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Surface Impoundments And Their Effects On Ground-Water Quality In The United States —A Preliminary Survey

June 1978

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SURFACE IMPOUNDMENTS AND THEIR EFFECTS ON GROUND-WATER QUALITY IN THE UNITED STATES--A PRELIMINARY SURVEY

PREPARED FOR THE

U.S. ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF DRINKING WATER

STATE PROGRAMS DIVISION

GROUND WATER PROTECTION BRANCH

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ABBREVIATIONS USED IN THIS REPORT

10^6	-	million
10^9	-	billion
10^{-6}	-	millionth
acre-ft	-	acre-foot
bbl	-	barrel (42 gal)
bgd	-	billion gallons per day
BOD	-	biochemical oxygen demand
Btu	-	British thermal units
Ca	-	calcium
$CaCO_3$	-	calcium carbonate
Ci	-	curie
Cl	-	chloride
cm	-	centimetre
CO_2	-	carbon dioxide
COD	-	chemical oxygen demand
cu cm	-	cubic centimetre
cu ft	-	cubic foot
cu m	-	cubic metre
F	-	fluoride
ft	-	foot
g	-	gram
gal	-	gallon
gpd	-	gallons per day
gpm	-	gallons per minute
ha	-	hectare
hp	-	horse power
hr	-	hour
in	-	inch
kg	-	kilogram
kg-cal	-	kilogram-calorie
km	-	kilometre
kwhr	-	kilowatt-hour
l	-	litre

lb	-	pound
l/s	-	litre per second
m	-	metre
mCi	-	millicurie
mgd	-	million gallons per day
mg/l	-	milligrams per litre
mi	-	mile
ml	-	millilitre
mm	-	millimetre
N	-	nitrogen
Na	-	sodium
NH_3	-	ammonia
NO_3	-	nitrate
NO_3-N	-	nitrate nitrogen
O	-	oxygen
OH	-	hydroxide
pCi	-	picocurie
PO_4	-	phosphate
ppb	-	parts per billion
ppm	-	parts per million
psi	-	pounds per square inch
Ra	-	radium
s	-	second
sq cm	-	square centimetre
sq ft	-	square foot
sq m	-	square metre
sq km	-	square kilometre
sq mi	-	square mile
TDS	-	total dissolved solids
TOC	-	total organic carbon
yd	-	yard
yr	-	year
°C	-	degrees Celsius
°F	-	degrees Fahrenheit
µg/l	-	micrograms per litre

SECTION I

SUMMARY

The investigation described in this report was designed to provide broad background information on the use of municipal, industrial, and agricultural surface impoundments in the United States, with particular reference to the potential threats they may pose to the quality of underground drinking water resources and to methods of controlling or abating such threats. The investigation was undertaken by EPA (U. S. Environmental Protection Agency) as part of that agency's responsibility for controlling subsurface emplacement of wastes, as mandated by Section 1442 (a)(8)(c) of the Safe Drinking Water Act (P.L. 93-523).

The principal subjects covered in the report are: (1) numbers, types, and uses of impoundments, (2) chemical characteristics of the impounded wastes, (3) mechanisms by which wastes that seep from impoundments may contaminate ground water, (4) selected case-history data on ground-water contamination, (5) technical controls and costs for preventing and alleviating contamination, and (6) State regulatory controls over the use of impoundments.

The work was accomplished largely through an analysis of published and unpublished data obtained from public agencies and through discussions and other contacts with specialists in the public and private sectors having first-hand knowledge and experience relevant to impoundments. Visits were made to some 16 States to gather such information.

Surface impoundments serve a variety of functions and contain wastes of all kinds, ranging from relatively innocuous substances to highly toxic materials. Few impoundments are lined and, because the soils beneath and adjacent to many of them are permeable, slow seepage of contaminated fluids from these impoundments represents a potential threat to ground-water quality. However, relatively few detailed field studies have been made of these threats, largely because few water wells are known to have

been adversely affected by them and also because of the difficulties and costs of making such studies.

Nearly every State has some information on the numbers and types of impoundments within its borders. However, few States have actually counted impoundments or compiled detailed records of their construction, operation, and effect on ground-water quality. The preliminary inventory made during this study indicates that there is an estimated total of at least 132,709 impoundment sites in the nation. Most sites have more than one impoundment. The total number of impoundment sites includes 13,670 municipal, institutional, and commercial sites; 27,844 industrial sites; 71,832 oil and gas extraction sites; and 19,363 agricultural sites.

Despite the potential for attenuation of contamination in some soils, a wide variety of inorganic and organic contaminants have seeped into ground water as indicated by records of selected case histories of contamination from industrial impoundments in 29 States. A number of alternatives, some very costly, are available for preventing contamination at new impoundments or alleviating contamination at existing impoundments. Some types of impoundments are regulated by State and Federal permits but in many instances the requirements are not adequate to prevent ground-water contamination.

SECTION II

FINDINGS

1. There is a minimum total of about 132,700 sites in the United States where municipal, industrial, or agricultural impoundments are used for the treatment, storage, or disposal of wastes. A large percentage of the sites contain more than one impoundment, and most likely, the actual number of impoundments is several times greater than the number of sites.

2. Industrial impoundments constitute about 75 percent of the total number of impoundments and are most numerous in the oil and gas extraction and mining industries. The mining, paper and pulp, and electrical utility industries operate some of the largest impoundments.

3. Municipal, commercial, and institutional impoundments comprise about 10 percent of the total number of impoundments and are used for processing and disposing of sanitary wastes. Agricultural impoundments constitute about 15 percent of the total number of impoundments and are used mainly in handling wastes from animal feedlot operations.

4. Billions of gallons of wastes are placed daily in surface impoundments. These wastes contain a wide variety of organic and inorganic substances, some of which are highly toxic.

5. Most impoundments are unlined, and because a large percentage of them are underlain by permeable soils, the potential for downward seepage of contaminants into the ground water is high. However, only incomplete data are available on the comparative volumes of contaminated fluids that are lost by seepage into the ground water, by evaporation, and by discharge to surface-water bodies.

6. Some contaminants that seep from impoundments may be attenuated in the soil by ion exchange, adsorption, or other geochemical reactions. Others can move readily through soil and into shallow unconfined aquifers, especially where the sorptive capacity of the soil is exhausted by continous seepage of contaminated fluids.

7. Incidents of ground-water contamination from impoundments have been reported in nearly all States. Although only 85 case histories of contamination involving industries are summarized in this report, hundreds more are in the files of various State agencies.

8. Case-history studies generally show that the water in shallow unconfined aquifers is the first to be contaminated by seepage of wastes from impoundments. The contaminated ground water is generally in the form of a discrete plume that may be localized or that may extend as much as one mile or more downgradient from an impoundment.

9. Actions that can be taken to prevent or alleviate contamination of ground water from impoundments include: installing impermeable liners; constructing various collection and recycling systems, such as underdrains, infiltration galleries, and wells; pretreating wastes; and retarding or preventing the movement of contaminated ground water by means of hydraulic or physical barriers. Where none of the foregoing techniques is feasible, it may be necessary to shut down the impoundment and to substitute other waste-disposal methods. Applicability of specific remedial actions at individual sites can be determined only on a case-by-case basis. Some preventive measures can be taken only during the construction of new impoundments.

10. Costs of preventive or remedial actions at individual impoundment sites can range from tens of thousands of dollars to several millions of dollars.

11. State pollution control or environmental control agencies commonly issue some type of approval for the use of many types of waste impoundments; these range from simple letters of authorization to very restrictive permits. Many States provide guidelines or have specific requirements for siting, construction, operation, and monitoring of impoundments. Many of these requirements, however, pertain to construction and operational features and are not very effective in preventing seepage of contaminated fluids into ground water.

12. There is a wide diversity in the degree of ground-water protection afforded presently by State rules and regulations relating to surface impoundments because of manpower and budget deficiencies, inadequate knowledge of the scope and nature of the problem, and the fact that many State regulatory programs are not stringent enough to deal with the contamination threat.

SECTION III

INTRODUCTION

During the period from October 1976 to 1978, EPA completed an investigation of the potential impact of a wide variety of surface impoundments on underground drinking-water sources that supply, or that can reasonably be expected to supply, public drinking-water systems in the United States. The investigation, authorized by Section 1442(a)(8)(c) of the Safe Drinking Water Act (P.L. 93-523), was concerned only with those impoundments, commonly referred to as "ponds, pools, lagoons, and pits," that are used for the treatment, storage, or disposal of wastes. This report describes the results of the investigation, whose principal tasks were to estimate, describe, and/or evaluate, on a State-by-State basis, the numbers of surface impoundments, composition of the impounded wastes, mechanisms of ground-water contamination, selected case histories, remedial actions and costs, and existing State regulations.

Surface impoundments are used throughout the nation to treat, store, or dispose of municipal, industrial, and agricultural wastewater and are also used in processing operations by major industries. Most impoundments are unlined and, consequently, there is a potential for seepage of part of their contents downward into the underlying soils and shallow aquifers. Not all impoundments leak; some are lined or are constructed in impermeable soils and others are thought to be self-sealing. However, no natural materials are completely impermeable, so that even very low seepage rates over long periods of time can result in significant contamination of ground water.

Contamination of ground water by seepage from impoundments is believed to be occurring throughout the country. Although the known instances of such contamination represent only a small percent of the total number of impoundments, case histories of contamination can be documented in nearly every State (Table 8). Many of the bodies of contaminated ground water, commonly referred to as plumes, are localized, are remote from populated areas, and do not constitute an immediate threat to community supplies. Others, however, are quite extensive and have degraded the quality of water in parts of aquifers used as drinking-water sources. Even after shutdown, abandonment, and backfilling, impoundments that seep may leave a residual problem in the form of a plume of wastes that remains in the ground water and continues to move downgradient toward discharge areas for many years. Generally, the amount of information available on the possible presence of a plume is too scanty to fully define the contamination threat. In many places, the plume may never be discovered unless the contaminated water reaches a nearby well or stream and is detected either by the taste, color, odor, or by routine sampling and chemical analysis of the water.

Costs of cleaning up existing ground-water contamination or of preventing additional contamination from seepage of contaminated fluids from impoundments are relatively high, and can range from thousands to millions of dollars for individual sites. In some instances, the remedial costs may be so prohibitive or the available techniques may be so impractical that communities would have little recourse but to seek fresh-water supplies elsewhere, either from deeper aquifers or from more remote surface-water or ground-water sources.

DEFINITION OF IMPOUNDMENT

In this study, a surface impoundment is defined as a natural topographic depression, artificial excavation, or dike arrangement having the following characteristics: (1) it is used primarily for storage, treatment, or disposal of wastes in the form of liquids, semi-solids, or solids; (2) it is constructed on, below, or partly in the ground; and (3) it is generally wider than it is deep. Concrete-lined basins and prefabricated above-ground tanks and steel vessels that are used in waste treatment and industrial processes have not been included in the definition of impoundment.

Fresh-water impoundments such as natural lakes, reservoirs, and farm ponds that are used for water supply, collection of storm-water runoff, flood-control, and irrigation also have been omitted from this inventory. Although such impoundments number in the millions, they mainly contain fresh water, so that most States do not consider them to be potential sources of contamination. However, infiltration from some storm-water basins and other similar types of impoundments could be sources of intermittent contamination locally.

SCOPE OF THE INVESTIGATION

The data compilations in the study were made largely on a State-by-State basis and were developed from literature research and information obtained from Federal and State agencies through field visits, correspondence, and telephone contacts; no specific field studies or field counts were made. A few plant managers were contacted for information on costs of remedial actions. Background information on surface impoundments was obtained from a number of EPA regional reports on ground-water contamination,[1-4] a report to Congress on waste-disposal practices,[5] and other references, which are listed at the end of each section of this report. State regulations, which ranged widely in coverage, were examined for applicability in preventing or controlling ground-water contamination from impoundments. Other ongoing or recently completed investigations of impoundments, sponsored by EPA, are discussed briefly in Section X.

The principal limitations in conducting the study were a scarcity of readily available data and a lack of uniform methods among the States in compiling information on numbers of impoundments and flow data. For example, only 19 States had detailed computerized data on impoundments that were available to the investigators. In some cases, the data sought were regarded as confidential and could not be divulged. Moreover, most individual cases of known contamination had not been thoroughly investigated. For example, only a small number of plumes of contaminated water emanating from impoundments have been mapped in detail. Also, reliable information on costs of remedial actions was very sparse.

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SECTION IV

PHYSICAL AND OPERATIONAL FEATURES OF IMPOUNDMENTS

TYPES, USES, AND CONSTRUCTION

Waste impoundments may be natural or man-made depressions; may be lined or unlined; and may range in area from a few tenths of an acre to hundreds of acres. Man-made impoundments range in depth from 2 to 3 ft (0.6 to 0.9 m) to as much as 30 ft (9 m) or more below the land surface. Generally, impoundments are above the water table, and some may be built on the land surface by construction of dikes or revetments. Most impoundments are rectangular or square; some are circular or irregular in shape. They may be operated individually or may be interconnected, so that flow takes place from one impoundment to another in series or in parallel.[1)] Many impoundments discharge, either continuously or periodically, to streams, lakes, bays, or the ocean; these are called "discharging" impoundments. Others lose their fluid contents only by evaporation or infiltration; these are called "non-discharging" impoundments.

Some impoundments are designed specifically to permit seepage of fluids into underlying aquifers and are commonly referred to as percolation, infiltration, or seepage ponds or lagoons. These impoundments are unlined and are sited on permeable soils. Others are designed to prevent seepage and to serve as temporary or permanent holding or evaporation impoundments; these are commonly lined with clay, concrete, asphalt, metal, or synthetic membranes, or are sited on clayey soils having a very low permeability. Some unlined impoundments are thought to be "self-sealing" as a result of deposition or precipitation of fine-grained materials. Impoundments whose principal function is to permit separation of suspended solids from liquids are called settling ponds. Oxidation ponds and aerated lagoons, are used for biologic treatment of wastewater; these are generally from 3 to 8 ft (0.9 to 2.4 m) deep and 8 to 15 ft (2.4 to 4.6 m) deep, respectively. Anaerobic lagoon systems, which require little or no oxygen, may be 12 to 17 ft (3.6 to 5.2 m) deep or more.

Disposal of wastewater in many non-discharging impoundments is accomplished by a combination of evaporation and seepage. Impoundments thus utilized are commonly referred to as evaporation ponds even though seepage of wastewater to the ground-water system may be the principal method of disposal. Evaporation is most effective in arid parts of some western States where climatic conditions favor losses by this mechanism and where inflow plus precipitation is less than the evaporation rate. Treatment accomplished in impoundments includes: reduction in temperature of cooling water, pH adjustment, chemical coagulation and precipitation, and biological oxidation.

The term "pit" is usually applied to a small impoundment that serves a special purpose. For example, they may be used on farms as storage and curing facilities for animal wastes, such as barn or feedlot litter and manure, prior to application on the land as fertilizer. In industry, they may be used for recharge of highly treated wastewater in a manner acceptable to regulatory agencies. Pits are used also for permanent storage of toxic wastes, in which case the pit walls and floor may be lined. Pits used for storage of sludge are commonly unlined.

