.4	92.7
DW3	45.7 (150)	98.5	96.6	89.6- 93.6 95.7- 96.6	85.3
DW4	45.7 (150)	100.9	100.9	93.9- 97.8 100.0-100.9	85.3
DW5	45.7 (150)	100.9	100.9	93.9- 97.8 100.0-100.9	85.3

* D = distance from disposal well in meters (feet).

A temporary shallow monitoring well network was then constructed. Test holes of 10 cm diameter were drilled through the unsaturated cinder discharge zone to a maximum depth of 42.7 m at distances of 7.6 m (SW1) and 61.0 m (SW2) in line with wells DW1 and DW2. Six additional test holes were placed at distances of 30.5 m and 61.0 m from the disposal well at 90° intervals around its circumference.

Wastewater was discharged to the disposal well, and the injected water was found to travel through the cinder and fractured basalt zones in relatively short times. Injected water reached the nearest shallow well, 7.6 m from the disposal well, in less than 20 min and was detected in the 30.5 m distant shallow wells in less than 1 day. In view of this information, the three additional deep wells were placed 45.7 m from the disposal well, one each above and below and one upgradient from the disposal well (fig. 4). Construction specifications were the same as for the existing deep wells (table 1).

Five of the original shallow wells (SW1-5) were maintained as part of the permanent shallow monitoring well network and were cased through the loess overburden to the first basalt layer. Four additional shallow wells (SW6-9) were then constructed in like manner at intervals around the disposal well (fig. 4). Construction features for these wells are given in table 2.

TABLE 2. CONSTRUCTION FEATURES OF SHALLOW MONITORING WELLS
(all wells 11.4 cm ID)

Well Number	D*	Depth of Well (m)	Depth of Casing (m)
1	7.6 (25)	41.8	6.1
7	15.2 (50)	38.7	6.1
8	15.2 (50)	40.2	6.1
9	15.2 (50)	40.8	6.1
3	30.5 (100)	40.2	6.1
4	30.5 (100)	40.2	6.1
5	30.5 (100)	40.2	6.1
6	30.5 (100)	41.1	6.1
2	61.0 (200)	38.7	13.7

* D = distance from disposal well in meters (feet).

Construction of Facilities--1976

Appearance of bacteria and Rhodamine WT dye in the artesian aquifer following the discharge events conducted in 1975 and results from geophysical logging suggested that the deep wells should be modified prior to conducting any future discharges to the disposal well. The five deep wells were plugged, pressure grouted with cement, and shot-perforated as per the specifications given in table 3. Upon completion of the modification work, the deep wells terminated in a saturated zone of moderately porous basalt (72.5-88.7 m below land surface) overlying the confining layer of dense basalt.

TABLE 3. FEATURES OF MODIFIED DEEP MONITORING WELLS
(all wells 12.7 cm ID)

Well Number	D*	Original Depth (m)	Modified Depth (m)	Perforated Zone (m)
DW1	15.2 (50)	102.4	88.4	85.0-88.1
DW2	30.5 (100)	102.4	88.4	84.1-87.2
DW3	45.7 (150)	96.6	89.0	86.0-89.0
DW4	45.7 (150)	100.9	89.6	85.6-88.7
DW5	45.7 (150)	100.9	95.7	90.5-93.6

* D = distance from disposal well in meters (feet).

Five cased shallow wells (SW10-14) were also constructed prior to the 1976 discharge event in line with DW1 and DW2 (fig. 4). These wells were drilled by air rotary methods through the clay and rubble discharge zone and were cased their entire length with 12.7 cm ID PVC plastic casing. Construction specifications are presented in table 4.

TABLE 4. CONSTRUCTION FEATURES OF CASED SHALLOW WELLS

Well Number	D*	Depth of Well (m)	Perforated Zone (m)
SW10	15.2 (50)	38.9	25.3-38.9
SW11	30.5 (100)	37.2	28.0-37.2
SW12	61.0 (200)	36.0	26.5-36.0
SW13	91.4 (300)	36.9	25.9-36.9
SW14	121.9 (400)	40.2	29.6-40.2

* D = distance from disposal well in meters (feet).

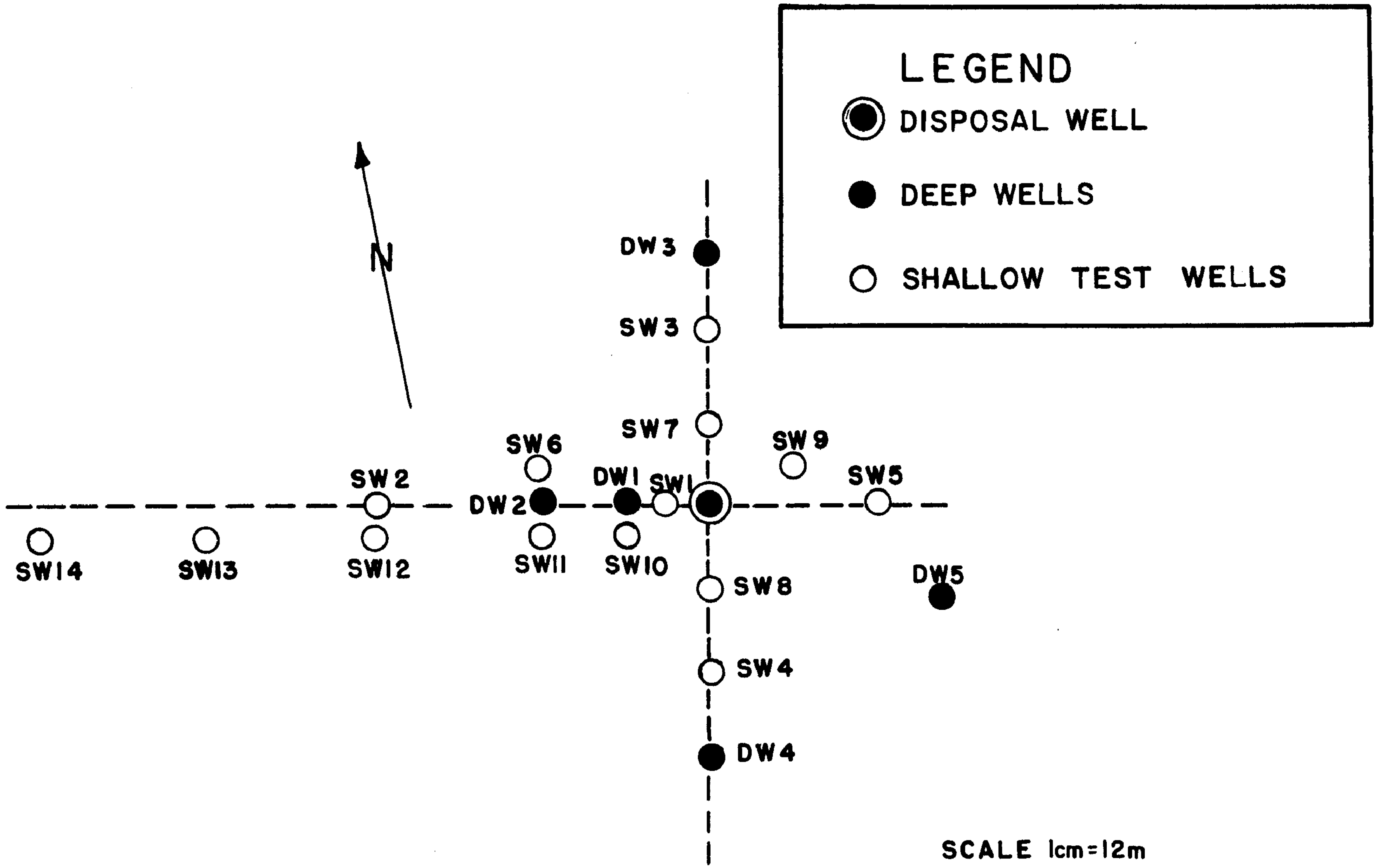

FIGURE 4. LOCATIONS OF DEEP MONITORING, AND SHALLOW TEST WELLS.

SECTION 5

METHODS

Wastewater samples were collected as grab samples at the inlet to the disposal well during periods of discharge and at the diversion dam at other times. The vast majority of samples were collected during discharge periods.

Methods used for the collection, preservation, and analyses for chemical constituents were as specified by EPA (7-8). Microbiological analyses were carried out by the membrane filter technique according to standard methods (9). All subsequent water-quality data presented in this report were obtained utilizing these same methodologies.

Artesian groundwater samples for determination of background quality were obtained from the deep wells by use of a portable groundwater sampling unit of a design modified from that of McMillion and Keeley (10). Samples were taken after a minimum of 30 min pumping from the 96 m depth in each well.

Three discharge events were carried out over the course of the 1975 irrigation season while a fourth event was conducted during the 1976 season after modifications to the monitoring well network were completed. Groundwater, water in the recharge zone, and injection water were monitored during the discharge events and thereafter.

The total volume of wastewater injected over a given discharge period was measured by use of a Parshall flume equipped with a Stevens A-70 water stage recorder. The rate of diverted water was adjusted to equal the maximum inflow to the well, and hence the flow rate through the flume was the rate of inflow to the well. A continuous record of flow rate through the flume allowed calculation of the total volume of discharge water.

Monitoring of groundwater focused on selected enteric bacteria (total coliforms, fecal coliforms, and fecal streptococci) and suspended solids (as indicated by turbidity) as these were the only contaminants found in wastewater at levels exceeding Idaho drinking water standards. In addition, groundwater was monitored periodically for possible degradation of chemical quality. Water samples were obtained with the groundwater sampling unit at a pumping rate of 26 l/min.

The sustained presence of indicator bacteria or high turbidity in groundwater would be taken as adequate evidence for contamination resulting from wastewater discharge to the disposal well. This presupposes that contamination introduced inadvertently during sampling occasions would be random which seems reasonable considering the results of monitoring for background groundwater quality.

Depths to water in the shallow wells were measured using a Fisher M-Scope water level indicator and water samples were taken at depths of 30.5 m whenever possible. Water samples for chemical analyses were taken once from the shallow wells after termination of discharge during each of the first and third discharge events. A Kemmerer water bottle constructed of PVC plastic was used repetitively to obtain adequate sample volumes.

Samples for Rhodamine WT dye analyses during the first two discharge events were taken from the upper recharge zone on the last day of the discharge period and on each subsequent sampling, while samples for dye analyses during the third discharge event were taken on each sampling occasion. The background fluorescence of wastewater was negligible compared to fluorescence levels from the dye and consequently was ignored.

Rhodamine WT dye was used as a tracer both to follow the movement of injected wastewater and to verify infiltration of this water into the artesian groundwater system. A Turner Model 111 fluorometer equipped with a far-infrared source and a high sensitivity cell holder was used for dye analyses. The limit of sensitivity was determined to be 0.005 parts per billion (ppb) of dye.

Artesian groundwater samples were taken from each deep well for the determination of chemical constituents at least once during each of the 1975 discharge events. Samples were obtained from depths of 96 m after pumping each well for at least 30 min. Some wells were first purged for 30 min at the 85 m depth.

First Discharge Event

Irrigation wastewater was discharged for a period of 3.4 days between July 27 and August 1, 1975. Initially, the well was taking water at a rate of 1.09 m^3/min. This decreased to a constant inflow of 0.48-0.51 m^3/min after approximately 6 hours. A total volume of 2360 m^3 of wastewater was discharged.

Rhodamine WT dye (4.5 kg) was added as a tracer in "slugs" over the period of discharge. A dye concentration of 0.01 ppb or greater in artesian groundwater would be taken as adequate evidence that discharge water had entered the artesian system. This would allow for a 1.9×10^5 dilution of dye in groundwater assuming an even distribution of dye in the discharged wastewater.

Artesian groundwater, depths to water, and quality of water in the recharge zone were monitored during the discharge period and for 25 days thereafter.