Many abandoned sand and gravel pits or rock-quarry pits are used for a variety of disposal purposes. Abandoned pits have been used to dispose of septic-tank cleanout wastes, municipal and industrial sludges, and their associated fluid wastes. Most commonly these pits have been used as industrial, municipal, household, and even agricultural landfills and dumps that receive both solid and liquid wastes.

Factors influencing the ground-water contamination potential of an unlined surface impoundment include: soil permeability, depth to the water table, rates of precipitation and evaporation, nature and volume of wastes, and geochemical characteristics of the soils such as ion-exchange and sorption. Also of importance is the chemical composition of the wastes, especially those containing potentially hazardous materials. To provide protection against direct or indirect opportunities for contamination of surface water and ground water, artificial liners can be used beneath impoundments, or the impoundments can be constructed in or on naturally impermeable soils. As a general rule, except in arid or semi-arid areas in parts of some western States, lined impoundments without some form of cover or without a discharge outlet may overflow as a result of excessive rainfall or flooding. Even in largely dry climates, an occasional cloudburst, torrential rainfall, or flood may cause impoundments to overflow or cause a break in the dikes around an impoundment.

SELECTED IMPOUNDMENT PRACTICES

Domestic Sewage Wastes

Domestic sewage wastes, generally defined as wastes of predominantly human origin, are collected, treated, and disposed of by systems operated by municipalities, towns, and subdivisions; institutions such as schools, parks, hospitals, and jails; and commercial establishments such as motels, restaurants, gas stations, and mobile home parks. Treatment plants for domestic sewage range in size from small units handling a few tens of thousands of gallons per day (about 76 cu m/day) to larger units handling several hundred millions of gallons per day (about 757,000 cu m/day) or more. Treatment methods are generally classified as primary, secondary, and tertiary. Although not used everywhere, lagoons or ponds are used as minor or major components of many large treatment and waste-disposal systems or they may be the sole components of such systems. For example, impoundments are the principal waste-treatment units in over 4,000 communities, 90 percent of which have less than 5,000 residents.[2)]

Primary treatment of wastes mainly involves screening and settling of solids. In primary systems impoundments may be used for temporary storage, settling, or disposal by percolation and evaporation. The impoundments may be lined or unlined. In secondary treatment, the effluent from the primary treatment step receives further processing in tanks or basins containing chemicals to settle suspended solids and activated sludge to help stabilize the wastes by bacterial action. Secondary treatment results in reduction or removal of BOD (biological oxygen demand), suspended solids, and bacteria. Impoundments may be used only for storage and settling as part of a conventional secondary treatment system or may be the principal components in secondary treatment systems that consist mainly of anaerobic or aerobic waste-stabilization ponds. Impoundments are also used for temporary holding or storage of effluent or for disposal by evaporation and percolation after secondary treatment. In some tertiary treatment systems, secondary effluent may be passed through shallow "polishing" ponds for further oxidation, aeration, and settling of organic particles. In many waste-treatment systems, the final effluent from ponds is discharged to streams rather than being disposed of by evaporation from lagoons or by seepage to ground water.

Sludge from community waste-treatment systems is treated and disposed of by several methods. Part may be digested and thickened in special sludge-handling tanks, and part may be recirculated through the secondary treatment system or placed on drying beds. Drying beds are generally shallow rectangular impoundments with permeable sand bottoms and are constructed with or without underdrains for leachate control. Following drying, the sludge may be scraped out, incinerated, hauled to a landfill, or spread on agricultural land. In some systems, the partly dehydrated sludge is disposed of in storage lagoons. After being filled, these lagoons are covered and abandoned and new lagoons are dug as needed. Sludge-disposal lagoons may be potential sources of contamination where they are unlined and are underlain by permeable materials.

Industrial Wastes

Industry employs a wide variety of practices in treating and disposing of waste fluids and sludge. Some industries discharge their wastewater to public sewer systems, with or without pretreatment; some treat their wastes using conventional package plants, trickling filters, or activated sludge systems and then discharge the treated effluent to a stream; and some treat and discharge wastes into ponds for storage, evaporation, recycling, or infiltration.

Stabilization ponds are one of the major waste-treatment systems used by industries because of the relatively low capital and operating costs compared to other systems such as activated-sludge plants. The stabilization ponds may be assisted by mechanical or diffused aerators. Because industrial wastes may be highly variable in composition and in rate of flow, the waste streams may require blending with other water, and the flows may have to be stabilized by means of equalization or storage ponds. In some plants, industrial wastes are handled by a combination of conventional activated-sludge systems with or without auxiliary ponds for polishing and temporary retention of the effluents before discharge to streams. Similarly, industrial sludge with or without pretreatment and digestion may be stored in impoundments permanently or temporarily before being removed to landfills or being spread on agricultural lands. Figure 1 shows a flow chart for a pulp mill that illustrates the use of several types of impoundments in an industrial waste-treatment system that ultimately discharges to a stream.

Large volumes of cooling water, mainly from power plants, may be discharged through long networks of ditches to streams essentially without treatment, or the heated water may be stored in very large cooling ponds and then ultimately discharged to streams or recycled through the plants. Air-scrubber wastes and cooling-tower blowdown are discharged to streams with or without treatment or are discharged to lagoons for treatment and retention. Settling ponds are commonly used to handle ash residues from coal-burning utilities. Filter backwash and sludge from municipal water-treatment plants are commonly classified as industrial wastes and generally require treatment before disposal to streams or ponds. The

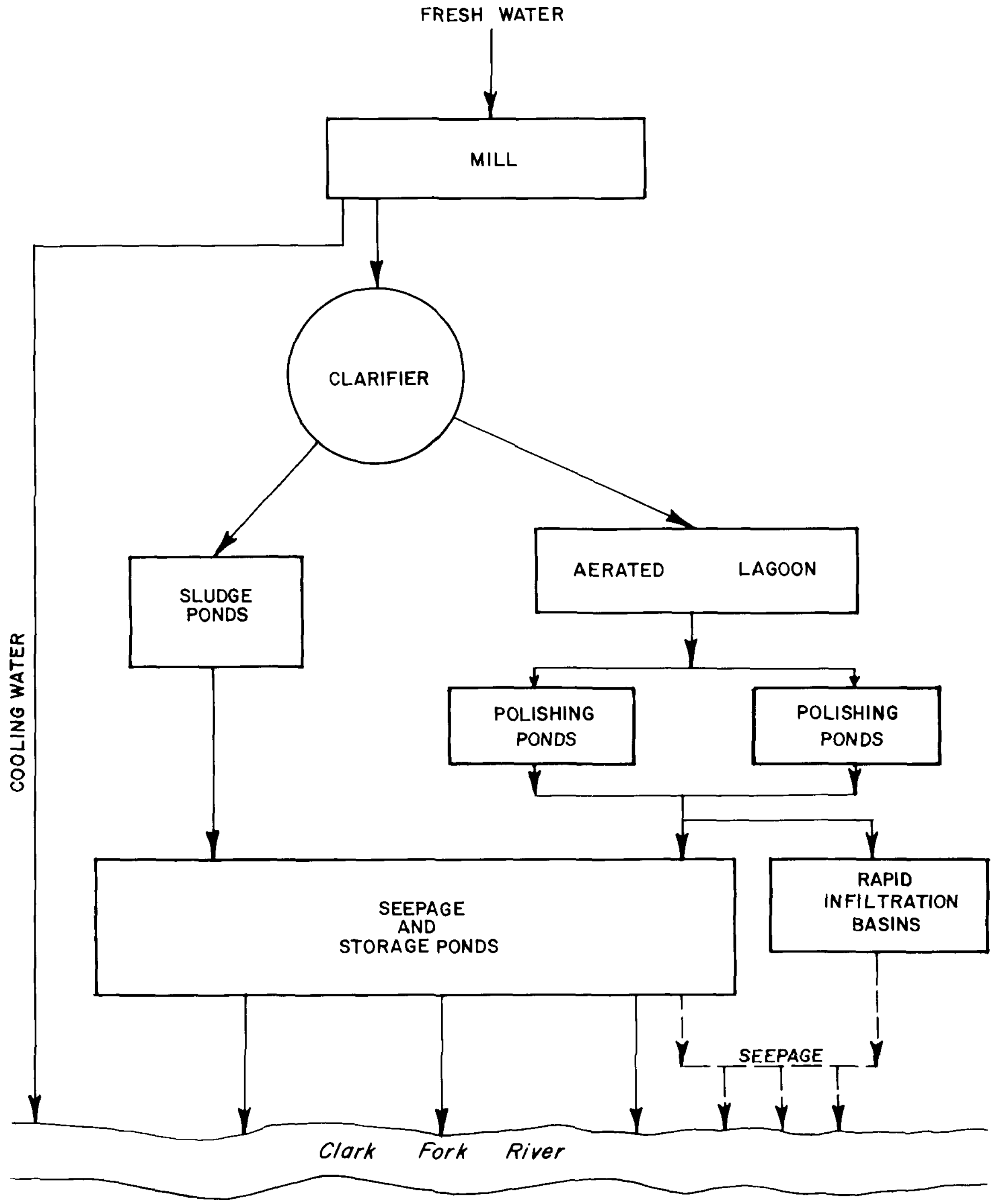

Figure 1. Flow chart for a pulp mill in Montana showing the types of impoundments used in the waste-treatment system.

nonferrous metal smelting and refining industry utilizes predominantly unlined settling pits and basins for handling waste and scrubber water and, in places, lagoons are used for permanent sludge disposal.

Mining and Milling Wastes

Mining

Many surface or open-pit mines are excavated to depths below the water table, which generally requires that the water be collected in sumps and be pumped out to settling ponds before discharge to a stream or lake. Likewise, in conventional underground mining, such as anthracite coal mining, acid mine water is commonly pumped to settling ponds for sediment control, precipitation of iron, and pH adjustment before discharge to a stream (Figure 2). In in-situ solution mining of metals such as copper and uranium, pumped fluids containing the solvents and the dissolved metals may be passed through storage and settling ponds for further treatment and removal of metals before the water is recycled, discharged to a stream, or recharged to a saline aquifer by deep-well injection.

Another type of mining operation, referred to as dump or heap leaching, can involve construction of impoundments in excavations, diked areas, or behind a dam on a stream. The objective of dump leaching is to concentrate metals such as copper from mine dumps composed of waste rock and low grade ore. In some locations, a solvent such as sulfuric acid or even plain water is applied to the heap. The leaching solutions pass down through the heap and commonly flow into an impoundment. From there, the metal-bearing water is pumped to a treatment plant for precipitation and recovery of the metals. The residual wastewater is usually stored in a holding pond for recycling or is treated to meet quality standards before being discharged to ground water or a stream.

Sand and gravel mining and processing operations make extensive use of impoundments, especially for washing and sorting. Ponds are generally used to settle fine-grained material before discharge of the effluent to

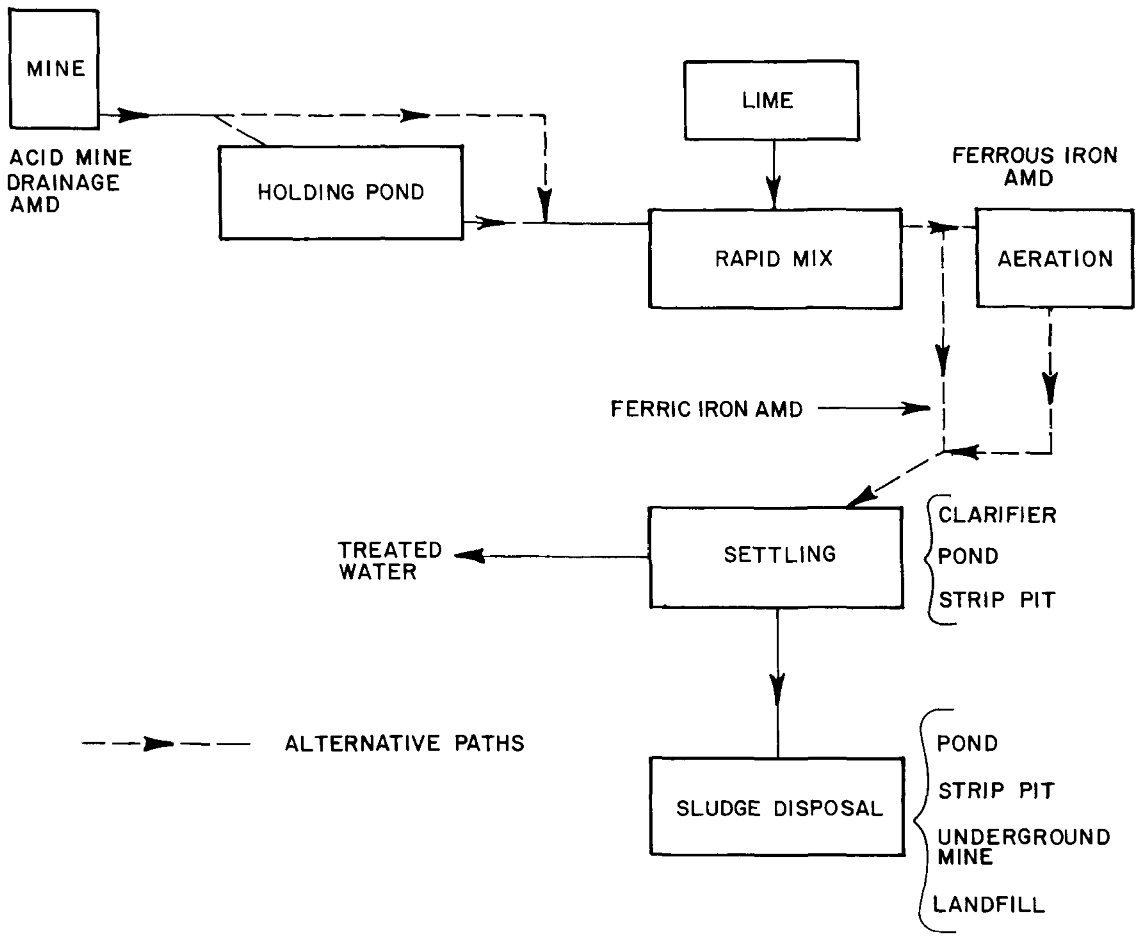

Figure 2. Generalized acid mine drainage flow chart, showing types of impoundments used in the treatment system.[3]

streams or lakes. In places, contaminated ground water or surface water is used in washing operations.

Milling

In conventional milling, the ore, consisting of the principal mineral, waste rock, and associated minor minerals, is generally crushed to a fine size, and the principal mineral is concentrated by gravity, flotation, or chemical leaching. These procedures may involve use of impoundments for storage or processing. The waste product of the milling operation, referred to as tailings, is generally composed of finely ground waste rock and various minerals, including clay-size particles. The tailings are commonly pumped as a slurry to a series of nearby ponds for settling of the solids and evaporation or decantation of the fluids (Figure 3). Some copper tailings ponds in Arizona are more than 1 mi (1.6 km) long, 100 ft (30.6 m) high, and cover 800 acres (324 ha). Tailings ponds may be formed by excavation, construction above grade by diking, or by construction of an earth dam or piling up of tailings across a stream. Seepage of impounded fluids into ground water below the bottom of a tailings pond or through a diked area is a potential cause of contamination of ground water and of surface water.

Sanitary sewage from mining and milling operations is commonly discharged along with the mining or process water. Normally, such wastes represent only a small percentage of the total volume of wastewater discharged from a site.

Among the States where impoundments are used extensively in mining and milling are: Alaska, Pennsylvania, West Virginia, Virginia, Indiana, Kentucky, and Illinois (coal); Arizona, Nevada, New Mexico, Colorado, Montana, Utah, Wyoming, and Michigan (copper, uranium, iron, and other metals); Missouri and Tennessee (lead and zinc); Florida, Tennessee, and North Carolina (phosphate); and numerous eastern, midwestern, and southeastern States (sand and gravel and non-metallic minerals).

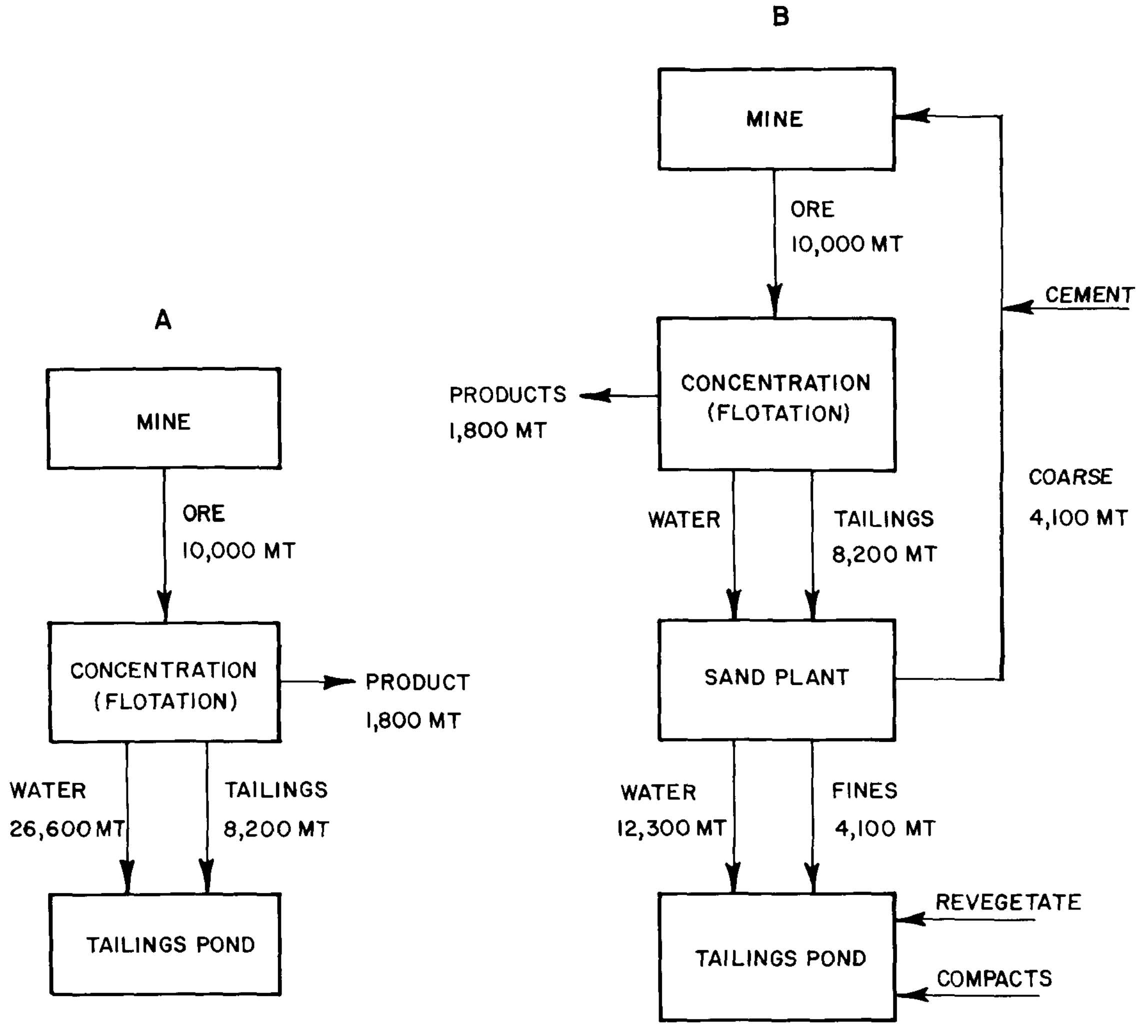

Figure 3. Flow charts showing two levels of technology in the use of tailings ponds for disposal of copper concentration wastes. Solid wastes are given in metric tons.[4)]

Oil and Gas Extraction Wastes

The oil and gas extraction industry is believed to be one of the largest, if not the largest, user of surface impoundments in the United States (Table 6). Oil and gas is produced commercially in 31 States, with Texas, Oklahoma, Louisiana, California, Wyoming, and Alaska among the leading producers. Only in the New England States and in scattered States in the southeastern, midwestern, and northwestern parts of the country is oil and gas extraction nonexistent or not commercially feasible at present. There are more than 500,000 producing oil wells and 126,000 producing gas wells in the United States,[5)] and some 30,000 new wells are drilled each year. The number of impoundments differs from State to State, not only in proportion to the production of oil and gas but also in relation to methods of extraction such as water flooding for secondary recovery, and other factors. Impoundments were formerly used extensively in Oklahoma, Texas, and elsewhere for disposal of salt water associated with oil extraction. Most of these impoundments were unlined, so that large quantities of salty water seeped into the underlying permeable shallow aquifers. Numerous cases of brine contamination of wells and streams as a result of such disposal methods have been documented in Texas[6)] and elsewhere. These methods are now prohibited in most States. However, earthen ponds excavated in clay or lined with clay or other material of low permeability are permitted by a number of States for evaporation of brine and emergency or other uses.

Impoundments for holding salt water are also used in connection with water flooding or repressurizing operations that involve injection of salt water into oil-bearing zones by means of deep wells. In places, lined and unlined ponds are used for aerating and settling iron-rich brine before injecting it into deep wells for disposal or for secondary recovery operations as noted above. It is common practice in these types of operations for one impoundment to serve a battery of as many as 100 injection wells. In the Rocky Mountain area, much of the produced water from oil and gas operations has a relatively low TDS (total dissolved solids) content; consequently, after temporary storage in holding ponds, the water can be used locally for irrigation and stock watering.

Impoundments, both lined and unlined, serve as oil-water and gas-fluid separator ponds in some States although, in many places, the separators are prefabricated steel and fiberglass leak-proof units such as API (American Petroleum Institute) approved separators. Emergency ponds are among the most common types of impoundments used in oil and gas extraction. They number from less than 100 in some States to as many as 11,000 in Ohio. Most of the time, emergency pits and ponds do not hold fluids but are intended only for temporary disposal or storage of salt water or oil in the event of failure of an oil skimmer or separator, a brine injection well, or other collection, distribution, or storage facility. Most emergency pits and ponds are unlined; but some States require lining and the pumping out or removal of the contents shortly after the emergency ceases. Brine-disposal or holding ponds, separator ponds, and emergency ponds are generally under some type of permit or approval system in many States and on Federal and Indian lands (see Section IX).

Another type of oil and gas field impoundment, considered to be less of a threat to ground water than the types noted above, is the temporary pit or pond excavated at a test-well or production-well site to hold drill cuttings and drilling mud. These temporary impoundments are constructed by the tens of thousands each year and are not included in the preliminary impoundment count (Table 6). Most of them are unlined, but may be self-sealing where bentonite or other kinds of drilling muds are used. Some States, for example, Florida, require use of steel tanks for recirculating drilling fluids where a potential threat exists of seepage of contaminants into major fresh-water aquifers. Burn pits are small shallow impoundments used to store or confine materials commonly referred to as tank bottoms, bottom sediments, or bottom settlings. These may be lined or unlined. Although there are many thousands of these pits, they are not considered to be a significant source of contamination and were not included in the present count.

Animal Feedlot and Other Agricultural Wastes

The principal potential mechanism for contamination of ground water from feedlot operations is seepage of contaminated water from lagoons that comprise parts of the waste-disposal systems. Virtually every State has some concentrated animal-feeding facilities (feedlots) for cattle, sheep, hogs, or poultry. Several hundred thousand known animal-feeding operations of all sizes generate large amounts of wastes, on the order of several billion tons (several billion tonnes) per year.[7] Ground-water contamination resulting from these operations has been described in regional ground-water contamination reports published by EPA[8-10] and in a recent report to Congress on waste-disposal practices.[11]

Because of the high content of TDS, BOD, COD, nitrogen compounds, phosphate, chloride, coliform bacteria, and other constituents in animal wastes, direct discharge of feedlot wastes to streams is prohibited in most States. Consequently, some form of land disposal is generally used.

Several systems involving use of impoundments have been developed by the U.S. Soil Conservation Service (SCS) to detain wastes for short or long periods and to dispose of wastes through storage or other land-spreading techniques. Figure 4 illustrates an anaerobic feedlot waste-control system and Figure 5 illustrates a basic holding-pond system.

Among the types of impoundments used in agricultural waste-disposal systems are debris basins, disposal lagoons, aerated lagoons, holding ponds, and storage lagoons. Design criteria for these facilities are given in SCS's National Engineering Handbook.[13] Debris basins are used to collect solids in runoff from pens and lots and commonly precede a holding pond. Holding ponds are used for storing the liquid part of runoff and animal wastes and are generally designed to be leakproof and to have sufficient capacity to prevent overflow except during severe storms or other emergencies. They may be emptied through irrigation

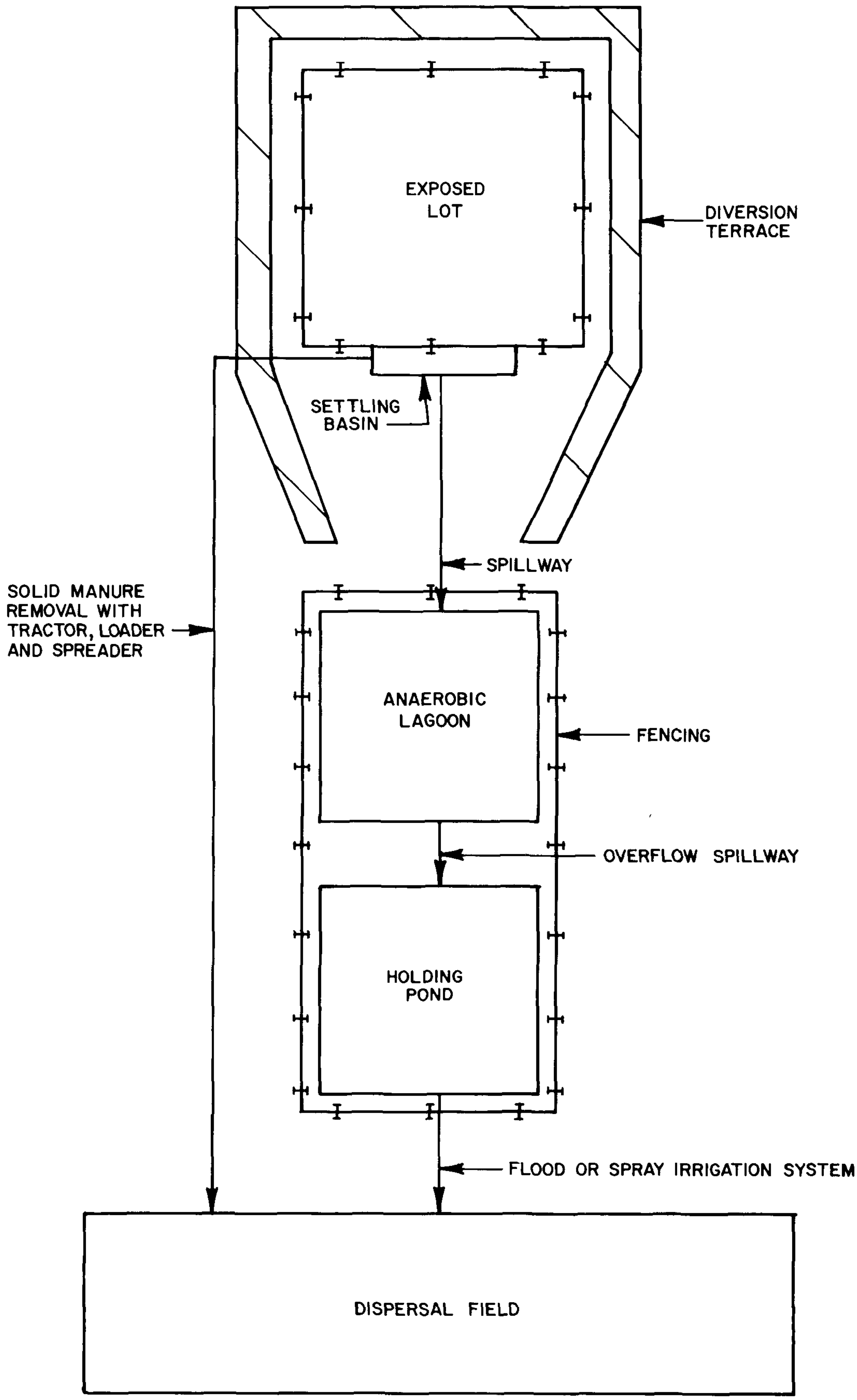

Figure 4. Anaerobic lagoon system used in southeastern region dairy farms. [12)]