Second Discharge Event

The second discharge event was initiated 25 days after termination of the first discharge period. Irrigation wastewater was discharged to the disposal well at a maximum inflow of 0.48-0.51 m^3/min for a period of 8.3 days between August 26, 1975 and September 3, 1975. The wastewater was labeled with 2.3 kg of Rhodamine WT which was added in "slugs" over the period of the discharge. A total volume of 4540 m^3 of wastewater was injected.

Artesian groundwater was monitored during the period of discharge and at 1-week intervals thereafter, with an emphasis on analyses for indicator bacteria and dye. Sampling techniques were modified in that the deep wells were purged by pumping at depths of 85 m for at least 30 min prior to sampling at depths of 96 m. On most occasions, water samples were taken at both depths.

Well DW1 was not sampled during the second discharge event or any of the succeeding events because it was judged to be a dead well. This decision was based on extreme drawdown within DW1 (13 m at a pumping rate of 26 l/min) relative to the other deep wells (0.2 m at the same pumping rate).

Depths to water in the shallow wells and the quality of water in the upper recharge zone were monitored in the usual manner during the discharge period and for 27 days thereafter.

Third Discharge Event

The third discharge event was carried out over a period of 16 days from September 30, 1975 to October 16, 1975. The volume of wastewater discharged over the first 8 days was 4540 m^3 while 2380 m^3 were discharged during the second 8 days for a total of 6920 m^3. The decrease in discharge volume during the second period was attributed to a loss in head at the point of diversion resulting from a substantial decrease in the flow of wastewater in the drainage ditch. No tracer was used in this discharge event.

Artesian groundwater was monitored during the discharge period and at 14 days thereafter. The wells were purged by pumping from depths of 85 m, except for wells DW4 and DW5 on days 2 and 29, prior to sampling at depths of 96 m. In most cases, water samples were taken from both depths.

Depths to water in the shallow wells and water quality monitoring of the recharge zone were carried out in the usual manner during the period of discharge and for 15 days thereafter.

Fourth Discharge Event

A fourth and final discharge event was conducted in 1976 after modification of the deep monitoring well network and addition of five cased shallow wells (SW10-14). The special objectives of this event were:

1) To determine if prior sampling techniques used in defining the quality of water in the recharge zone were providing representative results.

2) To confirm the premise that wastewater discharged into the shallow recharge zone was infiltrating a saturated fractured basalt zone situated just above the confining layer of dense basalt between 78 m and 95 m below land surface (hereafter referred to as the deep perched water zone).

Prior to initiation of the fourth discharge event, background quality of water of the deep perched water zone was determined. Samples were taken from DW3 and DW5 for this purpose after purging the wells for 30 min at the 85 m depth. Depths to groundwater were monitored to determine drawdown.

Irrigation wastewater was discharged for a period of 11.2 days from August 13, 1976 through August 24, 1976 at an average rate of 0.52 m^3/min. The total volume of water influent to the disposal well during this event was estimated to be 8330 m^3. Both irrigation wastewater and storm runoff water resulting from two heavy thunderstorms were injected into the recharge zone.

During this discharge event, water samples for chemical and bacterial analysis were taken from the cased shallow wells utilizing the mobile pumping unit. Samples were taken from SW10-13 after the wells were purged for 20 min. Depths to water were determined in the same manner as previously discussed.

Groundwater within the deep perched water zone was monitored from DW3-5 during the period of discharge with emphasis on analyses for indicator bacteria. Wells DW1 and DW2 were not sampled as the attempted modification of these wells was unsuccessful.

Determination of Geological Structure

The general geological formations and the lithologic characteristics of the upper recharge zone and underlying formations were determined from geophysical logs of the deep wells supplemented by driller's logs for both the deep and shallow wells. The nature of the groundwater system was defined by the same means..

Several geophysical functions were used to define lithologic characteristics, including: caliper, natural gamma, gamma-gamma, neutron-epithermal neutron, neutron-gamma, spontaneous potential, and single-point resistivity. Hydrologic characteristics were defined by use of fluid temperature, fluid resistivity, and neutron-epithermal neutron functions.

SECTION 6

RESULTS AND DISCUSSION

Geology

A geologic sequence of the project site constructed from geophysical logs is presented in figure 5. A loess overburden varying in thickness from 5.5 to 17.1 m overlies a basalt zone which extends to depths varying from 29.8 to 31.1 m. A clay and rubble zone to depths of 39.0 to 39.9 m underlies the basalt at well DW4 while a clay and sand zone extending to a depth of 41.5 m is found at well DW5. A second basalt layer to depths varying from 92.7 to 98.8 m overlies a saturated clay and rubble zone believed to be a principal component of the regional aquifer.

A more detailed representation of the principal geologic formations based on interpretations of geophysical logs is shown in figure 6. The heterogeneous strata of basalt underlying the recharge zone consist of several alternating zones of varying permeability and of unknown continuity. One zone of dense basalt is contiguous to the recharge zone and could impede the infiltration of discharge water into the saturated clay and rubble zone of the artesian aquifer.

A stratigraphic cross section of the formations from land surface to the upper recharge zone, compiled from both geophysical logs of the disposal well and deep wells and driller's logs for the shallow wells, is shown in figure 7. Here the recharge zone is seen as a clay and rubble zone with an overlying fractured basalt layer. Both are continuous across the cross-sections but vary considerably in depths from land surface and in formation thickness.

Considering the configurations of the clay and rubble and fractured basalt formations in the recharge zone, it seems apparent that wastewater discharged into these zones will not form a recharge mound in the usual sense. Furthermore, there exists the distinct possibility of channelized flow of injected water through any fractured basalt zones that would become saturated.

The groundwater system at the project site is rather simple, the primary aquifer being a leaky artesian system in the lower clay and rubble zone. The dense basalt strata overlying this zone is considered to be the confining layer for the artesian system.

Water-bearing formations were noted overlying the confining layer during the construction of wells DW2-DW5. These may be either naturally occurring, resulting from leakage through fractures in the confining layer, or