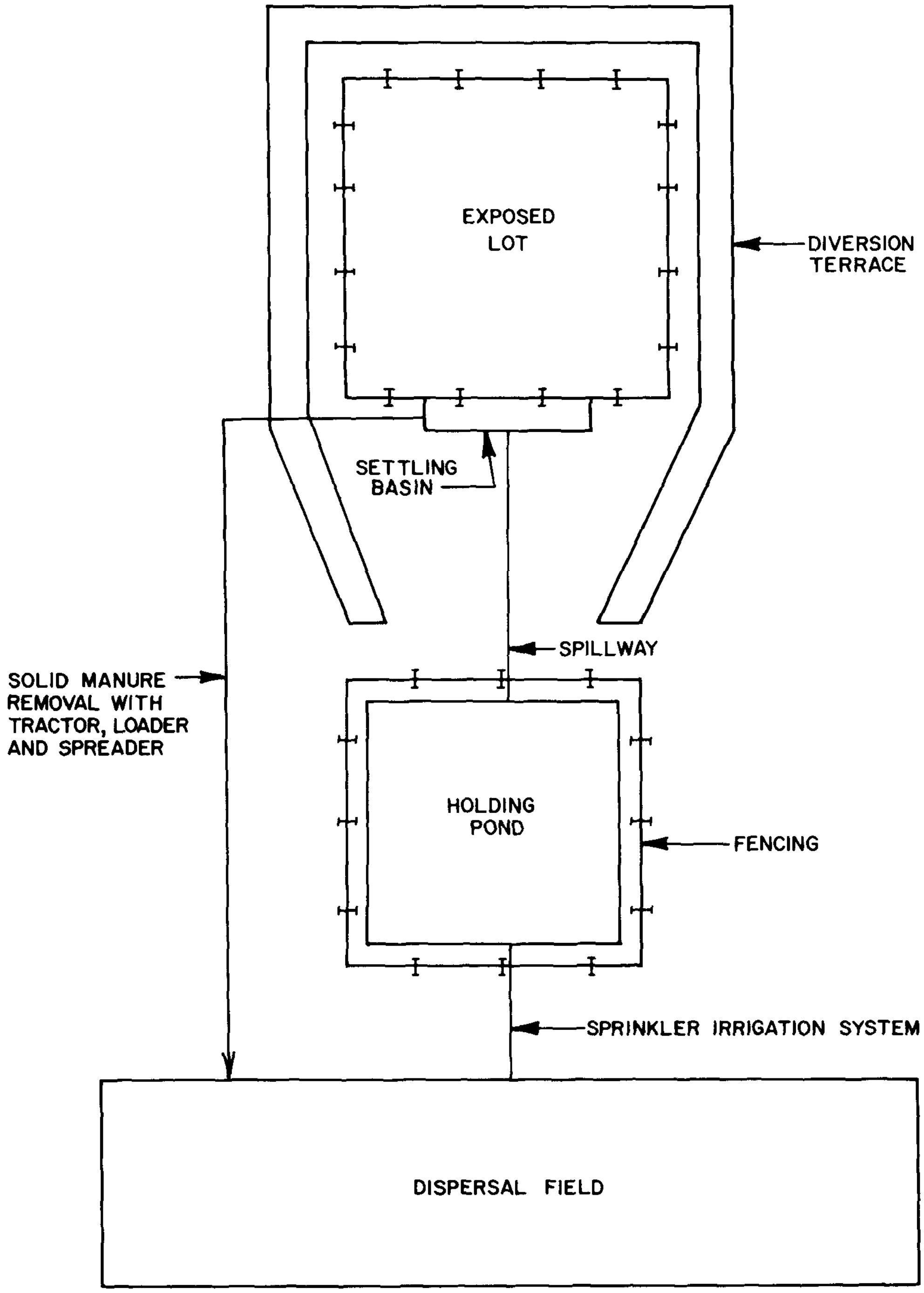

Figure 5. Settling basin-holding pond system used in northern region dairy farms.[12)]

ditches, pumping to nearby farmlands, or by evaporation. Disposal lagoons are constructed to biologically decompose organic wastes and may be aerobic, anaerobic, or a combination of the two. The effluent may be disposed of by evaporation in lagoons or by land spreading. Lagoons are also used to store manure temporarily or permanently. Both liquid and solid wastes are commonly disposed of by direct distribution or by spray irrigation on dispersal fields where crops are grown for non-human consumption.

The extent of contamination of ground water from feedlot operations is not well documented. Some studies[14)] have shown a correlation between high nitrate in ground water and proximity to feedlot operations. In contrast, a study in California[15)] concludes that agricultural ponds such as manure-holding ponds become essentially self-sealing over a period of time, depending in part on local soil characteristics and loading rates. More recently, Ciravalo and others[16)] reviewed the results of several studies of anaerobic agricultural lagoons which showed both positive and negative evidence of seepage of contaminants into ground water. In a study of three anaerobic swine waste-lagoon sites in the Virginia coastal plain, Ciravalo and others also found that the ground-water quality within 10 ft (3 m) of a lagoon in a clay subsoil was least affected by leakage of contaminants, whereas traces of contamination were found in ground water as much as 97 ft (30 m) downgradient from two above-ground diked lagoons constructed on sandy clay and sandy soils.

Because most feedlot impoundments are unlined, they are subject to the same mechanisms for ground-water contamination as other types of impoundments. A number of States are aware of these potential contamination problems and have special rules and permitting systems to cover feedlots and other agricultural practices (see Section IX). Moreover, feedlots may be regulated under the National Pollution Discharge Elimination System (NPDES) of the Federal Water Pollution Control Act, 1972 Amendments.

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SECTION V

NUMBERS OF IMPOUNDMENT SITES AND FLOW DATA

THE DATA BASE

Prior to this study, no national inventory of surface impoundments had ever been made, except for an inventory of municipal waste-treatment facilities compiled by EPA, which, although somewhat outdated, provided an approximation of the number of municipal waste impoundment sites on a State-by-State basis. Some States had made partial or fairly complete counts of certain types of impoundments, but such information was not available from central sources. Consequently, as part of this study, it was necessary to obtain readily available information by use of a number of techniques, including personal visits to selected State and Federal agencies, literature review, correspondence, and telephone interviews. Much of the information collected did not contain actual numbers of impoundments, but only provided estimates of numbers of sites known to have one or more impoundments.

The term "impoundment site," as used in this report, denotes a location where one or more impoundments are situated. The numbers in the data tables in this section are a combination of documented information and conservative or minimum estimates and, therefore, should be considered as preliminary. Although the counts given in this report for many individual States may represent reasonable approximations, the totals for the nation as a whole most likely are several times greater than indicated.

SOURCES OF DATA

State Agencies

The principal regulatory agencies in all States were contacted either by mail or telephone for readily available data on municipal, industrial, agricultural, and oil and gas impoundments. Only 19 States provided computer printouts of industrial and other impoundments that gave information on the name of the facility, Standard Industrial Classification (SIC) number, type of treatment, and flow. Some States provided copies of Section 303E River Basin reports that contained data mainly for impoundment facilities related to municipal and industrial point-source discharges to streams. The level of detail in these Basin reports differed from State to State and, although many such reports were quite useful, others provided little or no information on the numerous non-discharging impoundments that also exist in many States. Oklahoma supplied a Section 208 report which contained an excellent State-wide impoundment inventory. Visits were made to 16 States to consult with State personnel on case histories and regulations, to identify impoundment users from NPDES permit lists, and to examine records of non-discharging impoundments. Because of time and budget limitations, no attempt was made to visit all States or to make a thorough review of the files of the States visited.

Generally, permit lists for State Pollution Discharge Elimination Systems (SPDES) showed only the name of the owner of a treatment facility, SIC number, permit number, and in some instances, flow data; but no information was shown for the type of treatment. Consequently, in some States, engineers and field inspectors were asked to help identify from personal knowledge those systems which were thought to have impoundments; and, where feasible, this was checked against State permit records. A few States supplied lists of names of dischargers with no information on the methods of discharge. Several States had separate printouts of data on animal feedlot impoundments, showing the name of the owner, holding capacity, flow, use, and permit number. Estimates of numbers of oil and gas impoundments ranged from poor to good and were obtained mainly by mail and telephone contacts with State oil and gas regulatory agencies.

Federal Agencies

Most of the impoundment inventory data from Federal sources were obtained from EPA, which supplied a printout of a national municipal waste-facility inventory showing type of treatment, flow data, and population served. EPA also supplied lists of NPDES permitted facilities by State, SIC code number, and permit number. Although no indication of the use of impoundments or other treatment type was shown on the NPDES printouts, they were useful as a basis for discussions with State and Federal officials and in reviewing files in EPA Regional Offices.

Inquiries were made by telephone and mail to all EPA Regional Offices for impoundment inventory and case-history data, and visits were made to EPA Regions I, II, III, and VIII to review NPDES lists and files. The NPDES data files in Regional offices were mainly useful for counting discharging impoundments, but were of little or no value for counting or estimating the numbers of non-discharging impoundments.

Other Federal sources of impoundment data included the U.S. Bureau of Census, U.S. Department of Agriculture, U.S. Department of Army, and the U.S. Geological Survey. The Bureau of Census reports on water use in manufacturing[1)] and mining industries[2)] gave information on numbers of establishments, volumes of water used and treated, and SIC categories, by States. The statistical data in these reports provided a basis for inferring the possible existence and distribution of impoundments by States, but did not indicate actual numbers of impoundments. For example, Figure 6, based on Bureau of Census data, shows the number and distribution of those manufacturing and mining establishments that individually reported the use of more than 20 million gal (76,000 cu m) of water in 1973. Although these represent only a small percentage of the total number of all manufacturing and mining establishments, they do represent the bulk of the largest water users. Many of these establishments may use impoundments for processing or waste treatment, but the numbers shown in Figure 6 should not be compared directly with the more specific impoundment counts given in Tables 1 through 6.

The SCS provided estimates on a State-by-State basis of SCS-assisted animal feedlot operations (Mr. Charles Fogg, personal communication, 1976) and reports on operation and design of these impoundments. A

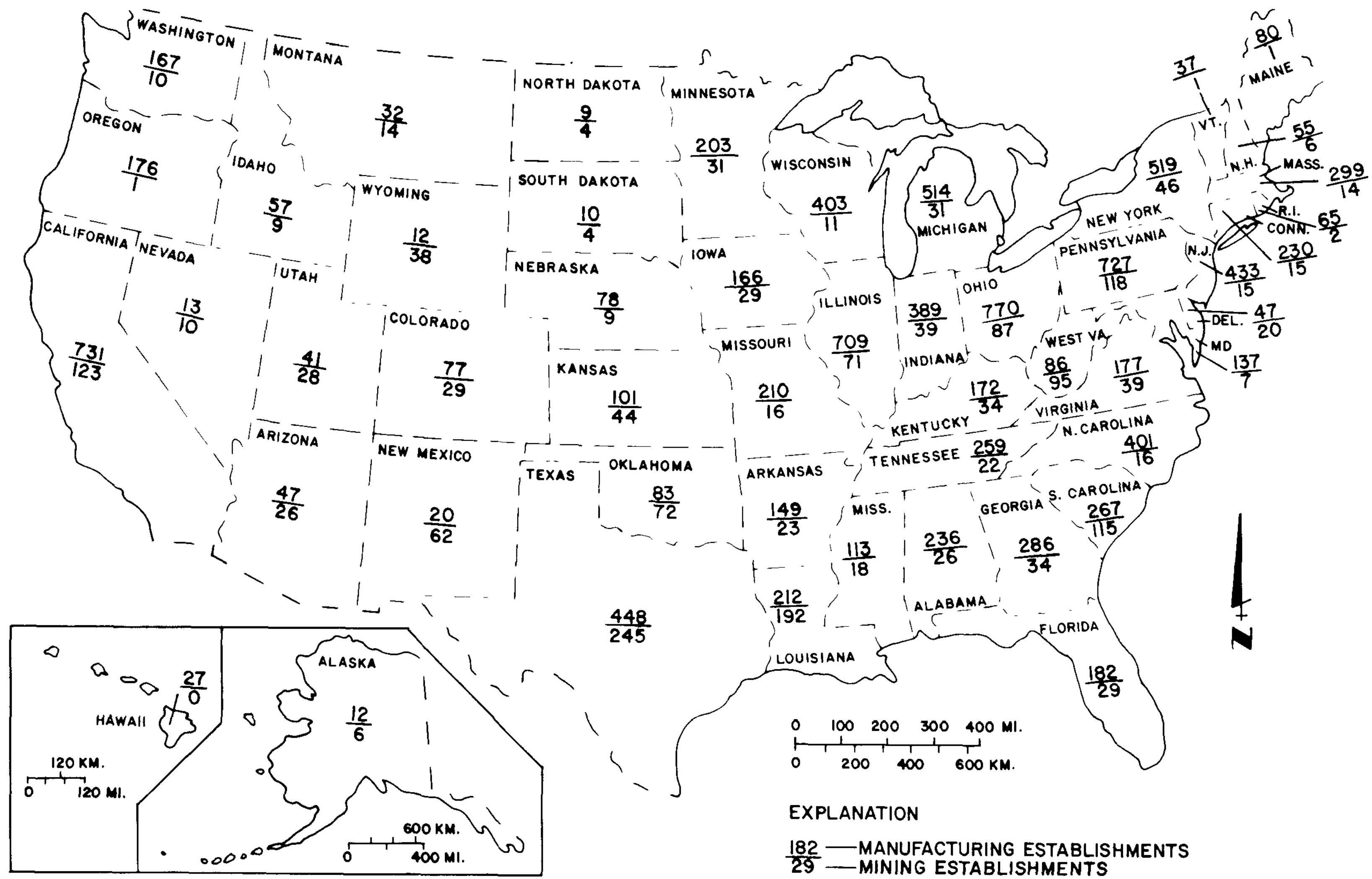

Figure 6. Distribution and number of manufacturing and mining establishments reporting use of more than 20 million gallons of water per year. Adapted from U. S. Bureau of Census, 1973. 1,2)

report by the U.S. Department of Army[3)] listed physical characteristics of selected dams and reservoirs in the United States, including a number of tailings ponds and other industrial impoundments. The U.S. Geological Survey provided information on oil and gas operations on Federal and Indian lands.

In general, the lack of standardization in Federal and State computer printouts made it difficult to retrieve comparable impoundment data and to compile the information in a uniform format for this preliminary survey. In some States, the only readily available information on numbers of impoundments consisted of informal estimates by officials or outdated or incomplete inventories which, nevertheless, were used as guides where no other data were available. Although estimates were made of the numbers of various types of impoundments, data on flow into or out of many of these types of impoundments were generally unavailable or incomplete.

PRELIMINARY IMPOUNDMENT COUNT

Table 1 shows the total number of waste-impoundment sites of all types, by States, for which data were available or could be reasonably estimated. The minimum estimated total impoundment site count was 132,709, of which about 75 percent consisted of industrial waste sites, 15 percent of agricultural waste sites, and 10 percent of municipal, institutional, and private/commercial (domestic or sanitary) waste sites. New Mexico led all the other States in the number of impoundment sites, with a total of 16,176; Pennsylvania had the next highest count, 15,341; and Rhode Island had the smallest count, 30. The distribution of impoundments by major use categories, population groups, types of wastes, and SIC categories is shown in Tables 2 through 6.