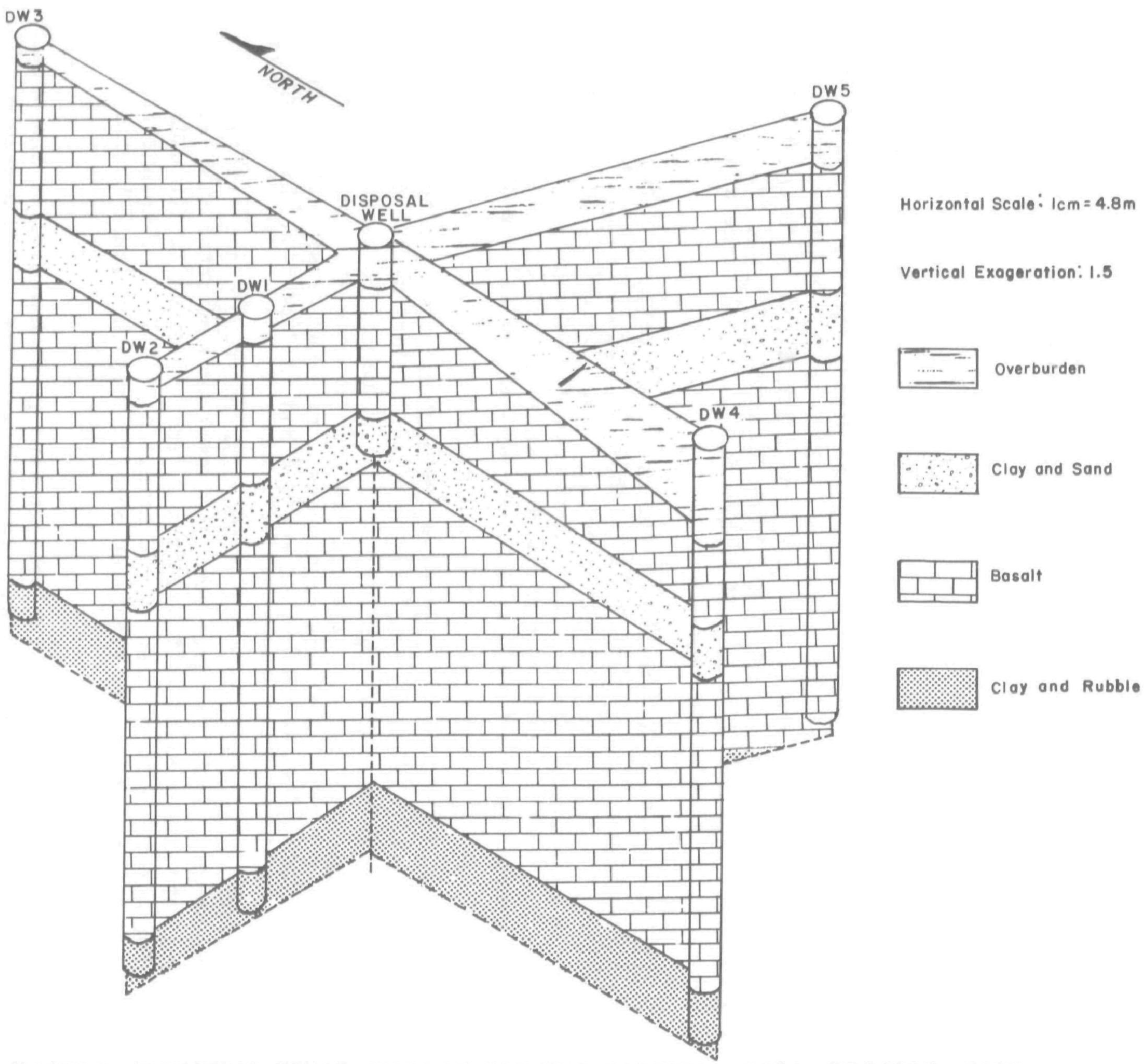

FIGURE 5. ISOMETRIC FENCE DIAGRAM FOR THE DISPOSAL WELL PROJECT SITE

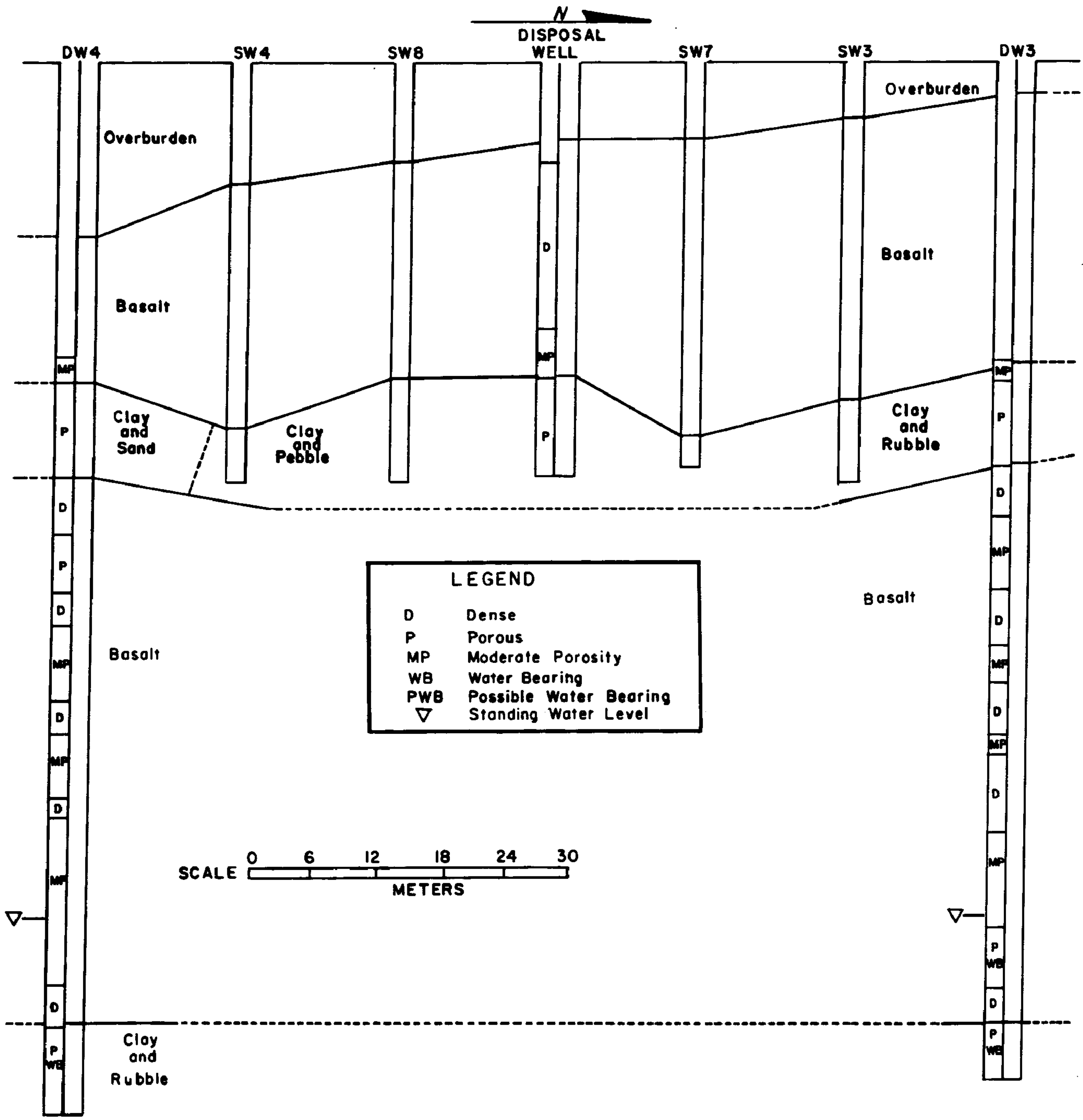

FIGURE 6. STRATIGRAPHIC CROSS SECTION OF THE DISPOSAL WELL PROJECT SITE

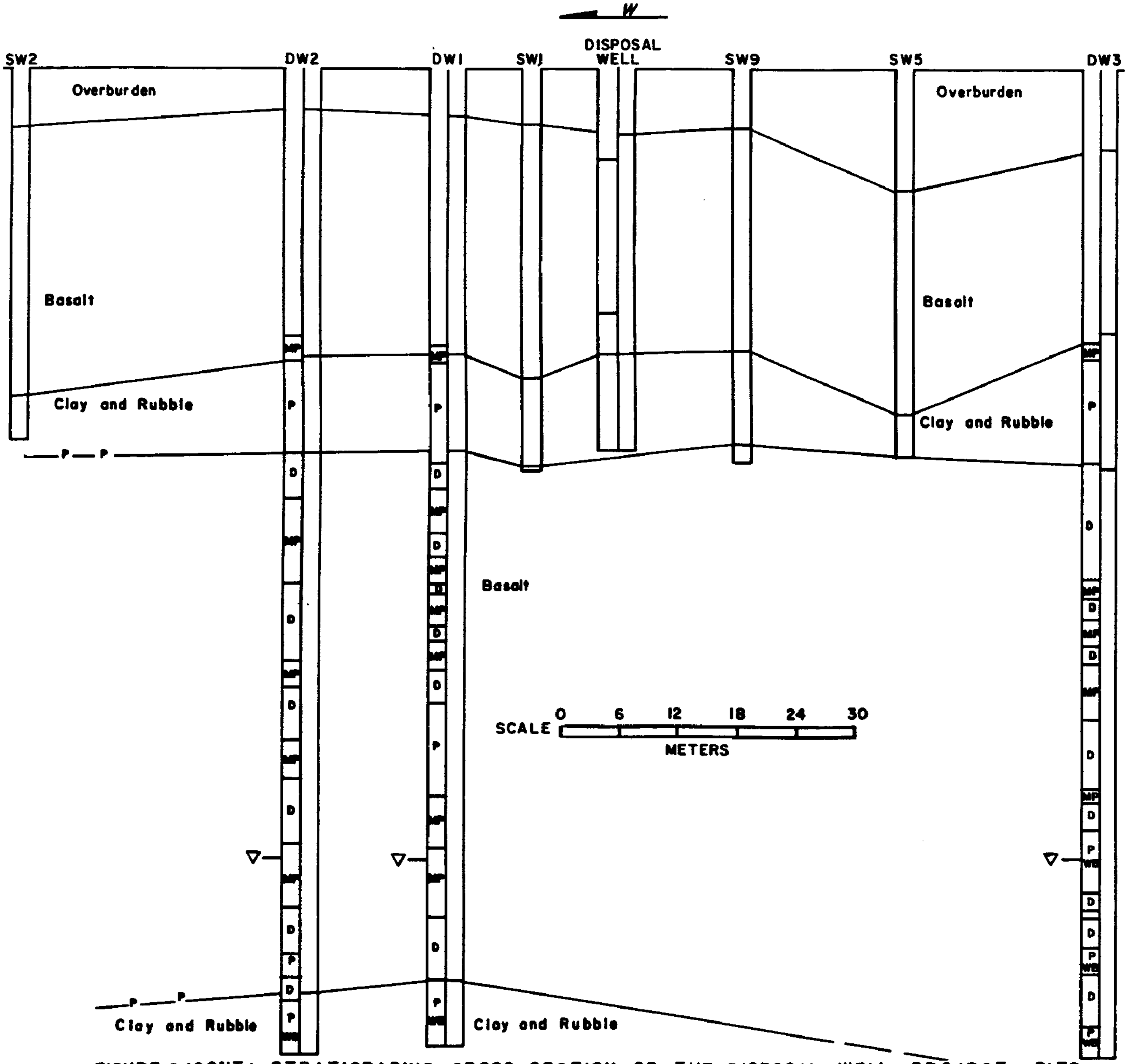

FIGURE 6 (CONT.). STRATIGRAPHIC CROSS SECTION OF THE DISPOSAL WELL PROJECT SITE

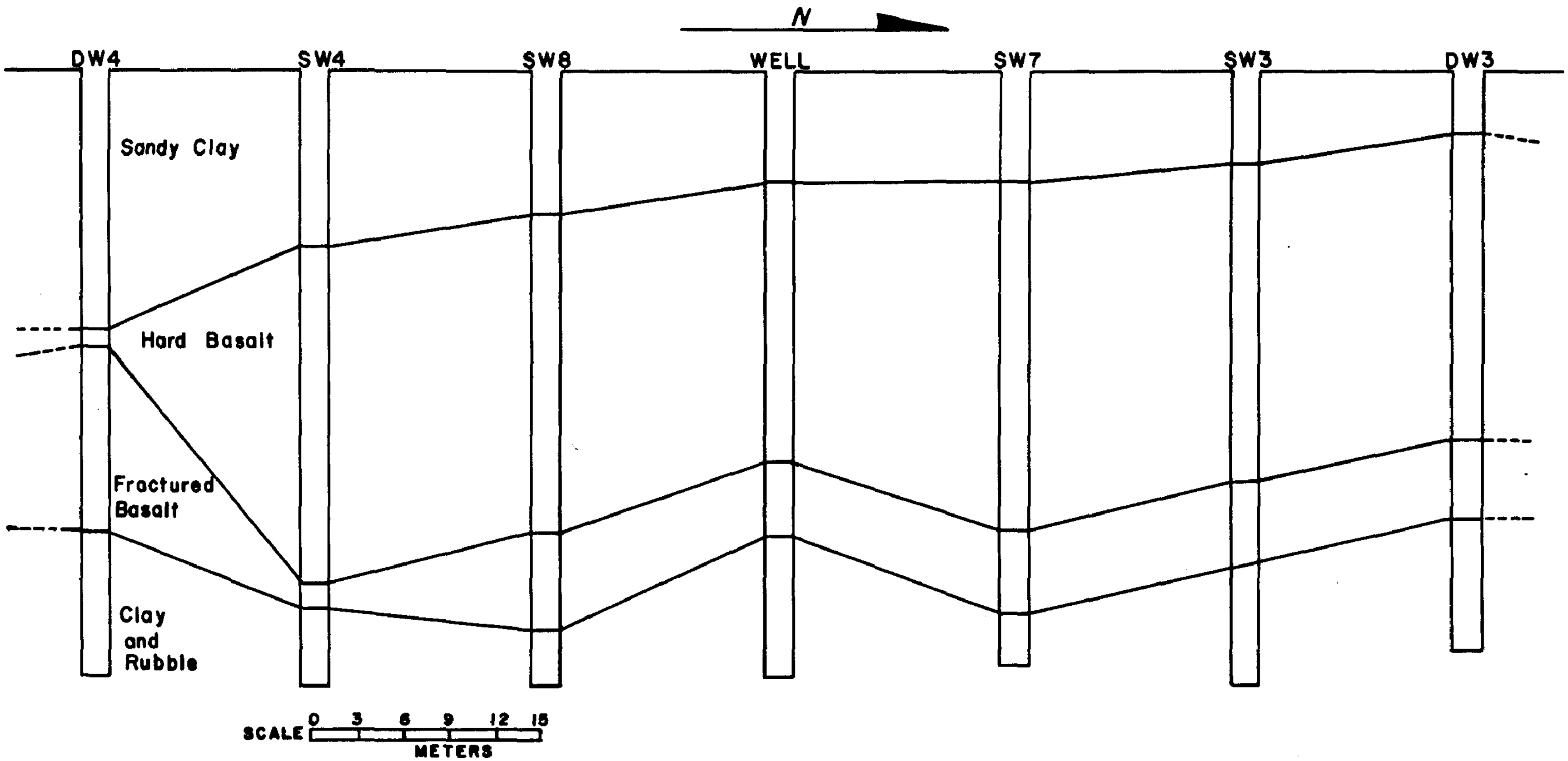

FIGURE 7. STRATIGRAPHIC CROSS SECTION OF INITIAL DISCHARGE ZONES

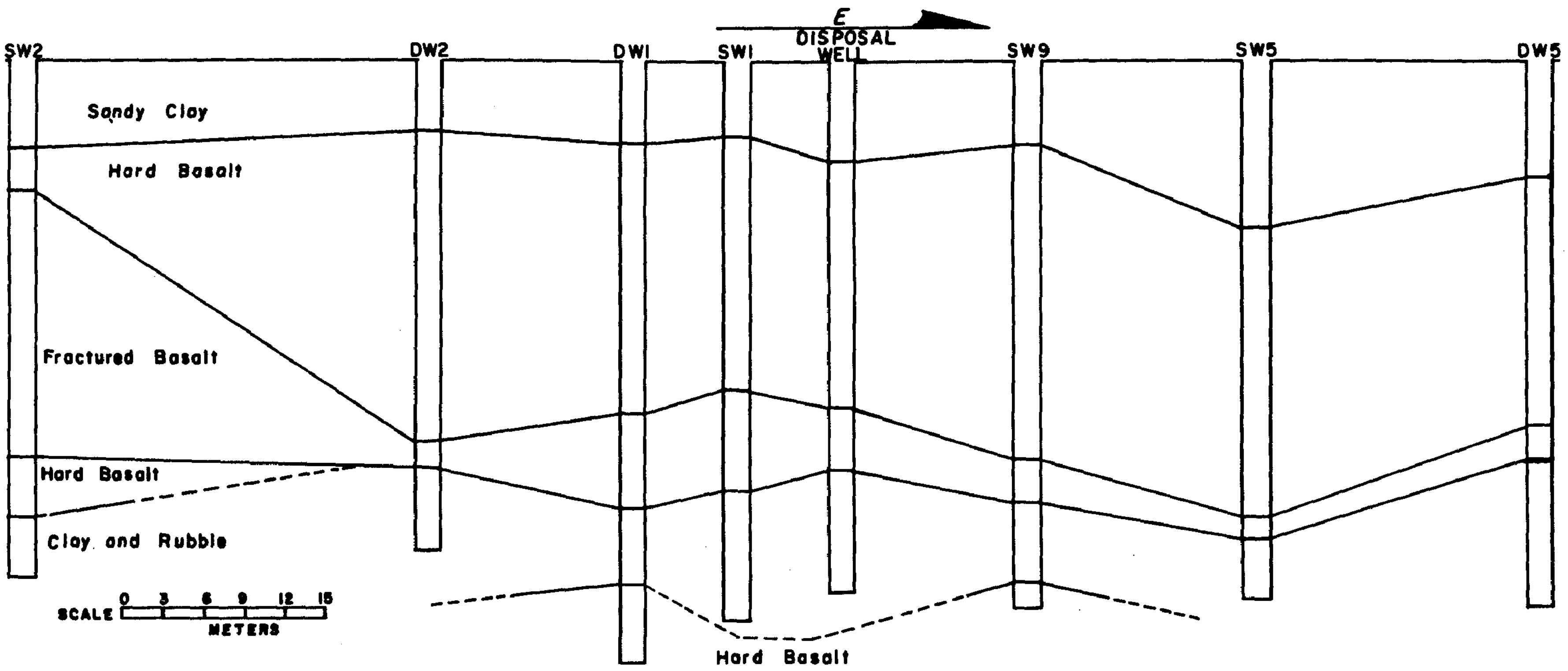

FIGURE 7 (CONT.). STRATIGRAPHIC CROSS SECTION OF INITIAL DISCHARGE ZONES

generated perched water zones. The source (or sources) of the latter could have been water used in drilling operations, wastewater discharged to the disposal well in the first year, or artesian groundwater leakage through the annular spaces at wells DW2-5. In any event, their existence must be recognized in future considerations of the quality of deep percolating discharge water which may intersect these water-bearing formations.