Table 2 lists approximate numbers and flow data for municipal sites and general industrial sites, exclusive of oil and gas extraction and agricultural sites. The total number of municipal impoundment sites was about 6,300 and the flow from these sites was about 4.2 bgd (15.8 million

Table 1. ESTIMATE OF NUMBERS OF IMPOUNDMENT SITES FOR ALL CATEGORIES, BY STATES

State	No.
Alabama	1,590
Alaska	130
Arizona	332
Arkansas	953
California	3,721
Colorado	5,237
Connecticut	96
Delaware	63
Florida	2,035
Georgia	1,438
Hawaii	78
Idaho	584
Illinois	3,667
Indiana	2,538
Iowa	1,466
Kansas	6,086
Kentucky	2,141
Louisiana	9,997
Maine	237
Maryland	523
Massachusetts	73
Michigan	3,229
Minnesota	1,540
Mississippi	1,676
Missouri	2,757
Montana	1,363
Nebraska	2,329
Nevada	261
New Hampshire	105
New Jersey	277
New Mexico	16,176
New York	960
North Carolina	1,038
North Dakota	2,784
Ohio	13,196
Oklahoma	2,006
Oregon	757
Pennsylvania	15,341
Rhode Island	30
South Carolina	911
South Dakota	650
Tennessee	776
Texas	8,436
Utah	669
Vermont	329
Virginia	2,116
Washington	1,045
West Virginia	2,803
Wisconsin	985
Wyoming	5,179
	132,709

Table 2. ESTIMATE OF NUMBERS OF MUNICIPAL AND INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY STATES
(Flow in 1,000 cubic metres/day)

State	Municipal		Industrial	
	No.	Flow	No.	Flow
Alabama	156	325.51	583	1,534.59
Alaska	6	3.78	100	-
Arizona	52	196.82	44	-
Arkansas	180	181.68	66	6,058.27
California	245	2,271.00	782	2,635.61
Colorado	137	113.55	103	2,337.40
Connecticut	11	56.78	48	87.66
Delaware	4	7.57	33	6.33
Florida	118	378.50	217	2,305.07
Georgia	195	170.32	205	1,923.92
Hawaii	5	7.57	29	-
Idaho	76	75.70	24	579.25
Illinois	413	5,117.32	445	-
Indiana	183	1,411.80	357	5,591.32
Iowa	257	454.20	210	690.99
Kansas	256	124.90	164	112.11
Kentucky	29	45.42	944	111.27
Louisiana	81	359.58	552	-
Maine	3	11.36	44	287.38
Maryland	53	45.42	321	-
Massachusetts	5	18.92	40	33.80
Michigan	142	79.48	279	98.77
Minnesota	235	166.54	52	352.74
Mississippi	283	215.74	266	4,439.69
Missouri	332	276.30	213	3,132.03
Montana	130	105.98	64	372.32
Nebraska	223	79.48	1,180	192.88
Nevada	23	280.09	110	-
New Hampshire	8	15.14	41	312.16
New Jersey	9	11.36	230	55.65
New Mexico	38	18.93	63	1,447.29
New York	33	363.36	308	546.97
North Carolina	147	155.18	282	1,319.56
North Dakota	250	246.02	76	581.57
Ohio	88	140.04	1,460	-
Oklahoma	260	257.38	354	52.10
Oregon	104	64.34	88	-
Pennsylvania	51	45.42	12,300	393.86
Rhode Island	2	7.57	12	17.03
South Carolina	255	299.02	81	213.97
South Dakota	192	90.84	34	22.08
Tennessee	58	98.41	215	71.16
Texas	379	605.60	1,042	59,748.00
Utah	38	68.13	68	380.02
Vermont	12	11.36	244	27.97
Virginia	90	246.02	1,409	46.37
Washington	91	193.04	255	1,269.19
West Virginia	48	34.06	1,631	4,127.72
Wisconsin	223	401.21	103	151.25
Wyoming	64	49.20	73	25.88
	6,273	16,002.94	27,844	103,693.20
		(4,228)[a]		(27,395)[a]

[a]Figures in parentheses represent flow, in million gallons daily.

cu m/day). Illinois had the largest number of municipal sites, about 400. About 27,800 general industrial sites had a minimum total flow of about 27.3 bgd (103.7 million cu m/day). The total industrial flow figure, which is heavily weighted by a large amount of cooling-pond water for power plants, is incomplete because of scanty data for many impoundments.

Table 3 shows the number of municipal waste-treatment impoundment sites by population groups served within individual States. The table shows that the smallest population group (communities of less than 2,500 people) had the largest total site count, about 4,900, and the lowest total flow, about 452 mgd (1.7 million cu m/day). For the largest population group (communities of more than 50,000 people), the total impoundment count was the smallest, about 90, but the total flow was the highest, about 2,300 mgd (8.7 million cu m/day).

Table 4 lists some 54,000 impoundments of all types for which major use categories could be identified or estimated from records. The largest number of impoundments, about 18,000, was used for settling, mostly in coal-mining operations. Storage and disposal impoundments each numbered more than 10,000; many of these were part of agricultural feedlot or municipal waste-treatment operations. The designation "disposal" was applied to impoundments designed for either evaporation or percolation or both. Most of the impoundments identified as oxidation and stabilization ponds were used in the treatment of municipal wastes. Not listed in Table 4 are more than 30,000 emergency pits and ponds used intermittently in the oil and gas extraction industry.

Table 5 shows the number of waste-impoundment sites at institutional, private/commercial, and agricultural facilities. Institutional facilities include jails, hospitals, schools, and public buildings; private/commercial facilities include camps, hotels, motels, restaurants, gas stations, and mobile home sites. Institutional impoundment sites totalled about 1,500 with the highest number, 150, in Florida. Private/commercial impoundment sites totalled about 5,900 with the highest number, 1,200, in

Table 3. ESTIMATE OF NUMBERS OF MUNICIPAL IMPOUNDMENT SITES AND FLOW DATA, BY POPULATION GROUPS[a]

(Flow, in 1,000 cubic metres/day)

Population Group	≤ 2,500		2,501 - 5,000		5,001 - 10,000		10,001 - 50,000		> 50,000		Total	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	118	-	25	-	10	-	3	-	0	0	156	325.51
Alaska	6	3.78	0	0	0	0	0	0	0	0	6	3.78
Arizona	26	11.36	10	11.36	8	11.36	5	22.71	3	140.04	52	196.82
Arkansas	132	45.42	21	30.28	22	60.56	5	49.20	0	0	180	181.68
California	78	60.56	58	98.41	46	113.55	49	522.33	14	1,476.15	245	2,271.00
Colorado	122	56.78	10	26.50	4	15.14	1	11.36	0	0	137	113.55
Connecticut	4	-	1	-	2	7.57	3	49.20	1	-	11	56.78
Delaware	3	3.78	1	-	0	0	0	0	0	0	4	7.57
Florida	56	-	21	-	20	-	19	-	2	-	118	378.50
Georgia	128	64.34	39	15.14	14	15.14	13	30.28	1	30.28	195	170.32
Hawaii	5	7.57	0	0	0	0	0	0	0	0	5	7.57
Idaho	63	30.28	5	11.36	3	11.36	4	22.71	1	0	76	75.70
Illinois	294	90.84	48	71.92	20	52.99	38	317.94	13	4,587.42	413	5,117.32
Indiana	143	49.20	10	18.92	11	37.85	15	401.21	4	529.90	183	1,411.80
Iowa	222	49.20	10	7.57	13	11.36	5	56.78	7	329.30	257	454.20
Kansas	232	71.92	15	15.14	4	11.36	3	3.78	2	22.71	256	124.90
Kentucky	19	7.57	6	7.57	3	15.14	1	15.14	0	0	29	45.42
Louisiana	52	18.92	15	22.71	6	18.92	5	37.85	3	264.95	81	359.58
Maine	1	-	1	-	0	0	1	7.57	0	0	3	11.36
Maryland	43	18.92	5	11.36	2	11.36	3	7.57	0	0	53	45.42
Massachusetts	2	-	1	3.78	1	3.78	1	11.36	0	0	5	18.92
Michigan	130	56.78	7	11.36	3	7.57	2	7.57	0	0	142	79.48
Minnesota	206	75.70	13	11.36	12	22.71	4	56.78	0	0	235	116.54
Mississippi	222	71.92	37	49.20	14	30.28	10	68.13	0	0	283	215.74
Missouri	273	87.06	30	37.85	16	45.42	13	105.98	0	0	332	276.30
Montana	110	75.70	14	52.99	4	11.36	2	-	0	0	130	105.98
Nebraska	213	37.85	4	3.78	4	11.36	2	22.71	0	0	223	79.48
Nevada	11	3.78	4	7.57	7	18.92	1	7.57	0	0	23	280.09
New Hampshire	7	3.78	0	0	1	11.36	0	0	0	0	8	15.14
New Jersey	1	-	1	3.78	4	7.57	1	-	2	-	9	11.36
New Mexico	31	3.78	3	3.78	3	7.57	1	3.78	0	0	38	18.93
New York	16	11.36	2	3.78	6	45.42	6	79.48	3	223.32	33	363.36
North Carolina	117	15.14	9	18.92	7	18.92	10	56.78	4	45.42	147	155.18

Table 3 (Continued). ESTIMATE OF NUMBERS OF MUNICIPAL IMPOUNDMENT SITES AND FLOW DATA, BY POPULATION GROUPS

(Flow, in 1,000 cubic metres/day)

Population Group	≤ 2,500		2,501 - 5,000		5,001 - 10,000		10,001 - 50,000		> 50,000		Total	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
North Dakota	226	34.06	5	3.78	6	22.71	13	185.46	0	0	250	246.02
Ohio	60	34.06	11	26.50	7	30.28	10	49.20	0	0	88	140.04
Oklahoma	231	83.27	16	26.50	8	26.50	4	26.50	1	98.41	260	257.38
Oregon	84	22.71	8	11.36	5	15.14	7	15.14	0	0	104	64.34
Pennsylvania	41	7.57	2	-	1	-	4	34.06	3	0	51	45.42
Rhode Island	1	-	0	0	0	0	1	7.57	0	0	2	7.57
South Carolina	223	79.48	21	18.92	4	11.36	5	60.56	2	128.69	255	299.02
South Dakota	172	37.85	7	7.57	3	7.57	8	34.06	2	-	192	90.84
Tennessee	55	22.71	2	71.92	0	0	1	-	0	0	58	98.41
Texas	247	45.42	58	26.50	30	30.28	29	117.34	15	386.07	379	605.60
Utah	32	11.36	4	7.57	1	3.78	1	45.42	0	0	38	68.13
Vermont	10	7.57	2	3.78	0	0	0	0	0	0	12	11.36
Virginia	75	26.50	10	15.14	2	7.57	2	0	1	200.60	90	246.02
Washington	72	79.48	9	26.50	3	3.78	5	37.85	2	49.20	91	193.04
West Virginia	43	30.28	5	3.78	0	0	0	0	0	0	48	34.06
Wisconsin	202	140.04	11	45.42	5	11.36	4	79.48	1	124.90	223	401.21
Wyoming	53	15.14	6	11.36	4	7.57	1	11.36	0	0	64	49.20
Total	4,913	1,710.79 (452)[b]	603	862.99 (228)	349	813.80 (215)	321	2,679.77 (708)	87	8,637.36 (2,282)	6,273	16,002.94 (4,228)

[a] Based mainly on EPA municipal waste inventory (1968-74).

[b] Figures in parentheses represent flow, in million gallons daily.

Table 4. NUMBERS OF IMPOUNDMENTS FOR WHICH USE CATEGORIES WERE DETERMINED

Use Category	No.
Aeration	924
Oxidation	6,047
Stabilization	1,573
Settling	18,073
Disposal	16,124
Storage	10,653
	53,394

Table 5. NUMBERS OF INSTITUTIONAL, PRIVATE/COMMERCIAL, AND AGRICULTURAL IMPOUNDMENT SITES, BY STATES

State	No. of Impoundments		
	Institutional	Private/Commercial	Agricultural
Alabama	50	130	669
Alaska	-	-	15
Arizona	55	63	112
Arkansas	10	50	107
California	118	560	1,106
Colorado	10	125	245
Connecticut	-	-	37
Delaware	3	10	13
Florida	150	1,200	350
Georgia	79	225	734
Hawaii	5	5	34
Idaho	10	20	454
Illinois	50	100	659
Indiana	62	117	1,067
Iowa	54	245	700
Kansas	14	64	1,063
Kentucky	6	26	136
Louisiana	50	150	323
Maine	5	10	175
Maryland	18	20	111
Massachusetts	5	15	8
Michigan	3	93	692
Minnesota	17	54	1,185
Mississippi	49	129	586
Missouri	50	1,092	1,064
Montana	8	20	316
Nebraska	8	15	703
Nevada	10	50	53
New Hampshire	2	10	44
New Jersey	5	20	13
New Mexico	2	28	45
New York	50	100	204
North Carolina	25	81	503
North Dakota	5	10	543
Ohio	50	100	498
Oklahoma	15	50	338
Oregon	10	28	527
Pennsylvania	90	41	359
Rhode Island	5	10	1
South Carolina	58	191	326
South Dakota	5	10	379
Tennessee	34	30	339
Texas	142	358	515
Utah	4	8	234
Vermont	2	9	62
Virginia	77	51	389
Washington	11	16	672
West Virginia	6	83	35
Wisconsin	11	50	598
Wyoming	5	15	22
	1,513	5,887	19,363

Florida and the second highest, 1,092, in Missouri. Agricultural impoundment sites, mostly for feedlot wastes, totalled about 19,400, with the highest number, 1,185, in Minnesota and the second highest number, 1,106, in California. The agricultural impoundment estimate is based mainly on those facilities whose construction was supported in part by the SCS and, therefore, is a minimum number. Virtually no flow data were available for agricultural impoundments. Most are believed to be non-discharging types.

The estimated number of surface impoundments associated with the oil and gas extraction industry totalled 71,832 (Table 6). The highest reported total of oil and gas impoundments in an individual State was 16,000 in New Mexico. The principal identified use of oil and gas impoundments is for emergency purposes such as temporary storage of salt water or petroleum. Ohio and Texas have the largest numbers of emergency impoundments, 11,000 and 6,000, respectively. The estimated number of oil and gas impoundments is conservative. For example, burn pits and cuttings or mud pits were not included in the count. If these and other unreported impoundments had been included, most likely the total count would have been increased by some tens of thousands (one eastern State reported more than 19,000 cuttings pits). No flow data were available for oil and gas impoundments; most are non-discharging types.

Table 12 in Section XII (Appendix B) lists the number of impoundment sites by States for which SIC codes could be determined. The highest numbers of industrial impoundments were as follows: SIC 13 (Oil and Gas), 71,832; SIC 01 and 02 (Agriculture - Crops and Livestock), 19,363; and SIC 12 (Coal Mining - Bituminous), 14,170. Because the flow data were fragmentary, no total flows were shown by SIC category. However, a report by EPA[4)] indicates that 91 percent of the total volume of wastes placed in lagoons and ponds in 1968 was generated by industries as follows: Paper and Allied Products (SIC 26), 29 percent; Petroleum and Coal Products (SIC 29), 22 percent; Primary Metals (SIC 33), 22 percent;

Table 6. ESTIMATE OF NUMBERS OF IMPOUNDMENTS ASSOCIATED WITH OIL AND GAS EXTRACTION

(Based in part on estimates or data supplied by State agencies)

State	Number of Impoundments				
	Saltwater Disposal[a]	Separator	Emergency	Undifferentiated	Total
Alabama	0	0	2	-	2
Alaska	0	0	9	-	9
Arizona	6	-	-	-	6
Arkansas	-	-	540	-	540
California	53	726	131	-	910
Colorado	2,747	-	-	1,870	4,617
Florida	0	0	0	-	0
Illinois	-	-	-	2,000	2,000
Indiana	600	20	40	92	752
Kansas	173	652	3,700	-	4,525
Kentucky	-	-	-	1,000	1,000
Louisiana	2,322	165	3,996	2,358	8,841[b]
Michigan	20	-	2,000	-	2,020
Mississippi	19	-	94	250	363
Missouri	-	-	-	6	6
Montana	-	-	-	825	825
Nebraska	-	12	188	-	200
Nevada	0	5	10	-	15
New Mexico	-	-	-	16,000	16,000[c]
New York	150	100	15	-	265
North Dakota	-	-	1,900	-	1,900
Ohio	0	0	11,000	-	11,000
Oklahoma	-	-	834	155	989
Pennsylvania	0	-	0	2,500	2,500
South Dakota	30	0	0	-	30
Tennessee	0	0	100	-	100
Texas	-	-	6,000	-	6,000
Utah	5	12	300	-	317
Virginia	-	-	-	100	100
West Virginia	-	-	-	1,000	1,000
Wyoming	-	-	-	5,000	5,000
	6,125	1,692	30,859	33,156	71,832

[a] Mostly by evaporation or by temporary storage for secondary recovery operations.