Background Quality of Groundwater

Background quality of artesian groundwater at the project site was determined from samples withdrawn from the five deep wells prior to initiation of the discharge studies in 1975 (table 5). The chemical quality of groundwater varied at a given well from one sampling occasion to another. In view of this, changes of similar magnitude in the chemical quality of groundwater during periods of wastewater discharge were not considered as evidence of deep percolating wastewater intercepting artesian groundwater.

The rather high total coliform count found in water from well DW3 on the first sampling event was thought to be residual bacteria introduced during well construction. Subsequent samples from this well showed no total coliforms present. Water samples from two other deep wells showed low total coliform counts on isolated occasions and, in these cases, the bacteria may have been introduced inadvertently during sampling. The majority of water samples showed no total coliforms, and thus the artesian groundwater was presumed to be free of such bacteria.

High levels of noncoliform bacteria were found in water samples from wells DW1-3. Filtration volumes of 50 ml or more often yielded a bacterial film on the membrane filter, and numerous colonies (up to 200) were found for 25 ml filtration volumes. It was assumed that these noncoliform bacteria would not interfere with the total coliform test, and further, the absence of total coliform colonies in a 25 ml filtration volume indicated no such bacteria in a 100 ml sample. Water samples from wells DW4 and DW5 showed a few noncoliform bacteria on occasions, which would be expected for groundwater. The extraneous bacteria noted in water from wells DW1-3 probably were introduced by well construction procedures.

The specific conductance of water from well DW3 was substantially lower than that from wells DW4 and DW5, which seemed unusual for water from wells of such close proximity in the same artesian system. One possible explanation was that water of low specific conductance entered well DW3 from a water-bearing formation overlying the confining layer. The upper perforated area of the well casing extended into this formation, and water withdrawn from both the artesian system and this zone could have yielded samples of lower specific conductance than those obtained from wells DW4 and DW5. The source of water in the upper zone may have been relatively low specific conductance wastewater injected during the preliminary discharges to the disposal well.

TABLE 5. BACKGROUND QUALITY OF ARTESIAN GROUNDWATER
(samples from 96 m after minimum of 30 min pumping)

		INORGANIC CHEMICAL																
Well number	Sampling date	Alkalinity (mg/l as $CaCO_3$)	Ammonia (mg/l as N)	Barium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Chloride (mg/l)	Chromium (mg/l)	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Mercury (µg/l)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	Orthophosphate (mg/l as P)
DW1	2/21/75	132	0.02	0.39	0.07	0.02	73.4	61.4	<0.02	0.08	4.60	<0.05	12.4	0.20	<1.0	1.00	0.01	0.01
	4/ 2/75	124	0.00	0.38	0.18	<0.01	70.0	68.5	<0.02	0.13	1.15	<0.05	13.4	0.12	<1.0	0.66	0.00	0.03
	7/ 9/75	149	---	0.24	0.18	<0.01	62.8	61.8	<0.02	0.04	1.05	<0.05	12.2	0.04	<1.0	0.69	0.00	0.03
DW2	2/20/75	144	0.00	0.23	0.04	0.02	73.4	59.3	<0.02	0.04	1.70	<0.05	14.4	0.02	<1.0	1.45	0.00	0.01
	4/ 2/75	144	0.00	0.15	0.09	<0.01	66.0	60.7	<0.02	0.03	0.90	<0.05	15.9	<0.01	<1.0	1.38	0.01	0.05
	7/ 9/75	153	---	0.19	0.14	<0.01	74.2	60.7	<0.02	0.05	0.50	<0.05	13.8	0.02	<1.0	1.37	0.01	0.03
DW3	1/16/75	193	0.00	---	---	---	41.6	26.6	---	---	---	---	17.8	---	---	0.97	0.02	0.02
	2/21/75	193	0.00	0.13	0.12	<0.01	38.4	27.0	<0.02	<0.01	0.33	<0.05	16.6	0.02	<1.0	0.98	0.00	0.02
	4/ 4/75	198	0.00	0.10	0.14	<0.01	38.0	28.4	<0.02	0.02	0.10	<0.05	17.1	<0.01	<1.0	0.94	0.00	0.02
	7/10/75	207	---	0.06	0.10	<0.01	36.4	29.5	<0.02	0.04	0.06	<0.05	16.6	0.01	<1.0	0.93	0.00	0.03
DW4	1/16/75	158	0.00	---	---	---	78.0	73.5	---	---	---	---	17.6	---	---	1.66	0.00	0.01
	2/20/75	130	0.00	0.23	0.05	0.02	77.4	72.4	<0.02	<0.01	0.55	<0.05	15.8	<0.01	<1.0	1.90	0.00	0.01
	4/ 4/75	149	0.00	0.33	0.13	<0.01	73.0	72.4	<0.02	0.02	0.45	<0.05	17.1	0.01	<1.0	1.54	0.00	0.02
	7/ 9/75	166	---	0.08	0.05	<0.01	84.6	78.8	<0.02	0.02	0.63	<0.05	15.2	0.01	<1.0	1.52	0.00	0.02
DW5	1/16/75	155	0.00	---	---	---	76.0	68.2	---	---	---	---	16.5	---	---	1.72	0.01	0.01
	2/20/75	127	0.00	0.16	0.04	0.02	75.0	67.8	<0.02	0.02	0.85	<0.05	14.6	0.01	<1.0	1.75	0.00	0.00
	4/ 3/75	148	0.00	0.29	0.09	<0.01	71.0	69.2	<0.02	0.02	0.92	<0.05	15.9	0.01	<1.0	1.58	0.00	0.01
	7/ 9/75	160	---	0.05	0.12	<0.01	82.6	68.5	<0.02	0.02	0.48	<0.05	13.3	0.02	<1.0	1.59	0.00	0.02

TABLE 5 (continued)

		INORGANIC CHEMICAL									PHYSICAL		MICROBIOLOGICAL		
Well number	Sampling date	Potassium (mg/l)	Silver (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Zinc (mg/l)	Chemical oxygen demand (mg/l)	pH	Specific conductance (μmhos/cm)	Total dissolved solids (mg/l)	Temperature (°C)	Turbidity (N.T.U.)	Total coliforms (organisms/100 ml)	Fecal coliforms (organisms/100 ml)	Fecal streptococci (organisms/100 ml)
DW1	2/21/75	8.21	<0.01	32.2	63.4	0.06	30	7.94	550	---	16.0	97	0	0	0
	4/ 2/75	7.04	<0.01	31.0	67.2	0.02	18	7.89	580	352	16.0	48	8	0	0
	7/ 9/75	8.21	<0.01	32.2	43.2	0.04	15	7.57	580	---	16.5	34	0	0	0
DW2	2/20/75	7.43	<0.01	28.1	63.4	0.03	25	7.17	570	---	16.0	33	0	0	0
	4/ 2/75	7.82	<0.01	27.6	67.2	0.01	16	7.54	600	370	16.0	10	0	0	0
	7/ 9/75	7.82	<0.01	28.3	65.3	0.02	14	7.63	610	---	16.5	6.5	0	0	0
DW3	1/16/75	5.86	---	48.8	45.6	---	--	7.80	520	---	15.0	17	20	0	0
	2/21/75	4.69	<0.01	50.8	46.6	0.02	13	7.57	510	---	16.0	1.5	0	0	0
	4/ 4/75	5.08	<0.01	47.8	37.4	<0.01	8	7.45	520	346	15.8	1.2	0	0	0
	7/10/75	5/47	<0.01	47.8	37.4	0.01	6	7.46	520	---	16.0	1.4	0	0	0
DW4	1/16/75	8.21	---	32.2	72.5	---	--	7.81	645	---	16.0	2.6	0	0	0
	2/20/75	7.04	<0.01	31.0	69.1	0.03	23	7.64	650	---	16.0	1.4	4	0	0
	4/ 4/75	7.43	<0.01	30.8	69.6	<0.01	15	7.49	670	438	16.2	3.8	0	0	0
	7/ 9/75	7.82	<0.01	34.5	73.9	0.03	13	7.55	680	---	17.0	2.4	0	0	0
DW5	1/16/75	7.82	---	26.9	64.3	---	--	7.72	650	---	16.0	5.0	0	0	0
	2/20/75	6.65	<0.01	27.1	63.4	0.02	22	7.65	640	---	16.0	1.8	0	0	0
	4/ 3/75	7.43	<0.01	26.4	64.3	<0.01	16	7.29	630	415	16.0	1.5	0	0	0
	7/ 9/75	7.43	<0.01	27.1	63.4	0.04	14	7.65	650	---	17.0	1.4	4	0	0

Quality of Irrigation Wastewater

Data for the quality of irrigation wastewater is presented in table 6. For purposes of comparison, Idaho drinking water standards (11), the proposed drinking water standards of the EPA (12), and the recommended water-quality criteria for public water supplies (13) are given for parameters included therein.

Data in table 6 substantiated our belief that bacteria and sediment would be the only contaminants in the wastewater at the site that could cause degradation of groundwater below drinking water standards. Removal of these contaminants from the discharge water prior to their intersecting groundwater would result in recharge with comparatively high quality water.

Discharge Events Conducted During the 1975 Irrigation Season

Depths to water in shallow monitoring wells, SW1-9, during the first discharge event and in the 25-day interval thereafter demonstrated that a normal cone-shaped recharge mound was not formed (table 7). To illustrate, depths to water in well SW4, 30.5 m from the disposal well, were substantially less than those in SW8, 15.2 m from the disposal well, throughout the discharge period. Furthermore, discharge water did not appear in well SW3, 30.5 m from the disposal well, although water reached wells SW7, SW4, and SW5, all 30.5 m within 1.3 days.

Dewatering of the upper recharge zone after termination of discharge also indicated the formation of an unsymmetrical recharge zone. Wells SW4 and SW5 were dry shortly after termination in contrast to a steady decline in depths to water in wells SW1, 5, 6, 7, 9, and the disposal well. Water in the latter wells may have been "ponded water" in a wetted recharge zone rather than water in a saturated perched zone.

Monitoring of the upper recharge zone during the second discharge event also indicated the formation of a nonsymmetrical recharge mound. Data for the depths to water in the shallow wells given in table 8 again show water levels in well SW8 to be greater than in well SW4, with no water in well SW3 as contrasted to wells SW9, 7, and 4. Water appeared in wells SW4 and SW8 sooner than during the first discharge event. This was attributed to the receiving formations having been wetted previously. The presence of water in well SW2 indicated that discharge water had traveled beyond 61 m in that direction.

Dewatering of the upper recharge zone, after termination of the second discharge, again appeared to be unusual. Wells SW2, 4, and 8 were dry within a short time; whereas water levels in wells SW1, 5, 6, 7, 9, and the disposal well gradually declined.

Depths to water in the shallow wells during and after the third discharge are given in table 9. These data affirm the generation of a nonsymmetrical recharge zone which extended an undefined distance beyond 61 m in the direction of well SW2. The increase in depths to water on days 7.2 and 8.0 is attributed to a lower wastewater inflow to the disposal well over the weekend.

TABLE 6. QUALITY OF IRRIGATION WASTEWATER, JUNE 26, 1975 to AUGUST 24, 1976

	PESTICIDES																HERBICIDES	
	Aldrin (ppt)	Chlordane (ppt)	DDD (ppt)	DDE (ppt)	DDT (ppt)	Dieldrin (ppt)	Diazinon (ppt)	Endrin (ppt)	Heptachlor (ppt)	Heptachlor epoxide (ppt)	Lindane (ppt)	Malathion (ppt)	Methoxychlor (ppt)	Methyl parathion (ppt)	Parathion (ppt)	Toxaphene (ppt)	2, 4-D (ppt)	2, 4, 5, -T (ppt)
Number of determinations	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Low	---	---	---	<10	<10	<10	---	---	---	---	---	---	---	---	---	---	---	---
Mean	---	---	---	<10	<10	<10	---	---	---	---	---	---	---	---	---	---	---	---
High	<10	<10	<10	10.6	14.9	37.3	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Idaho Drinking Water Standards	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Public Water Supply Criteria	1,000	3,000	---	50,000	---	1,000	---	500	100	100	5,000	---	1,000	---	---	5,000	20,000	2,000
E.P.A. Proposed Drinking Water Standards	---	3,000	---	---	---	---	---	200	100	100	4,000	---	100,000	---	---	5,000	100,00	10,000

TABLE 6 (continued)

	INORGANIC CHEMICAL																		
	Alkalinity (mg/l as $CaCO_3$)	Ammonia (mg/l as N)	Arsenic (mg/l)	Barium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Chloride (mg/l)	Chromium (mg/l)	Copper (mg/l)	Cyanide (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Mercury (µg/l)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	Orthophosphate (mg/l as P)
Number of determinations	10	4	4	5	10	5	10	10	5	5	7	5	5	10	5	5	10	10	10
Low	148	---	---	0.04	0.05	---	40.2	14.6	---	0.01	---	<0.02	---	10.7	<0.01	<1.0	0.08	0.00	0.05
Mean	168	---	---	0.05	0.10	---	42.4	16.6	---	0.02	---	0.02	---	14.4	0.02	1.0	0.35	0.03	0.11
High	198	0.00	<0.01	0.07	0.18	<0.01	46.0	19.9	<0.02	0.02	<0.01	0.06	<0.05	27.6	0.04	1.3	1.82	0.07	0.22
Idaho Drinking Water Standards	---	---	0.05	1.0	---	0.05	---	250	0.05	1.0	0.20	0.3	0.05	---	0.05	2.0	10		---
Public Water Supply Criteria	---	0.5	1.0	1.0	1.0	0.01	---	250	0.05	1.0	0.20	0.3	0.05	---	0.05	2.0	10		---
E.P.A. Proposed Drinking Water Standards	---	---	0.05	1.0	---	0.01	---	---	0.05	---	---	---	0.05	---	---	2.0	10		---

TABLE 6 (continued)

	INORGANIC CHEMICAL										PHYSICAL						MICROBIOLOGICAL		
	Potassium (mg/l)	Selenium (µg/l)	Silver (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Zinc (mg/l)	Chemical oxygen demand (mg/l)	pH	Specific conductance (µmhos/cm)	Total dissolved solids (mg/l)	Color (C.U.)	Temperature (°C)	Turbidity (NTU)	Total nonfilterable residue (mg/l)	Nonfilterable fixed residue (mg/l)	Nonfilterable volatile residue (mg/l)	Total coliforms (organisms/100 ml)	Fecal coliforms (organisms/100 ml)	Fecal streptococci (organisms/100 ml)
Number of determinations	10	4	5	10	10	5	10	14	49	9	9	27	48	35	33	33	45	45	38
Low	3.91	0.9	---	15.9	30.7	0.01	13	7.94	350	197	<5	5.6	7.7	9.3	0.6	4.1	580	65	900
Mean	5.90	1.2	---	17.6	33.2	0.02	24	---	382	225	43	17.2	86	237.1	151.8	33.2	29,000	850	7,400
High	11.3	1.8	<0.01	22.8	37.4	0.02	37	8.94	445	290	>70	35.0	320	1652	731.2	108.1	96,000	13,000	16,000
Idaho Drinking Water Standards	---	10	0.05	---	250	5.0	--	---	---	500	15	---	5	---	---	---	2(MPN)	---	---
Public Water Supply Criteria	---	10	0.05	---	250	5.0	--	---	---	500	75	29.0	5	---	---	---	---	---	---
E.P.A. Proposed Drinking Water Standards	---	10	0.05	---	---	---	--	---	---	---	--	---	1	---	---	---	1	---	---

TABLE 7. DEPTHS TO WATER FOR SHALLOW WELLS--FIRST DISCHARGE EVENT (measurements in meters from reference elevation of 1263.7 m; discharge terminated after 3.4 days)

Well Number	D*	Days from Inception of Discharge 0	0.3	0.9	1.3	1.9	2.3	2.9	3.2	9.3	14.3	28.3
SW1	7.6	DRY	26.76	26.09	26.15	26.15	25.85	25.85	25.54	27.77	28.10	28.56
SW7	15.2	DRY	DRY	25.82	25.82	25.82	25.51	25.51	25.21	27.74	28.10	28.53
SW8	15.2	DRY	DRY	DRY	34.47	34.47	34.47	34.17	28.68	DRY	DRY	DRY
SW9	15.2	DRY	26.95	25.73	25.42	25.42	25.42	25.42	25.42	27.77	28.13	28.83
SW3	30.5	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
SW4	30.5	DRY	DRY	DRY	26.95	26.03	26.34	26.03	DRY	DRY	DRY	DRY
SW5	30.5	DRY	27.77	26.24	26.24	26.24	26.24	25.94	25.94	27.71	28.04	28.41
SW6	30.5	DRY	27.98	27.07	26.76	26.76	26.58	26.58	26.46	27.71	28.10	28.47
SW2	61.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
Disposal well	0	DRY	---	---	---	---	---	---	---	27.77	28.10	28.50

* D = distance from disposal well in meters.

TABLE 8. DEPTHS TO WATER FOR SHALLOW WELLS--SECOND DISCHARGE EVENT (measurements in meters from reference elevation of 1263.7 m; discharge terminated after 8.0 days)

Well Number	D*	Days from Inception of Discharge								
		0	0.9	1.1	1.9	2.9	8.0	8.9	15.0	35
SW1	7.6	28.50	25.88	25.82	25.70	25.54	26.09	26.76	27.68	28.44
SW7	15.2	28.44	25.79	25.63	25.70	25.45	25.21	26.15	27.65	28.41
SW8	15.2	DRY	34.35	33.01	32.22	29.44	27.22	33.01	DRY	DRY
SW9	15.2	28.65	25.48	25.48	25.48	25.18	25.48	26.34	27.62	28.53
SW3	30.5	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
SW4	30.5	DRY	26.18	26.31	26.24	25.97	26.18	DRY	DRY	DRY
SW5	30.5	28.13	26.37	24.99	26.49	26.09	26.09	26.82	27.83	28.26
SW6	30.5	28.41	26.98	26.82	26.64	26.00	26.46	25.73	27.68	28.44
SW2	61.0	DRY	DRY	DRY	DRY	DRY	29.63	DRY	DRY	DRY
Disposal well	0	28.29	---	---	---	---	---	26.46	27.62	28.29

* D = distance from disposal well in meters.

TABLE 9. DEPTHS TO WATER FOR SHALLOW WELLS--THIRD DISCHARGE EVENT (measurement in meters from reference elevation of 1263.7 m; discharge terminated after 16.0 days)

Well Number	D*	Days from Inception of Discharge 0	0.1	0.9	1.2	1.9	2.2	3.0	7.2	8.0	15.0	28.3
SW1	7.6	28.44	26.70	25.94	25.82	25.66	25.54	25.51	26.46		25.97	27.95
SW7	15.2	28.41	27.01	25.85	25.70	25.54	25.45	25.27	26.27	26.85	25.85	27.95
SW8	15.2	DRY	DRY	34.44	32.89	29.41	27.95	27.04	27.52	31.18	29.78	DRY
SW9	15.2	28.53	26.85	25.63	25.48	25.36	25.21	25.05	25.79	26.88	25.70	27.92
SW3	30.5	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
SW4	30.5	DRY	DRY	27.49	26.61	26.12	25.88	25.66	26.24	26.91	26.03	DRY
SW5	30.5	92.6	27.49	26.49	26.49	26.00	25.94	25.88	26.24	26.79	26.03	27.83
SW6	30.5	28.44	27.77	26.98	26.82	26.58	26.49	26.43	26.46	26.82	26.58	27.92
SW2	61.0	DRY	DRY	DRY	DRY	DRY	DRY	27.74	27.37	28.32	27.62	DRY
Disposal well	0	28.29	---	---	---	---	---	---	---	---	---	---

* D = distance from disposal well in meters.

Dewatering of the upper recharge zone paralleled that for the first two discharge events; i.e., wells SW2, 4, and 8 were dry shortly after termination of discharge. Depths to water in all other wells (excluding SW3) was approximately 30.0 m 15 days after termination of discharge.

Chemical quality of water from the shallow wells was determined after completion of the first and third discharge events (table 10). A comparison of these values with the corresponding constituents in the wastewater over a given discharge event indicated an overall deterioration in the chemical quality of discharge water in the upper recharge zone.

The chemical quality of groundwater was monitored both during and after the three wastewater discharge events conducted in 1975 (table 11). No degradation in the chemical quality of the regional groundwater system was observed.

Dye concentrations of water from the shallow wells for the three discharge events indicated that considerable adsorption of the dye had taken place (table 12). A homogeneous solution of the dye in the wastewater discharged during the first event would have yielded a dye concentration of 1930 ppb. An even greater dye concentration would have been expected on the last day of discharge as 10% of the dye was added to the last 5% of the discharged wastewater. However, the maximum dye concentration in well SW1 on the last day of discharge (8/1/75) was determined to be 64% of the value calculated for a homogeneous solution. Furthermore, considerable decreases in dye concentrations occurred after termination of the first and second discharge events. These data could be taken as evidence of adsorption of the dye both on the sediment in the wastewater and on the clays in the upper recharge zone.

A look at the data for the third discharge event (no dye was added) shows the expected decrease in dye concentrations from 10/1/75 (or 10/2/75) to 10/15/75. However, there was an increase in dye concentration 14 days after termination of discharge, which indicates that an equilibrium had been reached for dye adsorption-desorption. An equilibrium dye concentration of 45 bbp (mean value for 10/5/75) was attained.

Further adsorption of dye was possible as discharge water percolated down through lower geological formations. The dye concentration could have been reduced to a level such that subsequent dilution in groundwater would have resulted in a concentration below the limit of detection a short distance from the point of entry. Thus, it appeared that adsorption limited the value of Rhodamine WT dye as a tracer for wastewater discharges.

Significant dye concentrations in the regional groundwater table were detected on days 15, 16, and 17 after initiation of the first discharge event and on days 1, 2, 8, 9, and 15 after initiation of the second discharge event (table 13). A failure in the groundwater sampling unit prevented earlier detection of the dye during the initial discharge in 1975. However, presence of the dye within the regional aquifer indicated that discharge water had infiltrated the groundwater.