[b] Based on reports from five of six districts.

[c] Includes numerous small dehydration pits associated with natural gas wells.

and Chemical and Allied Products (SIC 28), 18 percent. The discharge to ponds from these four industrial groups totalled about 1,514 bgd (5,730 million cu m/day). The same report estimates total leakage to ground water from all industrial waste impoundments at about 100 billion gal/yr (378 million cu m/yr).

In summary, reasonably complete inventory data on a national basis were available only for municipal impoundments. Other inventories, especially for industrial categories, ranged from fairly complete in California, Washington, and Florida, for example, to sparse and fragmentary in many States. The total number of waste-impoundment sites has been very conservatively estimated at about 132,700 in this study. If it is assumed that the national average is 2 to 3 impoundments per site, the total number of impoundments would be at least 260,000 to 400,000.

The data on flow into or out of impoundments were particularly incomplete. Moreover, for most impoundments, no data were available on the comparative fluid losses by evaporation or by seepage to ground water.

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2. Bureau of the Census. 1975. 1972 census of mineral industries, water use in mineral industries. U.S. Department of Commerce, Washington, D.C. 58 pp.

3. U.S. Department of the Army - Office of Chief of Engineers. 1975. National program of inspection of dams. Five volumes.

4. U.S. Environmental Protection Agency. 1977. Report to Congress on waste disposal practices and their effects on ground water. EPA-570/9-77-001. 512 pp.

SECTION VI

CHEMICAL CONTENTS OF IMPOUNDED WASTES

TYPES AND SOURCES OF DATA

The overall chemical characteristics of waste fluids in impoundments are discussed briefly in this section, and further details for 26 major SIC categories are given in Section XII, Appendix C. The 26 categories include all the major agricultural, manufacturing, processing, and utilities industries. Certain categories (such as SIC 10-Metal Mining, SIC 28-Chemicals and Allied Products, SIC 33-Primary Metals, and SIC 49-Electric, Gas, and Sanitary Services) include a large number of widely differing industrial activities and associated wastes. For many such categories, it was necessary to introduce a degree of generalization on an industry segment level in order to provide a broad characterization of the impounded wastes.

Most of the descriptions of the nature of the wastes given in this section were summarized from EPA effluent guidelines development documents and hazardous waste practices reports, which provided a good review of the process technology and of the character of liquid and solid wastes and sludges by individual industries. Textbooks on industrial waste management[1)] and on waste production and disposal in the mining and milling industries[2)] also provided background descriptions of wastes and waste-treatment technologies.

CHARACTER OF THE WASTES

Impounded wastes may be liquid, semi-solid, or solid and may range from harmless to highly toxic, depending on the nature and concentration of the constituents. From a chemical classification viewpoint, the waste streams entering impoundments may be composed of inorganic or organic substances, or a combination of the two.

Inorganic industrial waste streams are generally characterized in terms of suspended solids, TDS, pH, acidity or alkalinity, and specific elements and components that form part of the chemical process or product. Treatment is generally physicochemical in nature with separation of suspended solids by the use of settling ponds, clarifiers and thickeners, filters, centrifuges, and coagulation tanks, if necessary. Dissolved solids can be removed by precipitation, ion exchange, and reverse osmosis or can be neutralized or oxidized.

The contaminant parameters that are commonly used to characterize organic industrial waste streams are: BOD, COD, TOC, oil and grease, and suspended solids. Other potential contaminants are in waste streams originating from various manufacturing processes; these contaminants include organic chemicals, such as phenols, cyanide, chlorinated hydrocarbons, and other miscellaneous organics. Organics, which generally are not included in routine analyses, have become recognized as significant waterborne contaminants only in recent years. In principle, all organic materials can be converted to more elemental forms such as carbon dioxide and water. The most commonly used process is secondary biological treatment by activated sludge and aerated lagoons. Some organic compounds such as phenols, chlorinated hydrocarbons, and aromatic hydrocarbons are degraded only with difficulty or not at all and may retard or prevent biological treatment of waste streams containing these substances.

Domestic (municipal) sewage effluent has a high TDS content, various nitrogen compounds, phosphate, sulfate, chloride, BOD, and coliform bacteria, and other constituents. Most of these are natural constituents of human wastes. Locally, detergents, phosphate, heavy metals, and other compounds derived from man's activities are present in sewage. Some municipal sewage consists of a mixture of domestic and industrial wastes. Sludge from sewage-treatment plants commonly contains heavy metals as well as pathogenic organisms. Leaching of organics, nitrate, and other constituents from sewage sludge in unlined drying beds or lagoons can cause contamination of ground water.

Table 7 contains a summary of the principal constituents in wastewater from selected industries and municipal sewage. These constituents include all the common cations and anions, heavy metals, and organics. Unusual constituents, which may be in wastewater from specific industrial sources, are not listed in Table 7.

RELATION TO GROUND-WATER QUALITY

With the exception of a few constituents that may be derived from or adsorbed on aquifer materials during movement of fluids into and through an aquifer, contaminated ground water beneath and near many impoundments, as shown by the case histories discussed in Section VII, commonly reflects the approximate character of the source fluids in impoundments. Knowledge of the composition of the impounded waste fluids, therefore, can provide a basis for predicting or explaining the composition of ground water contaminated by seepage of waste fluids from impoundments.

Most of the dissolved inorganic and organic constituents in waste fluids can move readily into ground water by direct seepage of the fluids through the sides and bottoms of unlined impoundments. Similarly, solids in impoundments may be leached by precipitation or by inflow of other fluids and, following dissolution, the leachate may seep into ground water. Although such factors as pH, sorptive capacity, and the low permeability of some soils may slow down or impede the movement of selected ions, many waterborne contaminants, given an adequate source of supply, sufficient time, and a hydraulic gradient, have the potential for eventually reaching the water table and moving downgradient in an aquifer.

Table 7. CONSTITUENTS IN INDUSTRIAL AND MUNICIPAL WASTEWATER HAVING SIGNIFICANT POTENTIAL FOR GROUND-WATER CONTAMINATION[3,4]

MINING (SIC 10, 11, and 12)

Metal and Coal Mining Industry (SIC 10, 11, and 12)

pH	Zinc	Magnesium
Sulfate	Tin	Silver
Nitrate	Vanadium	Manganese
Chloride	Radium	Calcium
Total dissolved solids	Phenol	Potassium
	Selenium	Sodium
Phosphate	Iron	Aluminum
Copper	Chromium	Gold
Nickel	Cadmium	Fluoride
Lead	Uranium	Cyanide

PAPER AND ALLIED PRODUCTS (SIC 26)

Pulp and Paper Industry (SIC 261 and 262)

COD/BOD	Phenols	Nitrogen
TOC	Sulfite	Phosphorus
pH	Color	Total dissolved solids
Ammonia	Heavy metals	
		Biocides

CHEMICALS AND ALLIED PRODUCTS (SIC 28)

Organic Chemicals Industry (SIC 286)

COD/BOD	Alkalinity	Phenols
pH	TOC	Cyanide
Total dissolved solids	Total phosphorus	Total nitrogen
	Heavy metals	

Inorganic Chemicals, Alkalies, and Chlorine Industry (SIC 281)

Acidity/alkalinity	Chlorinated benzenoids and polynuclear aromatics	Chromium
Total dissolved solids		Lead
		Titanium
Chloride	Phenols	Iron
Sulfate	Fluoride	Aluminum
COD/BOD	Total phosphorus	Boron
TOC	Cyanide	Arsenic
	Mercury	

Table 7 (Continued). CONSTITUENTS IN INDUSTRIAL AND MUNICIPAL WASTEWATER HAVING SIGNIFICANT POTENTIAL FOR GROUND-WATER CONTAMINATION

CHEMICALS AND ALLIED PRODUCTS (Continued)

Plastic Materials and Synthetics Industry (SIC 282)

COD/BOD	Phosphorus	Ammonia
pH	Nitrate	Cyanide
Phenols	Organic nitrogen	Zinc
Total dissolved solids	Chlorinated benzenoids and polynuclear aromatics	Mercaptans
Sulfate		

Nitrogen Fertilizer Industry (SIC 2873)

Ammonia	Sulfate	COD
Chloride	Organic nitrogen compounds	Iron, total
Chromium	Zinc	pH
Total dissolved solids	Calcium	Phosphate
Nitrate		Sodium

Phosphate Fertilizer Industry (SIC 2874)

Calcium	Acidity	Mercury
Dissolved solids	Aluminum	Nitrogen
Fluoride	Arsenic	Sulfate
pH	Iron	Uranium
Phosphorus	Cadmium	Vanadium
		Radium

PETROLEUM AND COAL PRODUCTS (SIC 29)

Petroleum Refining Industry (SIC 291)

Ammonia	Chloride	Nitrogen
Chromium	Color	Odor
COD/BOD	Copper	Total phosphorus
pH	Cyanide	Sulfate
Phenols	Iron	TOC
Sulfide	Lead	Turbidity
Total dissolved solids	Mercaptans	Zinc

Table 7 (Continued). CONSTITUENTS IN INDUSTRIAL AND MUNICIPAL WASTEWATER HAVING SIGNIFICANT POTENTIAL FOR GROUND-WATER CONTAMINATION

PRIMARY METALS (SIC 33)

Steel Industry (SIC 331)

pH	Cyanide	Tin
Chloride	Phenols	Chromium
Sulfate	Iron	Zinc
Ammonia	Nickel	

ELECTRIC, GAS, AND SANITARY SERVICES (SIC 49)

Power Generation Industry (SIC 491)

COD/BOD	Copper	Phosphorus
pH	Iron	Free chlorine
Polychlorinated biphenols	Zinc	Organic biocides
Total dissolved solids	Chromium	Sulfur dioxide
Oil and grease	Other corrosion inhibitors	Heat

Municipal Sewage Treatment (SIC 495)

pH	Nitrate	Sulfate
COD/BOD	Ammonia	Copper
TOC	Phosphate	Lead
Alkalinity	Chloride	Tin
Detergents	Sodium	Zinc
Total dissolved solids	Potassium	Various Organics

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SECTION VII

PATTERNS OF GROUND-WATER CONTAMINATION AND CASE HISTORIES

GENERAL NATURE OF THE CONTAMINATION THREAT

A large majority of the surface impoundments in the nation are unlined and, as a consequence, waste fluids that seep down from them can constitute a potential threat to the natural quality of underground drinking-water sources. Only a very small percentage of these impoundments are monitored routinely or have been investigated in sufficient detail to show the full nature and extent of the contamination threat, but enough case histories have been compiled, as discussed later in this section, to indicate that the potential threat could be widespread. Many impoundments are virtually watertight, either because of excavation in relatively impermeable natural materials such as clay and silt or because of the use of liners. Some impoundments are thought to be "self-sealing" because of the settling of silt and clay-size particles or the deposition of chemical precipitates or organic slimes on the sides and bottoms of the impoundments. These impoundments generally present no significant threat to ground-water quality unless the watertight seal is ruptured or the impoundment overflows.

Many impoundments that are referred to as "evaporation ponds," especially in humid parts of the country, actually lose little of their fluid contents by evaporation and, instead, depend on subsurface infiltration to keep from overflowing. When the natural soils at the bottoms and sides of these impoundments become clogged, it may be necessary to scarify or scrape them to improve seepage.

GEOLOGIC AND HYDROLOGIC CONTROLS

Shallow water-table aquifers are commonly the first to undergo contamination by seepage from impoundments and, on a national basis, are generally far more vulnerable than deeper artesian aquifers, which are usually protected against contamination by overlying beds of clay or other geologic materials of low permeability. No two impoundment sites are exactly alike, even in areas underlain by aquifers having similar hydrogeologic characteristics. Aquifers may be composed of unconsolidated sediments, such as sand, gravel, silt, and clay, or consolidated rocks, such as sandstone, shale, and limestone. The mineralogy of these materials controls their ion-exchange and adsorptive capacity. The depth to the water table differs from place to place and ranges from a few feet to possibly hundreds of feet below the land surface. The permeability of aquifer materials may range from low to high and generally is much less vertically than it is horizontally; in some areas, aquifers may be separated by thick extensive confining beds composed of silt, clay, or rocks of low permeability that retard vertical movement of water from one aquifer to another. In some locations, local "perched" water-table bodies, underlain by lenses of silt and clay, exist above the main water table, at least during periods of wet weather. These perched zones can provide temporary storage for contaminated water seeping down from impoundments.

PATTERNS OF CONTAMINATION

Patterns of contamination of ground water resulting from seepage of wastes from surface impoundments have some common features. Contaminated fluid first seeps out through the bottom or sides of the impoundment, under the influence of gravity or head differences, and then moves slowly downward until it reaches the water table. In beds of extremely low permeability, the fluid may move only a fraction of an inch over a long period of time, but in more permeable materials, the fluid may move at rates of up to several feet (about 1 m) per day or more.

Upon reaching the water-table aquifer, the pattern of flow and the chemical character of the contaminated fluid are influenced by various mechanisms, such as head differences, vertical and horizontal permeabilities, attenuation processes, nature of the soil materials, precipitation, density differences, and other factors. Commonly, the concentrations of constituents in the wastewater are altered by passage through the unsaturated zone as various physical, chemical, and biological reactions occur. Most dissolved constituents, however, ultimately enter or have the potential for entering the saturated zone of the aquifer, especially where the sorptive capacity of the soil is exhausted by continuous seepage of contaminated fluids.

Usually, the contaminated water seeping into an aquifer from an impoundment assumes the form of a discrete body or plume of contamination. The plume is elongated in the direction of ground-water movement and is generally at least several times longer than it is wide (Figures 8 and 20). The boundaries of a plume, which are generally marked by a zone of dispersion or zone of mixed waters, may be smooth or irregular, depending on variations in lithology, permeability, head distribution, degree of dispersion, density differences of the fluids, and effects of nearby pumping wells.