TABLE 10. CHEMICAL QUALITY OF WATER IN SHALLOW WELLS AND OF INJECTED WASTEWATER FIRST AND THIRD DISCHARGE EVENTS

Well number	Date(s) of sampling	Alkalinity (mg/l as $CaCO_3$)	Ammonia (mg/l as N)	Boron (mg/l)	Calcium (mg/l)	Chloride (mg/l)	Magnesium (mg/l)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	Orthophosphate (mg/l as P)	Potassium (mg/l)	Silica (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Chemical oxygen demand (mg/l)	Specific conductance (µmhos/cm)	Total dissolved solids (mg/l)
FIRST DISCHARGE EVENT																	
Disposal well	8/13/75	183	---	0.16	36.6	24.8	17.4	2.45	0.01	0.14	7.43	31.0	19.8	31.7	28	470	276
SW1	8/13/75	160	---	0.19	33.2	26.3	22.4	3.15	0.03	0.16	7.43	31.7	19.6	31.7	32	460	289
SW5	8/13/75	156	---	0.16	30.2	24.5	25.1	1.80	0.01	0.07	7.82	40.8	20.9	32.6	35	425	277
SW6	8/13/75	144	---	0.19	30.0	25.6	21.8	1.45	0.00	0.12	7.43	31.6	17.7	30.7	32	430	259
SW7	8/13/75	171	---	0.19	27.0	23.1	26.1	1.15	0.10	0.10	7.82	36.5	20.9	31.7	26	430	263
SW9	8/13/75	179	---	0.18	26.8	23.4	29.3	2.15	0.00	0.10	9.00	37.5	22.1	32.6	20	480	288
Wastewater*	7/28-8/1/75	176	---	0.09	42.2	16.0	11.2	0.19	0.05	0.12	5.71	14.1	16.3	30.9	27	365	205
THIRD DISCHARGE EVENT																	
Disposal well	10/30/75	180	0.26	0.13	48.4	21.6	21.0	0.48	0.00	0.33	5.87	27.0	23.0	41.8	24	470	287
SW1	10/30/75	230	0.01	0.11	43.2	20.9	21.2	1.60	0.00	0.26	6.26	28.5	22.5	40.3	47	460	259
SW5	10/30/75	245	0.01	0.12	34.2	20.6	25.3	0.88	0.00	0.13	7.04	31.7	22.5	43.7	18	460	252
SW6	10/30/75	189	0.02	0.08	42.6	20.9	19.0	1.48	0.01	0.26	5.47	24.9	21.1	40.8	13	450	239
SW7	10/30/75	202	0.01	0.12	29.8	19.9	25.4	0.80	0.00	0.13	7.04	34.9	22.1	40.3	14	440	241
SW9	10/30/75	180	0.01	0.07	35.0	20.6	27.3	1.38	0.00	0.15	7.43	35.6	23.9	44.2	12	480	269
Wastewater *	9/30-10/16/75	169	0.00	0.05	44.8	19.2	17.0	0.08	0.01	0.05	4.30	19.1	19.3	37.4	13	417	252

* Wastewater: Mean values for first and third discharge events.

TABLE 11. CHEMICAL QUALITY OF ARTESIAN GROUNDWATER DURING DISCHARGE EVENTS (samples from 96 m after minimum of 30 min pumping)

Well number	Sampling date	Alkalinity (mg/l as $CaCO_3$)	Ammonia (mg/l as N)	Boron (mg/l)	Calcium (mg/l)	Chloride (mg/l)	Magnesium (mg/l)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	Orthophosphate (mg/l as P)	Potassium (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Chemical oxygen demand (mg/l)	pH	Specific conductance (μmhos/cm)	Total dissolved solids (mg/l)	Temperature (°C)	Turbidity (N.T.U.)
DW1	7/29/75	142	---	0.05	56.6	64.3	12.9	0.30	0.01	0.02	7.43	29.0	65.3	18	7.77	590	374	16.5	34
	8/12/75	146	---	0.16	62.0	60.7	15.0	1.06	0.00	0.02	7.04	31.7	62.4	24	7.68	590	389	16.5	38
DW2	7/29/75	153	---	0.07	71.0	62.1	14.5	1.08	0.00	0.01	7.82	28.1	66.2	19	7.91	600	397	16.5	1.1
	8/12/75	141	---	0.16	69.0	62.5	15.9	1.20	0.01	0.02	7.04	27.1	64.3	23	7.63	600	403	16.5	6.0
	8/28/75	154	---	0.11	71.2	62.1	16.0	1.42	0.00	0.02	7.04	27.1	69.1	19	7.72	600	393	16.0	1.3
	9/10/75	152	0.00	0.06	72.4	61.8	14.4	1.54	0.00	0.00	7.43	27.4	67.2	16	7.62	610	397	16.5	3.8
	10/ 3/75	151	0.00	0.04	71.8	63.2	15.6	1.58	0.00	0.01	7.04	26.9	49.9	--	7.51	605	380	16.0	2.9
DW3	7/29/75	204	---	0.14	41.0	29.5	18.1	0.94	0.00	0.02	5.87	46.2	40.3	6	7.70	540	---	17.0	0.9
	8/12/75	191	---	0.22	40.8	29.5	18.9	0.90	0.00	0.02	5.47	51.1	40.3	17	7.74	540	---	16.5	3.6
	9/10/75	202	0.00	0.13	42.4	29.1	18.7	0.96	0.00	0.02	5.47	46.5	42.7	13	7.60	550	335	16.5	6.7
	10/ 3/75	205	0.00	0.09	40.8	30.8	20.3	1.06	0.00	0.02	5.08	43.7	420	--	7.44	540	339	16.5	1.0
DW4	7/29/75	166	---	0.07	76.6	80.2	17.9	1.28	0.00	0.01	8.60	34.7	74.9	17	7.50	640	398	16.5	1.9
	8/12/75	153	---	0.15	74.8	86.3	19.2	1.49	0.00	0.01	7.43	30.1	69.1	23	7.64	660	420	16.5	6.0
	9/10/75	166	0.00	0.02	79.0	73.5	19.6	1.53	0.00	0.00	7.82	31.0	72.0	21	7.48	660	430	16.5	1.2
	10/ 2/75	166	0.00	0.04	79.0	88.7	17.0	1.79	0.00	0.01	7.82	30.8	48.0	--	7.41	670	---	17.0	1.5
DW5	7/29/75	158	---	0.08	77.0	69.6	13.7	1.38	0.01	0.01	7.43	27.4	65.3	16	7.49	640	410	16.5	1.0
	8/12/75	150	---	0.16	76.6	84.1	16.3	1.41	0.00	0.01	7.04	26.2	63.4	23	7.67	635	402	16.5	3.5
	8/28/75	147	---	0.12	78.2	68.9	16.9	1.68	0.00	0.02	7.04	26.4	65.3	32	7.65	640	403	16.8	2.0
	9/10/75	157	0.00	0.02	75.8	69.9	15.4	1.06	0.00	0.00	7.04	26.4	65.3	20	7.42	630	399	16.5	4.2
	10/ 2/75	161	0.00	0.02	76.6	71.0	16.7	1.71	0.00	0.01	7.04	25.8	67.2	--	7.46	630	404	16.5	0.67

TABLE 12. DYE CONCENTRATIONS IN WATER FROM SHALLOW WELLS (ppb)

Well number	First discharge event				Second discharge event			Third discharge event					
	8/1	8/6	8/13	8/26	9/3	9/10	9/30	10/1	10/2	10/3	10/7	10/15	10/30
SW1	1240	514	524	380	343	254	270	4.00	5.19	9.70	10.4	0.91	49.5
SW2	---	---	---	---	132	---	---	---	---	34.8	13.7	9.90	---
SW4	720	---	---	---	378	---	---	43.5	43.5	36.2	22.8	22.8	---
SW5	616	406	402	288	132	204	150	87.0	51.0	43.5	24.2	27.2	37.8
SW6	696	518	524	370	570	310	200	27.3	22.8	14.5	8.45	3.75	45.0
SW7	640	378	366	336	301	260	180	51.0	46.5	39.0	34.0	30.2	48.0
SW8	572	---	---	---	186	---	---	40.5	43.5	36.2	30.2	27.2	---
SW9	972	432	330	336	380	177	171	34.8	25.8	11.6	21.2	4.00	45.0
Disposal well	---	508	526	325	---	322	150	---	---	---	---	---	45.0

TABLE 13. DYE CONCENTRATIONS IN ARTESIAN GROUNDWATER (ppb)

First Discharge Event

Well Number	Days from Inception of Discharge						
	4*	15*	16#		17#		25#
DW2	--	4.5	--	--	6.0	1.0	--
DW3	0	1.4	--	--	1.4	0.01	--
DW4	--	0	0.5	0	--	--	0
DW5	0	0	0.5	0	--	--	0

Second Discharge Event

Well Number	Days from Inception of Discharge									
	0*	1*	2#		8#		9#		15#	
DW2	--	0.14	1.1	0	--	--	0.08	0	0.01	0
DW3	--	0.01	--	--	0.1	0	--	--	0.01	0
DW4	0	--	--	--	0.0	0	--	--	--	0
DW5	0	--	--	0	0.45	0	--	--	--	0

Third Discharge Event

Well Number	Days from Inception of Discharge											
	1#		2*	3#		7#		8#		29*	30#	
DW2	0.12	0	--	0	0	0.01	0	--	--	--	0.01	0
DW3	0	0	--	0	0	--	--	0	0	0	--	--
DW4	0	0	0	--	--	--	--	0	0	0	--	--
DW5	0	0	0	--	--	--	--	0	0	0	--	--

* Samples from depth of 96 m after minimum of 30 min pumping.

Samples from two depths: 85 m (1st column) after 5 min pumping and 96 m (2nd column) after minimum of 30 min pumping.

The absence of dye in the groundwater during the third discharge event except for samples from DW2 at the 85 m depth appeared unusual. One would have anticipated the presence of dye in samples which showed high total coliform counts. However, no dye was added in the third discharge event; and the adsorption of dye previously added coupled with dilution of dye in receiving water could have been responsible for dye concentrations below interpretative significance.

Bacterial samples collected from the deep monitoring wells (DW1-5) were analyzed for total coliforms, fecal coliforms, and fecal streptoccoci (table 14). Though not shown in table 14, water from wells DW1-3 gave high counts of noncoliform bacteria (150-300 colonies for 25 ml filtration volumes) on each sampling occasion, as did water from wells DW4 and DW5 on day 4 and thereafter (50-200 colonies for 40 ml filtration volumes). It was assumed the extraneous bacteria did not interfere with the test for total coliforms.

TABLE 14. LEVELS OF INDICATOR BACTERIA IN GROUNDWATER--FIRST DISCHARGE EVENT (organisms/100 ml)

Well Number	Organism*	Days from Inception of Discharge 1#	2#	4#	15#	16†		17†		25#
DW1	TC	0	4	--	2	--	--	--	0	--
	FC	0	0	--	2	--	--	--	0	--
	FS	0	8	--	0	--	--	--	0	--
DW2	TC	0	8	--	8	--	--	4	0	--
	FC	0	0	--	6	--	--	0	0	--
	FS	4	12	--	1	--	--	--	--	--
DW3	TC	0	3	0	66	--	--	0	0	--
	FC	0	0	0	32	--	--	0	0	--
	FS	3	0	4	0	--	--	0	0	--
DW4	TC	1	8	--	16	20	4	--	--	0
	FC	0	0	--	4	0	0	--	--	0
	FS	0	2	--	0	0	0	--	--	0
DW5	TC	0	0	4	8	28	2	--	--	0
	FC	0	0	0	0	8	0	--	--	0
	FS	2	2	0	1	0	0	--	--	0

* TC = total coliforms; FC = fecal coliforms; FS = fecal streptococci.

Samples from depths of 96 m after 30 min pumping.

† Samples from two depths: 85 m (1st column) after 5 min pumping and 96 m (2nd column) after minimum of 30 min pumping.

From the data in table 14, it is obvious that bacterial contamination of artesian groundwater had occurred during the first discharge event. An analysis of the data indicates that the bacteria could have been introduced from contaminants adhering to the submersible pump on day 15. However, it seems highly improbable that the bacteria found on other sampling occasions were introduced by sampling techniques.

Levels of indicator bacteria were determined for water in the shallow wells during and after the discharge period (table 15). The variations in bacterial levels in the upper recharge zone reflected the wide variations for bacteria in the wastewater. In some wells, the levels of indicator bacteria approached those of the wastewater. This indicated that discharge water pursued a relatively direct path to those wells.

A rather rapid decrease in levels of indicator bacteria were found after termination of discharge (fig. 8). However, after 25 days, levels of total coliform bacteria remained high relative to drinking water standards.

Results of monitoring artesian groundwater for indicator bacteria during the second discharge event are given in table 16. As in the previous discharge event, high counts of noncoliform bacteria were found in samples from all deep wells. Data in table 16 show bacterial contamination of artesian groundwater from wells DW2 and DW3 on days 8, 9, and 15 and no contamination in water from wells DW4 and DW5.

Levels of indicator bacteria in the shallow wells are presented in table 17. Variations in the level of indicator bacteria were expected in view of pronounced variations found for these bacteria in wastewater. As in the first discharge event, levels of indicator bacteria decreased considerably with time.

Data obtained from the monitoring of artesian groundwater for indicator bacteria during the third discharge event are given in table 18. Again, high levels of noncoliform bacteria were found in water from all wells which limited filtration volumes to 25 ml or less.

The rather high levels of indicator bacteria found in water from wells DW2 and DW3 on days 2, 7, and 8 offer evidence that wastewater discharged to the disposal well led to contamination of artesian groundwater at these wells. Furthermore, the repeated presence of noncoliform bacteria noted in water from wells DW4 and DW5 indicates that discharged wastewater entered the artesian system. Prior to the discharge of wastewater, few, if any, noncoliform bacteria were found.

The levels of indicator bacteria in water from the shallow wells are given in table 19. Here it can be seen that levels of total coliform bacteria increased during the first days of discharge and then decreased noticeably on days 7.2 and 8.0 even though the levels of bacteria in the wastewater were found to remain relatively constant. This could indicate preferred movement of wastewater through the fractured basalt layer once the underlying clay and rubble zone was saturated. Water within the latter zone, from which we were sampling, would not be continually intermixed with recently

TABLE 15. LEVELS OF INDICATOR BACTERIA IN WATER FROM SHALLOW WELLS FIRST DISCHARGE EVENT (organisms/100 ml; discharge terminated at 3.4 days)

Well number	D*	Organism#	Days from inception of discharge						
			0	1.4	2.4	3.0	8.0	14.4	28.3
SW1	7.6	TC	---	63,000	24,000	68,000	20,000	1,000	580
		FC	---	1,300	50	600	<100	35	<5
		FS	---	6,300	5,200	5,000	200	600	10
SW7	15.2	TC	---	29,000	23,000	14,000	500	580	40
		FC	---	350	200	<4	<100	<5	<5
		FS	---	5,400	3,100	2,800	100	10	20
SW8	15.2	TC	---	---	22,000	10,000	---	---	---
		FC	---	---	<50	100	---	---	---
		FS	---	---	2,000	2,400	---	---	---
SW9	15.2	TC	---	47,000	23,000	15,000	1,000	260	40
		FC	---	1,000	550	100	<100	10	<2
		FS	---	6,500	5,500	4,200	<100	40	4
SW4	30.5	TC	---	27,000	40,000	18,000	---	---	---
		FC	---	500	350	200	---	---	---
		FS	---	6,800	2,300	4,400	---	---	---
SW5	30.5	TC	---	9,800	10,000	10,000	<100	130	20
		FC	---	150	200	200	<100	<5	<5
		FS	---	5,500	6,600	2,400	100	<5	15
SW6	30.5	TC	---	14,000	33,000	25,000	800	660	70
		FC	---	130	300	200	<50	10	<5
		FS	---	6,200	3,800	4,200	<100	40	5
Disposal well	0	TC	---	---	---	---	40,000	25,000	670
		FC	---	---	---	---	<100	35	<5
		FS	---	---	---	---	200	440	25

* D = distance from disposal well in meters.

TC = total coliforms; FC = fecal coliforms; FS = fecal streptococci.

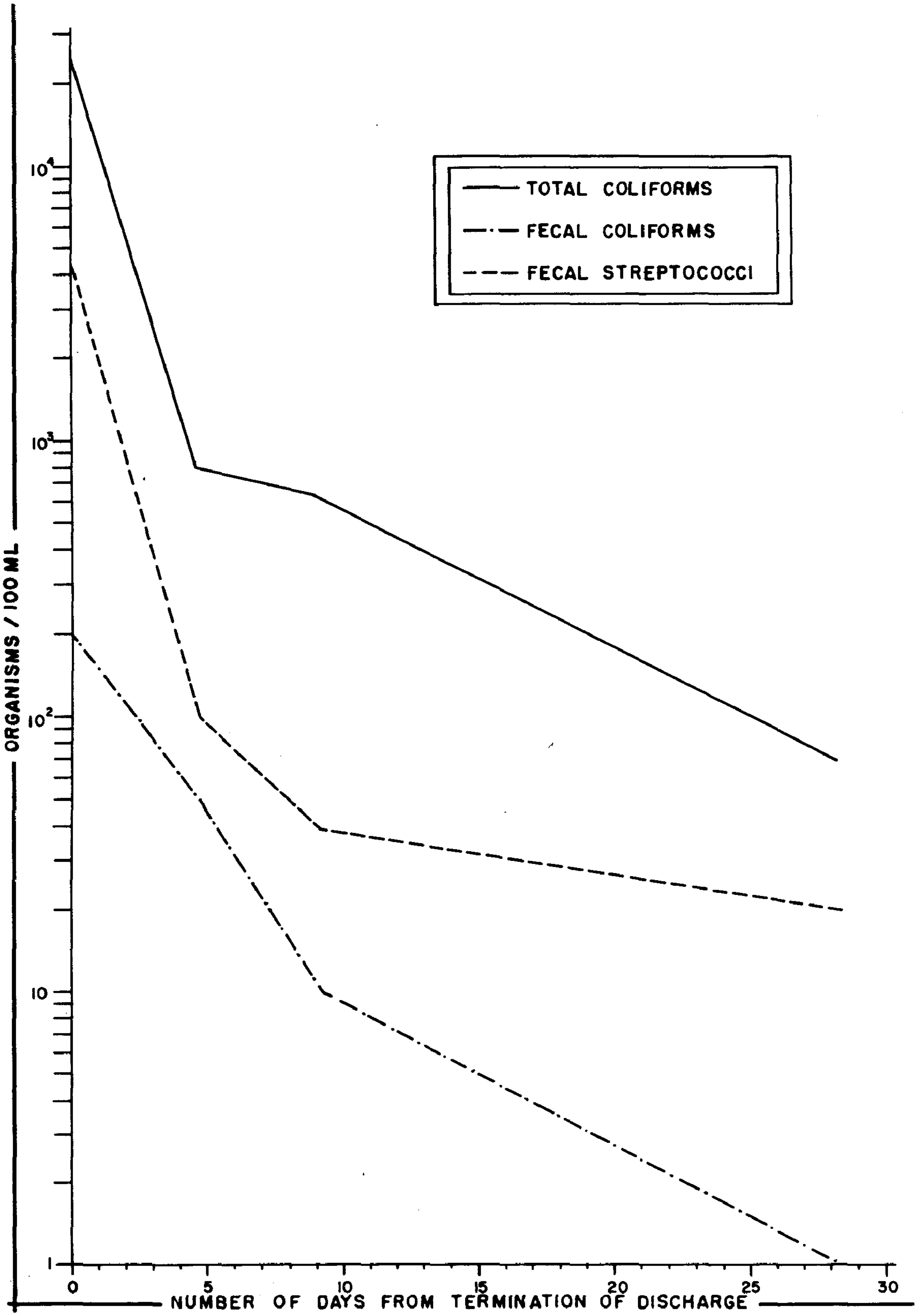

FIGURE 8. DECREASE OF SELECTED ENTERIC BACTERIA IN WATER FROM SHALLOW WELL 6 DURING THE FIRST DISCHARGE EVENT.

TABLE 16. LEVELS OF INDICATOR BACTERIA IN GROUNDWATER--
SECOND DISCHARGE EVENT (organism/100 ml)

Well Number	Organism*	Days from Initiation of Discharge 0#	1†		2#	8†		9†		15†	
DW2	TC	--	0	0	0	--	--	8	0	8	0
	FC	--	0	0	0	--	--	0	0	0	0
	FS	--	0	0	0	--	--	0	0	0	0
DW3	TC	--	--	0	--	800	76	--	--	12	0
	FC	--	--	0	--	0	0	--	--	0	0
	FS	--	--	0	--	--	0	--	--	0	0
DW4	TC	0	--	--	--	0	0	--	--	0	0
	FC	0	--	--	--	0	0	--	--	0	0
	FS	0	--	--	--	0	0	--	--	0	0
DW5	TC	0	--	--	0	0	0	--	--	0	0
	FC	0	--	--	0	0	0	--	--	0	0
	FS	0	--	--	0	0	0	--	--	0	0

* TC = total coliforms; FC = fecal coliforms; FS = fecal streptococci.

Samples from depths of 96 m after minimum of 30 min pumping.

† Samples from two depths: 85 m (1st column) after 5 min pumping and 96 m (2nd column) after minimum of 30 min pumping.

discharged wastewater. In this event, a decrease in levels of total coliforms would be expected in the clay and rubble zone from both die-off and adsorption.

Geophysical logs showed that the packers on wells DW2-5 were placed above the suspected confining layer. Consequently, deep percolating wastewater could have entered the artesian system by traveling through the annular space below the packers. In order for this to have occurred, the wastewater would have had to penetrate five additional layers of dense basalt (fig. 6) situated below the recharge zone but above the confining layer. Furthermore, an artesian head of approximately 14 m would need to have been overcome.

Discharge Event Conducted in 1976

Water levels within the five cased shallow wells are presented in table 20. Depths to water in wells SW10 and SW11 decreased within hours (0.2 days) after commencement of discharge to the disposal well. Wells SW12 and SW13 responded within 4 days; and water was detected in the bottom of SW14, 122 m distant from the disposal well, on day 5. Depths to water increased with increasing distance from the disposal well from day 4 through

TABLE 17. LEVELS OF INDICATOR BACTERIA IN WATER FROM SHALLOW WELLS SECOND DISCHARGE EVENT (organisms/100 ml; discharge terminated at 8.0 days)

Well number	D*	Organism#	0	1.0	2.0	2.9	8.0	8.9	15.0	35.0
			Days from inception of discharge							
SW1	7.6	TC	580	5,500	11,000	11,000	5,500	300	150	25
		FC	<5	600	400	100	50	<20	<10	<3
		FS	10	3,200	2,400	2,300	1,600	75	80	---
SW7	15.2	TC	40	8,200	8,400	6,500	750	500	120	780
		FC	<5	80	130	50	25	17	<10	<5
		FS	20	4,700	1,100	2,600	700	280	55	---
SW8	15.2	TC	---	---	1,600	3,800	500	400	---	---
		FC	---	---	50	<50	<25	17	---	---
		FS	---	---	1,300	2,400	500	350	---	---
SW9	15.2	TC	40	2,600	3,400	10,000	3,300	700	80	520
		FC	<2	260	75	50	50	<20	<10	<5
		FS	4	2,400	1,300	4,200	2,100	300	20	---
SW4	30.5	TC	---	6,200	4,200	4,800	1,800	---	---	---
		FC	---	460	50	100	25	---	---	---
		FS	---	3,700	1,700	2,300	1,300	---	---	---
SW5	30.5	TC	20	1,100	1,200	2,800	500	500	45	5
		FC	<5	410	100	50	25	<20	<5	<3
		FS	15	750	700	1,000	350	300	35	---
SW6	30.5	TC	70	4,200	2,600	2,000	4,000	2,500	90	35
		FC	<5	240	50	50	50	17	<3	<5
		FS	5	4,000	1,600	5,800	1,300	350	35	---
SW2	61.0	TC	---	---	---	---	4,000	---	---	---
		FC	---	---	---	---	25	---	---	---
		FS	---	---	---	---	1,800	---	---	---
Disposal well	0	TC	670	---	---	---	6,300	1,000	400	320
		FC	<5	---	---	---	75	<25	<10	<2
		FS	25	---	---	---	5,000	130	290	---

* D = Distance from disposal well in meters.