Figure 7 is a hypothetical vertical section through a plume and its associated zone of dispersion showing the pattern of flow of contaminants from a surface impoundment to the water table and, from there, into a nearby lake or stream. The contaminated water first seeps downward by gravity to form a recharge mound at the water table beneath the impoundment and then moves laterally downgradient in the water-table aquifer. The shape and configuration of the plume will vary, other things being equal, with the differences in density between the wastewater and the ground water. A dense contaminated fluid such as brine may form a nearly vertical column downward from the surface impoundment until it encounters confining beds at the base of the aquifer, where it then begins to form a low mound. On the other hand, a contaminated fluid that has a density similar to that of the native ground water may never reach the base of the aquifer but may be carried away in the regional flow pattern in the upper part of the aquifer. As can be seen from Figure 7, it is important to select proper locations and depths for

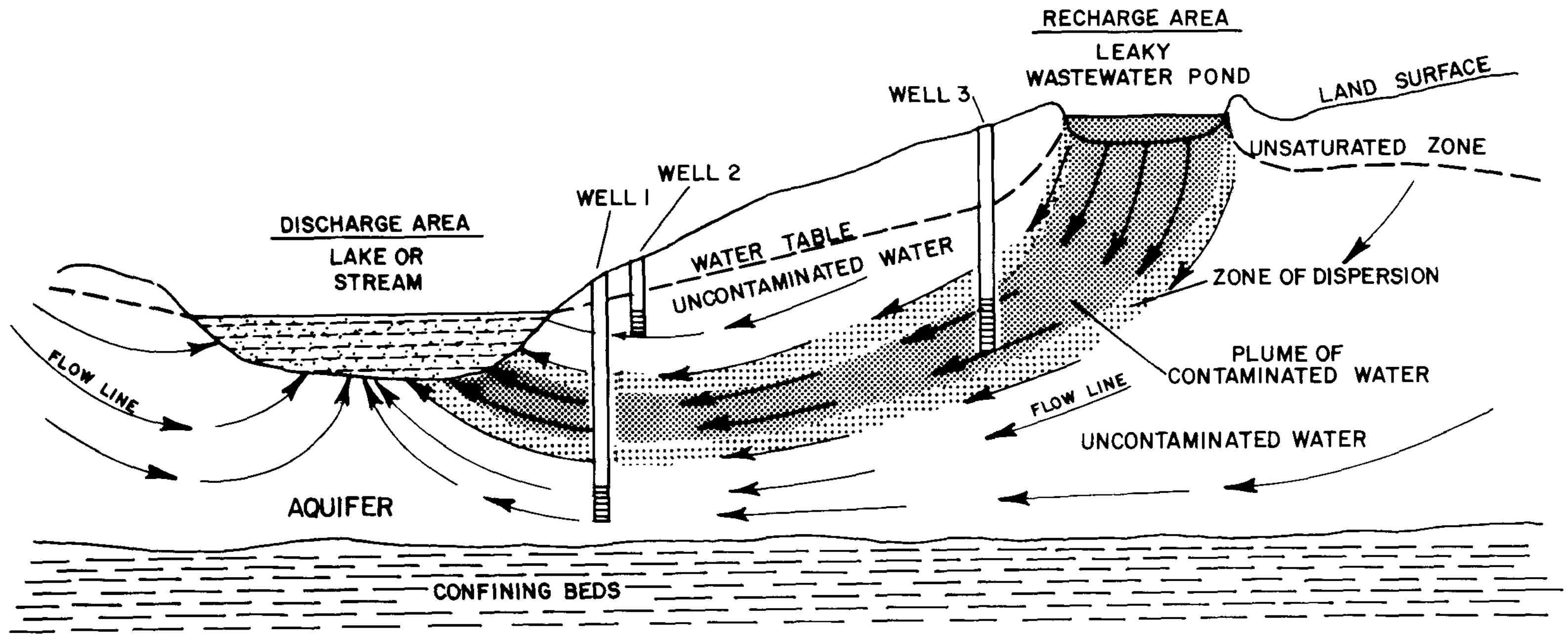

Figure 7. Section through a plume of contaminated ground water extending from a recharge area at a wastewater pond to a discharge area at a lake or stream.

sampling wells in order to map the boundaries of a plume of wastes and the internal concentration distribution of the contaminants.

Because ground water is always in motion, contaminated plumes tend to become longer, wider, and thicker with time, especially where seepage continues at the source impoundment. In places, however, the leading edge of a plume may be stabilized at a hydraulic discharge boundary such as a stream or a line of pumping wells. Under these conditions, contaminants from the plume most likely would be detected in samples from the stream or pumping wells.

Contaminants in ground water can be partly removed or reduced in concentration by attenuation. Attenuation mechanisms include: sorption, ion exchange, dispersion, and radioactive decay. The rate of attenuation is a function of the type of contaminant and of the characteristics of the local hydrogeologic framework. Predicting the degree to which contaminants may become attenuated is extremely difficult, owing to the wide differences in soil properties and hydrologic characteristics of various locations. Despite the potential for attenuation, however, case histories show that plumes emanating from impoundments can extend downgradient thousands of feet in highly permeable aquifers composed of materials such as sand, gravel, and limestone.

EVIDENCE OF CONTAMINATION FROM CASE HISTORIES

Summary of National Situation

Table 8 provides summary data for 85 cases of ground-water and/or surface-water contamination associated with leaky impoundments in 29 States. Most of the data have been derived from reports published by EPA and from various scientific, technical, and trade journals; data on a small number of cases were obtained directly from State agencies by mail or as a result of visits. The cases were selected essentially at random and are not intended to indicate either the actual or relative magnitude of the contamination problem in any particular industry or

Table 8. SUMMARY OF SELECTED CASE HISTORIES OF CONTAMINATION FROM IMPOUNDMENTS

State	Nature of Activity	SIC Code[a]	Contaminants in Ground Water[b]	Contaminants in Surface Water[b]	Environmental Impact	Remedial Actions	Remarks
Alabama	Petroleum production	13	Chloride	--	GWD; loss of wells; vegetation destroyed	--	Two other cases reported.
Arkansas	Petroleum production	13	Chloride, 49,500 mg/l	--	GWD[b]	Pits filled	Two other cases reported.
California	Do.	13	Oil-field wastes	--	GWD	Pits abandoned	--
Do.	Borax mining	147	Evaporation pond leakage	--	GWD	--	--
Colorado	Uranium ore processing	109	--	Ammonia, 40 mg/l	SWD	--	--
Do.	Do.	109	Molybdenum, 5 mg/l; copper	--	GWD	Pond lined; additional treatment	Molybdenum, 856 mg/l, in pond.
Do.	Beet sugar production	206	Manganese; iron	Manganese; iron	GWD	Stream discharge under permit	--
Do.	Chemical manufacturing	28	Pesticides; herbicides; arsenic; chlorate; chloride, 4,000 mg/l	--	Crop damage; temporary abandonment of wells	Impoundment lined	--
Do.	Petroleum production	13	Oil-field brines	--	Loss of public-supply wells	--	--
Florida	Phosphate processing	1475 2874	Acid waste; Radium-226	--	GWD; shallow aquifer	--	Sampling programs 1966, 1973, 1975.
Do.	Do.	2874	Cyanide, 0.02-0.57 mg/l Total phosphate (P), 0.4-33 mg/l	--	GWD	--	Observation wells within 200 ft of holding ponds.
Do.	Chemical manufacturing	28	Fluoride; sulfate; TDS; excessive hardness	--	GWD; loss of supplies	Deep well disposal	Municipal well abandoned.
Georgia	Chemical manufacturing	285	Chemical wastes	Chemical wastes	Discoloration of pond, spring, ground water	--	--
Idaho	Lead, zinc, phosphate processing	103 2874	Fluoride, 170 mg/l; zinc, 180 mg/l; cadmium; lead; iron; manganese	Zinc, cadmium	GWD; SWD	Collector well and metal removal	Fluoride, 840 mg/l; zinc, 220 mg/l, in impoundment.
Do.	Chemical processing	28	Tritium; strontium-90; cobalt-60; chromium-51	--	GWD	--	Continued monitoring.
Do.	Do.	28	Sulfate; sulfite; phosphate; sodium; chloride	--	GWD	--	Do.

Table 8 (Continued). SUMMARY OF SELECTED CASE HISTORIES OF CONTAMINATION FROM IMPOUNDMENTS

State	Nature of Activity	SIC Code[a]	Contaminants in Ground Water[b]	Contaminants in Surface Water[b]	Environmental Impact	Remedial Actions	Remarks
Louisiana	Petroleum production	13	Sodium; chloride; calcium; magnesium	--	GWD	Pits abandoned	Two other cases reported.
Maryland	Wood products	24	Phenols, 14.4 mg/l; tannin; lignin	Phenols, 2.1 mg/l; tannin; lignin	Damage to aquatic life	--	--
Do.	Fertilizer storage	2873	Nitrate, as nitrogen, 27 mg/l	--	GWD	--	Seepage probably aggravated by spills.
Do.	Sewage	495	Sodium; chloride	--	GWD	--	--
Michigan	Chemical manufacturing	28	Chloride, 1,000 mg/l	--	GWD	Hydraulic barrier	--
Do.	Metal finishing	347	Cyanide, 14 mg/l; chromium, 0.36 mg/l; copper, 2.8 mg/l	--	GWD	Monitoring	Plant wells contaminated.
Mississippi	Chemical manufacturing	28	Chloride	--	GWD	--	Seepage probably aggravated by spills.
Do.	Petroleum production	13	Chloride	Chloride	GWD; SWD	--	--
Do.	Textile mill	22	Dye effluent, sulfur base	--	GWD	Pond lined	--
Do.	Disposal service	49	Carbon black; organics	Carbon black; organics	GWD; SWD	New lagoons constructed; seepage continues	--
Missouri	Sewage treatment	495	Sewage	Sewage	SWD	Lagoon sealed	--
Montana	Paper industry	26	Phenols; discoloration	--	GWD	--	--
Do.	Petroleum production	13	Oil-field brines	--	GWD	--	--
Nebraska	Beet sugar	206	Manganese; iron	--	GWD	--	--
Do.	Sewage treatment	28	Herbicide	Herbicide	GWD; Damage to plants	Use of herbicides discontinued	--

Table 8 (Continued). SUMMARY OF SELECTED CASE HISTORIES OF CONTAMINATION FROM IMPOUNDMENTS

State	Nature of Activity	SIC Code[a]	Contaminants in Ground Water[b]	Contaminants in Surface Water[b]	Environmental Impact	Remedial Actions	Remarks
Nevada	Metal processing and chemical manufacturing	33 28	Increase in TDS; nitrate	Increase in TDS; nitrate	GWD	Ponds lined; additional waste treatment	Proposed ground-water pumpage to remove contaminants
New Jersey	Fiberglass production	282	Phenols; TOC; nitrate	--	GWD	--	--
New Mexico	Copper ore processing	102	Acid wastes; sulfate, 4,800 mg/l	--	GWD	--	--
Do.	Uranium ore processing	1094	Uranium; selenium; 6-10 mg/l	--	Abandonment of wells	Treatment; recycling; interceptor wells	Selenium, 30 mg/l, in pond.
Do.	Uranium ore processing	1094	Nitrate	--	GWD	Injection well	--
Do.	Petroleum production	13	Chloride	--	GWD	Abandoned pit	Brine disposal; sand and gravel aquifer.
New York	Metal plating	347	Hexavalent chromium, 40 mg/l; cadmium; copper; aluminum	--	GWD; SWD	Waste treatment	--
North Carolina	Fertilizer production	2873	Ammonium; nitrate total nitrogen, 10,000 mg/l	Total nitrogen, 400 to 500 mg/l	GWD; SWD	--	--
Do.	Chemical manufacturing	28	Organics	--	GWD	--	--
Do.	Transportation	40	Phenols; nitrate	--	GWD	--	--
Ohio	Sewage treatment	4952	Nitrogen, 679 mg/l; MBAS, 11 mg/l; phenol; chloride	--	GWD	--	Observation well, 6 feet from lagoon.
Do.	Glass manufacturing	281	TDS; chloride, 20,000 mg/l	TDS; chloride, 6,000 mg/l	Abandonment of well fields	Ceased production of soda ash	4 lagoons, 520 acres.
Do.	Iron foundry	3321	Sodium; potassium; sulfate; chloride; fluoride	--	GWD	--	--
Do.	Wire manufacturing	3315	Zinc; calcium; sulfate	--	GWD	--	--
Do.	Aluminum processing	33	Sodium; fluoride; sulfate	--	GWD	Interceptor wells	--

Table 8 (Continued). SUMMARY OF SELECTED CASE HISTORIES OF CONTAMINATION FROM IMPOUNDMENTS

State	Nature of Activity	SIC Code[a]	Contaminants in Ground Water[b]	Contaminants in Surface Water[b]	Environmental Impact	Remedial Actions	Remarks
Ohio	Truck terminal	423	Organics; dimethylformamide, phenols	--	GWD	Lining of pits recommended	--
Do.	Waste disposal	4953	Sodium; potassium; chloride; fluoride; ammonium; MBAS; organics	--	GWD	Liquid waste disposal discontinued	Lagoon used for scrubber water.
Do.	Chemical manufacturing	2899	Sodium; potassium; sulfate; phosphate; chloride; fluoride; ammonium; MBAS; phenols	--	Loss of supply wells	Impoundment lined; additional treatment	--
Do.	Plastics manufacturing	2821	Barium; lead; sodium; potassium; chloride; MBAS; phenols; organics; benzene; toluene; styrene; xylene	--	Loss of supply wells	Impoundment lined; additional treatment	--
Do.	Do.	2821	Carbon tetrachloride; chlorinated benzenes	--	GWD	Additional treatment	--
Do.	Do.	3079	Barium; copper; sodium; MBAS; phenols	--	GWD	Additional treatment	Discharge to city sanitary sewer.
Do.	Waste disposal	49	--	Acid wastes; high TDS; fluoride; iron chromium; nickel zinc; aluminum	SWD; fish kills	Treatment and containment of wastes	--
Do.	Petroleum production	13	Chloride, 35,000 mg/l	--	--	Pits filled	--
Do.	Petroleum production	13	Oil-field brines	--	Loss of supply wells	Pits abandoned	--
Oregon	Wood products	24	Lignin-tannin, 7.5 mg/l; manganese, 106 mg/l; iron, 13 mg/l	--	Loss of water supplies	--	--
Do.	Aluminum processing	33	Increase in TDS; sulfate	--	GWD	Pumped out contaminants; practice discontinued	--