TC = total coliforms; FC = fecal coliforms; FS = fecal streptococci.

TABLE 18. LEVELS OF INDICATOR BACTERIA IN GROUND-WATER--THIRD DISCHARGE EVENT (organisms/100 ml)

Well Number	Organism*	Days from Inception of Discharge											
		1†		2#	3†		7†		8†		29#	30†	
DW2	TC	0	0	--	TNTCδ	560	0§	10	50	5	--	5	0
	FC	0	0	--	0	0	0	0	0	0	--	0	0
DW3	TC	0	0	--	56	20	--	--	4	4	0	--	--
	FC	0	0	--	0	0	--	--	0	0	0	--	--
DW4	TC	0	0	0	--	--	--	--	0	0	0	--	--
	FC	0	0	0	--	--	--	--	0	0	0	--	--
DW5	TC	0	0	8	--	--	--	--	0	0	4	--	--
	FC	0	0	0	--	--	--	--	0	0	0	--	--

* TC = total coliform; FC = fecal coliform.

Samples from depths of 96 m after minimum of 30 min pumping.

† Samples from two depths: 85 m (1st column) after 5 min pumping and 96 m (2nd column) after minimum of 30 min pumping.

δ TNTC = Too numerous to count for a filtration volume of 2 ml.

§ 150 distinct deep red colonies plus numerous other noncoliform colonies for a filtration volume of 1 ml.

termination of the discharge event. Water levels in all the cased shallow wells declined after day 4 because of reduced inflows to the disposal well.

The above data indicate that recharge during the fourth discharge event was of a regular pattern along the axis of the cased shallow wells (fig. 4). This may indicate that the injected wastewater moved uniformly through the clay and rubble zone rather than assuming a more channelized path as was apparent with the 1975 discharge events.

Depths to water within the modified deep wells were between 81.3 m and 81.9 m below land surface prior to initiation of the fourth discharge event (table 20). These levels were approximately 1 m above the level of the artesian aquifer (82.3 m below land surface) which indicate that the modification procedures effectively isolated the deep perched water zone from the artesian aquifer.

Water levels within wells DW3 and DW5 increased after 4 days of discharge to the disposal well and appeared to be directly influenced by the volume of injected wastewater. Reduced inflows to the disposal well not only

TABLE 19. LEVELS OF INDICATOR BACTERIA IN WATER FROM SHALLOW WELLS
THIRD DISCHARGE EVENT (organisms/100 ml; discharge terminated at 16.0 days)

Well number	D*	Organism#	Days from inception of discharge						
			0	1.2	2.2	3.0	7.2	15.0	30.0
SW1	7.6	TC	25	250	1,500	2,600	270	1,200	5
		FC	<3	180	260	200	55	43	<5
		FS	---	---	---	---	730	2,200	40
SW7	15.2	TC	780	600	2,200	2,300	180	450	10
		FC	<5	70	60	130	40	20	<5
		FS	---	---	---	---	200	120	35
SW8	15.2	TC	---	300	1,200	2,200	20	100	---
		FC	---	85	130	80	5	10	---
		FS	---	---	---	---	120	100	---
SW9	15.2	TC	520	300	1,200	2,750	450	750	<5
		FC	<5	60	140	230	160	100	<5
		FS	---	---	---	---	460	1,000	55
SW4	30.5	TC	---	300	1,400	1,800	200	320	---
		FC	---	100	120	260	10	25	---
		FS	---	---	---	---	190	220	---
SW5	30.5	TC	5	350	1,100	950	25	70	<5
		FC	<3	95	80	100	10	3	<5
		FS	---	---	---	---	140	65	15
SW6	30.5	TC	35	200	1,500	2,500	280	650	15
		FC	<5	110	190	230	110	90	<5
		FS	---	---	---	---	480	1,140	15
SW2	61.0	TC	---	---	---	2,000	200	450	---
		FC	---	---	---	270	55	60	---
		FS	---	---	---	---		480	---
Disposal well	0	TC	320	---	---	---	---	---	15
		FC	<2	---	---	---	---	---	5
		FS	---	---	---	---	---	---	55

* D = distance from disposal well in meters.

TC = total coliforms; FC = fecal coliforms; FS = fecal streptococci.

TABLE 20. DEPTHS TO WATER WITHIN SHALLOW AND DEEP MONITORING WELLS--FOURTH DISCHARGE EVENT (measurement in meters from reference elevation of 1263.7 m)

Well Number	D*	Days from Inception of Discharge 0.0	0.2	0.4	4.4	5.1	6.0	11.3	12.0
					SHALLOW WELLS				
SW10	15	DRY	24.87	24.41	23.74	23.77	23.77	24.11	24.99
SW11	31	34.32	27.19	26.49	24.41	24.48	24.48	24.69	24.99
SW12	61	DRY	DRY	DRY	25.12	25.18	25.15	25.24	25.57
SW13	91	33.99	34.29	34.29	26.58	26.58	26.58	26.58	26.82
SW14	122	DRY	DRY	DRY	DRY	39.41	39.41	DRY	DRY
					DEEP WELLS				
DW3	46	81.32	---	---	81.20	81.23	81.26	81.23	---
DW4	46	---	81.38	---	81.38	81.41	81.47	81.41	---
DW5	46	81.90	---	---	81.47	81.50	81.50	81.50	---

* D = distance to disposal well in meters.

led to decreased water levels within the recharge zone but also resulted in lower water levels within the deep perched water zone.

Specific conductance and turbidity of wastewater and water withdrawn from the shallow and deep monitoring wells are presented in table 21. Specific conductance of the wastewater ranged from 325-400 µmhos/cm, while values of turbidity varied from 18 to 120 NTU. Values of both specific conductance and turbidity for samples withdrawn from the shallow wells approached those of the injected wastewater.

Specific conductance and turbidity of water withdrawn from the modified deep wells were similar to values obtained for the artesian aquifer (table 21). However, specific conductance of the deep perched water zone was observed to decrease after 5 days of discharge to the disposal well, thus indicating that this zone was influenced by injected wastewater. Levels of turbidity did not appear to be affected by deep-percolating wastewater.

Levels of indicator bacteria were determined for the injected wastewater and water from both shallow and deep monitoring wells (table 22). Variations in the bacterial levels of the wastewater were attributed to a diversity of sources of wastewater. Two heavy thunderstorms occurred during the discharge event, and storm runoff water comprised a large portion of the irrigation return flows shortly thereafter. Storm runoff was followed by a period of low irrigation demand during which the return flows decreased and were principally comprised of bypass water of relatively low bacterial levels.

TABLE 21. SPECIFIC CONDUCTANCE AND TURBIDITY OF WASTEWATER, AND WATER FROM BOTH SHALLOW AND DEEP MONITORING WELLS--FOURTH DISCHARGE EVENT

Well Number	Parameter*	Days from Inception of Discharge 0	1	5	11
Disposal well inlet	K_s	---	400	349	325
	Turb.	---	120	28	18
			SHALLOW WELLS		
SW10	K_s	---	---	350	---
	Turb.	---	---	30	---
SW11	K_s	---	---	350	---
	Turb.	---	---	25	---
SW12	K_s	---	---	350	---
	Turb.	---	---	20	---
SW13	K_s	---	---	350	---
	Turb.	---	---	35	---
			DEEP WELLS		
DW3	K_s	520	---	520	450
	Turb.	0.4	---	4.1	0.4
DW4	K_s	---	---	650	549
	Turb.	---	---	2.0	0.8
DW5	K_s	645	---	600	550
	Turb.	1.5	---	17	1.8

* K_s = specific conductance (μmhos/cm); Turb. = turbidity (NTU).

TABLE 22. LEVELS OF BACTERIA IN WASTEWATER AND WATER FROM BOTH SHALLOW AND DEEP MONITORING WELLS-- FOURTH DISCHARGE EVENT (organisms/100 ml)

Well Number	Organisms*	Days from Inception of Discharge						
		0.0	0.2	0.4	5.2	5.6	11.2	11.4
Disposal well	TC	---	1660	5600	3222	3518	1900	---
	FC	---	---	100	2560	2200	120	---
	FS	---	4620	5200	1950	3050	4200	---
				SHALLOW WELLS				
SW10	TC	---	---	---	2480	---	---	---
	FC	---	---	---	300	---	---	---
	FS	---	---	---	2050	---	---	---
SW11	TC	---	---	---	680	---	---	---
	FC	---	---	---	110	---	---	---
	FS	---	---	---	3100	---	---	---
SW12	TC	---	---	---	1500	---	---	---
	FC	---	---	---	60	---	---	---
	FS	---	---	---	4850	---	---	---
SW13	TC	---	---	---	1120	---	---	---
	FC	---	---	---	330	---	---	---
	FS	---	---	---	2100	---	---	---
				DEEP WELLS#				
DW3	TC	0	---	---	---	15	22	---
	FC	0	---	---	---	0	0	---
	FS	0	---	---	---	510	200	---
DW4	TC	---	---	---	---	0	---	24
	FC	---	---	---	---	0	---	0
	FS	---	---	---	---	380	---	1000
DW5	TC	4	---	0	---	---	---	76
	FC	0	---	0	---	---	---	0
	FS	2	---	360	---	---	---	1920

* TC = total coliform; FC = fecal coliform; FS = fecal streptococcus.

\# Samples from depths of 96 m after minimum of 30 min pumping.

Bacterial levels of the recharge zone, as monitored through the cased shallow wells, approached those levels determined for the wastewater. Differences found between samples withdrawn from the cased shallow wells were indicative of integration of different sources of wastewater and bacterial movement and die-off rates. There were no apparent differences in bacterial levels between samples withdrawn from the cased shallow wells during the 1976 discharge event and samples collected from the uncased shallow wells during the three discharge events conducted in 1975.

Prior to initiation of the fourth discharge event, bacterial levels in the deep wells were found to approach those of Idaho drinking water standards. However, within 5.6 days after inception of discharge, increases in levels of total coliforms and fecal streptococci were observed. These increased bacterial levels clearly indicate that wastewater was infiltrating the deep perched water zone situated some 42 m below the recharge zone.

SECTION 7

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16. ABSTRACT

An investigation was conducted to evaluate the impact of irrigation disposal well practices on the water quality of the Snake Plain aquifer. A study site was selected where the geology was determined to be characteristic of areas in the Snake River Plain where irrigation disposal wells are extensively used. Alternating permeable and dense basalt layers underlie the discharge site. The aquifer at the project site was defined as a leaky artesian groundwater system.

Initial quality of the artesian groundwater was found to be within Idaho drinking water standards. Pesticides, herbicides, and trace metal concentrations in the irrigation wastewater were within drinking water standards. Total and fecal coliform bacteria and sediment were the only contaminants found in irrigation wastewater in excess of drinking water standards.

Wastewater discharge to the disposal well resulted in the formation of a nonsymmetrical recharge zone. Rapid lateral movement of the discharge water through the recharge zone indicated that flow was through fractures and channels. Bacterial levels and turbidity within the recharge zone approached those of the discharged wastewater and were far in excess of drinking water standards.

Deep percolation of injected wastewater resulted in bacterial contamination of both the deep perched water zone overlying the confining layer and the artesian groundwater system. Suspended solids were filtered out by the percolation process.

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