Table 8 (Continued). SUMMARY OF SELECTED CASE HISTORIES OF CONTAMINATION FROM IMPOUNDMENTS

State	Nature of Activity	SIC Code[a]	Contaminants in Ground Water[b]	Contaminants in Surface Water[b]	Environmental Impact	Remedial Actions	Remarks
Oregon	Paper products	26	Increase in TDS	--	GWD	--	--
Pennsylvania	Copper recovery	33	--	Sulfuric acid; toxic wastes	Destruction of aquatic life	Neutralization; removal of wastes	--
Do.	Waste disposal	49	Acid and organic wastes	Acid and organic	Destruction of aquatic life; GWD	Pit abandoned	--
Do.	Chemical manufacturing	283	Arsenic, 2,100 mg/l	Arsenic, 0.94 mg/l	GWD; SWD	Removal of contaminants by groundwater pumpage	--
Do.	Waste disposal	49	--	Acid wastes	SWD	--	--
South Carolina	Chemical manufacturing	281	Sulfate; zinc	--	GWD	--	Sulfate, 48,000 mg/l; zinc, 13,000 mg/l, in pond.
South Dakota	Gold mining	1041	Mercury, 0.0018 mg/l	Mercury	GWD; SWD	Piping of wastes to oxidation lagoon proposed	--
Tennessee	Nylon manufacturing	28 49	BOD; COD; organics; domestic wastes	BOD; COD; organics; domestic wastes	Contamination of springs and streams	Pond sealed	--
Texas	Meat processing	201	Ammonia, 104 mg/l; nitrite, 27.0 mg/l	--	GWD	Pits lined	--
Do.	Chemical manufacturing	28	Magnesium; chloride; waste brine	--	GWD	Pits abandoned	--
Do.	Sewage disposal	49	Nitrate	Nitrates	GWD; SWD	Lagoons lined	--
Do.	Chemical manufacturing	29	Phenols, 0.03 mg/l	--	GWD	Lagoons lined	--
Do.	Chemical manufacturing	29	Plant waste water	--	GWD	Lagoons lined	--
Do.	Tannery	31	Ammonia, 7.5 mg/l; nitrite	--	GWD	Lagoons lined	--
Do.	Electrical equipment manufacturing	36	Sodium; chloride; acid wastes	Sodium; chloride; acid wastes	GWD; SWD	Lagoons lined	--
Do.	Seed preparation	07	Arsenic; 0.12 mg/l; acid wastes	--	GWD	--	--

Table 8 (Continued). SUMMARY OF SELECTED CASE HISTORIES OF CONTAMINATION FROM IMPOUNDMENTS

State	Nature of Activity	SIC Code[a]	Contaminants in Ground Water[b]	Contaminants in Surface Water[b]	Environmental Impact	Remedial Actions	Remarks
Texas	Meat processing	201	Bacteria	--	GWD	Pits lined	--
Do.	Petroleum production	13	Calcium; sodium; magnesium; chloride	Chloride	GWD; SWD	Use of pits discontinued	--
Do.	Petroleum production	13	Oil-field brines	--	GWD	Use of pits discontinued	Three other cases reported.
Do.	Waste disposal	49	Acid wastes; organics; manganese; iron; zinc; cadmium	Acid wastes; organics	GWD; SWD; temporary loss of wells; air pollution	Practice discontinued	--
Virginia	Chemical manufacturing	286	Organics; TOC, 6,500 mg/l	--	GWD	--	Regional TOC, 4-6 mg/l.
Do.	Do.	28	Oil	--	GWD	--	--
Washington	Chemical processing	28	Tritium; nitrate	--	GWD	--	Disposal of radioactive wastes in trenches.
Do.	Clearing explosive projectile casings		TNT, 12.6 mg/l and RDX (cyclonite), 3.4 mg/l	--	GWD	Carbon filtration of pumped water; continue monitoring	Unlined disposal pit in recharge area; underlain by glacial deposits; estimated velocity 36 to 90 ft/yr.
Do.	Sewage disposal	49	Coliform bacteria, detergents	--	GWD	--	Well contaminated Sand and gravel aquifer.
Wisconsin	Metal plating	347	Fluoride; chloride; unpleasant taste and odor	--	Loss of supply wells	Additional treatment	--
Do.	Paper mill	26	BOD, 17,200 mg/l	--	GWD	Pumpage to remove contaminants; practice discontinued	--
Do.	Do.	26	Spent sulfite liquor	Spent sulfite liquor	GWD; SWD	Evaporation and incineration	--

[a] SIC, Standard Industrial Classification.

[b] TDS, Total dissolved solids; mg/l, milligrams per litre; MBAS, Methylene-blue active substances; TOC, Total organic carbon; BOD, Biological oxygen demand; COD, Chemical oxygen demand; GWD, Ground-water degradation; SWD, Surface-water degradation.

State. For example, a number of States such as California, Texas, and Pennsylvania have records of hundreds of case histories in their files, and some States reported few or no contamination incidents from impoundments. In most instances, States with numerous case-history records have had more time, personnel, and funds to investigate these problems; whereas in some States reporting few or no case histories, data were sparse or unavailable because: (a) litigation was in progress, (b) the data were considered confidential by an industry, or (c) no special studies had been made to document the cases. Acquisition and review of the records of the hundreds of past and recent case histories, which are believed to be in State and EPA files, would have required an expenditure of time and funds beyond the scope of this study.

Table 8 indicates, where known, the kinds of contaminants in ground water and surface water that have been attributed to leaky impoundments and also contains brief references to environmental impacts and remedial actions. The case histories have been categorized in the table by SIC code number and by State. The data indicate a general prevalence of contamination problems in the industrialized eastern and north-central regions of the United States and also in other scattered areas, particularly in some western and southwestern States where mining and oil and gas extraction are major industries.

Ground-water contamination by process wastes derived from the manufacture of chemicals, pharmaceuticals, herbicides, and pesticides (SIC 28) is reported in many of the case histories. Contamination is also noted in connection with other manufacturing industries, including wood and paper products (SIC 24 and 26). Contamination by acid wastes and heavy metals has been reported for the primary metal industries and in the manufacture and plating of metal products (SIC 33 and 34). Seepage from mine tailings ponds and treatment lagoons has contaminated ground water and streams with metals, acids, radioactive substances, and other toxic substances (SIC 10 and 14). Moreover, there is residual groundwater degradation from two disposal practices that have been largely discontinued in recent years, namely the disposal of oil-field brines and production wastes in unlined lagoons. These two practices, especially prior to 1965, caused contamination by seepage in many oil and gas producing areas (SIC 13). The formerly widespread practice of disposal of liquid industrial and other wastes in unlined leaky impoundments at landfills and elsewhere also has resulted in degradation of ground water locally by a wide variety of contaminants, including various organic compounds and other sewage constituents (SIC 49).

Case Histories of Specific Wastes

Because each incident of ground-water contamination stemming from leaky impoundments has certain unique characteristics, it is informative to review how some of these problems have been investigated in the past. The following expanded case histories, listed according to the type of waste and SIC code number, convey some idea of the types of data and other information that are useful in making an assessment of ground-water contamination at an impoundment site.

Arsenic Wastes (SIC 283)

Waste products containing arsenic from the manufacture of pharmaceutical products have been discharged into sludge lagoons near Myerstown, Pa., since 1957.[2] Arsenic contamination of ground water in the area was first noted in 1964, and in 1965 arsenic concentrations were as high as 2,100 mg/l in water from wells tapping a dolomitic limestone aquifer at the plant site. According to EPA Primary Drinking Water Regulations, arsenic concentrations in drinking water should not exceed 0.05 mg/l. Three of the highly contaminated wells had been drilled to depths of 350 and 400 ft (106 and 121 m). Ground water moves easterly from the lagoon area toward Tulpehocken Creek, which contributes to Philadelphia's water supply.

In order to minimize the migration of the arsenic, contaminated ground water was pumped from wells at rates of 70 to 140 gpm (4 to 8 l/s) from

1964 to 1971. During the first 4 yr of pumping, the water was treated to form an insoluble precipitate of arsenic that was removed and stored at the plant site; treated water was returned to the aquifer. Beginning in December 1971, when concentrations of arsenic had been reduced to about 100 mg/l or less, the pumped water was discharged without treatment into Tulpehocken Creek. Although concentrations of arsenic in the aquifer have continued to decline with pumping, seepage of contaminated ground water into Tulpehocken Creek has apparently taken place, based on a water sample taken upstream from the plant in 1975 that contained 0.01 mg/l of arsenic.

Timber and Wood Products Wastes (SIC 24)

Disposal of wood wastes, including bark, in a water-table pond and sand pit near Turner, Or., caused contamination of ground water and loss of domestic supply wells.[3)] Alluvial sand and gravel constitute a shallow aquifer, in which the depth to ground water ranges from near land surface to about 10 ft (3 m) below. In August 1972, only a few weeks after disposal operations began, water samples collected from wells downstream from the disposal site showed concentrations of 7.5 mg/l of lignin-tannin (as tannic acid), 106 mg/l of manganese, and 13 mg/l of total iron. These concentrations were markedly higher than in natural water; moreover, the ground water contaminated by the leachate from the wood waste was commonly discolored and had an unpleasant odor. At least 11 domestic wells had to be abandoned and a new supply of water had to be obtained from a nearby public water-supply system.

The plume of contaminated ground water, defined by lignin-tannin concentrations of 0.4 mg/l or more, extended about 1,000 ft (305 m) downgradient and covered an area of about 4 acres (1.6 ha) in August 1972. By late January 1973, the area had increased to about 15 acres (6 ha); the leading edge of the plume had advanced to a point about 1,500 ft (457 m) from the disposal pit (Figure 8); and the concentrations of contaminants in the plume had diminished somewhat.

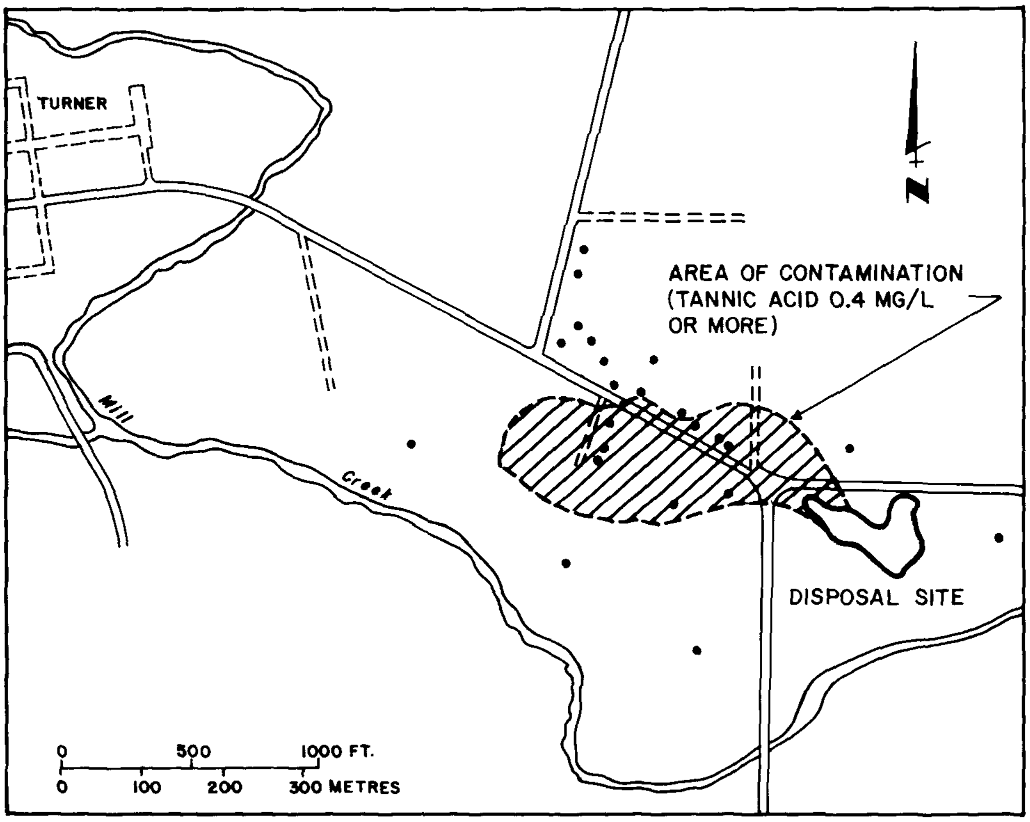

Figure 8. Plan view of a plume of lignin-tannin contaminated ground water, near Turner, Oregon, January 1973. 3)

Pickling Liquors (SIC 33)

The disposal of acid wastes from steel mills in an abandoned strip mine pit in eastern Ohio has caused widespread degradation of ponds, streams, and ground water since 1966.[4] The disposal pit, about 1,700 ft (518 m) long and as much as 200 ft (60 m) wide, is located on mine spoil and is confined by an earthen dam and spoil embankments. Prior to waste disposal, drainage waters from the abandoned strip-mining area, presumably acid in part, were capable of sustaining healthy aquatic life in streams and ponds.

Beginning in 1964, a disposal firm placed spent pickling liquors from mills in Pennsylvania and Ohio in the pit; it is reported that the firm disposed of about 725,000 gpd (2,750 cu m/day) of waste liquids in 1972. The wastes, largely neutralized prior to disposal, consisted of sulfuric and hydrochloric acid, with minor amounts of nitric and hydrofluoric acid. Acidic, highly mineralized fluids seeping through the soils eventually reached streams and ponds, causing environmental damage and two major fish kills in 1970 and 1971. TDS contents as high as 14,500 mg/l have been reported. Moreover, the seepage water is characterized by a low pH and high concentrations of sulfate, nitrate, iron, manganese, nickel, zinc, chromium, aluminum, fluoride, and chloride.

Although conclusive evidence is lacking, it is likely that ground water adjacent to the disposal pit is also highly mineralized. Three domestic wells, 0.5 to 0.75 mi (0.8 to 1.2 km) downgradient from the pit, tap a shallow aquifer that appears to be threatened by contamination, although the wells still were not contaminated in 1973. To alleviate surface-water and ground-water degradation, it was proposed to expand waste-treatment and pumping facilities at the disposal site.

Phenolic Wastes (SIC 24)

A plant near Hollywood, Md., engaged in treating wood by the high-pressure injection of creosote, accumulated process wastes in clay-lined lagoons beginning in 1965.[5] Ten years later, it was discovered that seepage from the pits (phenols, tannin, and lignin) had contaminated a fresh-water holding pond and a stream downgradient from the disposal site. A geophysical survey and test drilling revealed that ground water in the vicinity of the pits was contaminated, largely by phenolic wastes, and that seepage of ground water had contaminated the pond and stream. Phenolic wastes are manifest along the stream channel over a distance of about 2 mi (3.2 km). Concentrations of phenolics were 14.4 mg/l in ground water and 2.1 mg/l in the stream and are sufficiently high to have a deleterious effect on the aquatic life in the stream. It has been estimated that the small stream will remain contaminated for at least 100 yr after the source of contamination is eliminated.

Tailings Pond (SIC 109)

A plant processing uranium near Canon City, Colo., has discharged mill wastes to tailing ponds since 1953.[6] Seepage from the ponds has contaminated ground water downstream with excessive amounts of molybdenum; concentrations as high as 5 mg/l have been reported. Molybdenum concentrations of 856 mg/l have been determined in the ponded waste water. In a farming area located downgradient, stock water and irrigation supplies are obtained from shallow wells about 40 ft (12 m) deep. Deteriorating health of cattle, first noted in 1965, has been attributed to the high alkalinity and excessive molybdenum content of the ground water and to the concentration of molybdenum in forage crops irrigated with water from the contaminated wells. Farming operations had to be curtailed in the affected area.

Lining of the tailings pond nearest to the farming area has resulted in a gradual reduction of contaminants in the shallow aquifer. Moreover, there are plans to modify the processing plant so as to permit the recovery of molybdenum from the wastes.

Mine Wastes (SIC 109)

Acid wastes from the milling of uranium and vanadium ores are neutralized with ammonium hydroxide and are then routed to a series of ponds near Uravan, Colo.[7] Water from the ponds, containing high concentrations of ammonia (up to 88 mg/l in 1974), enters the San Miguel River by seepage or through Atkinson Creek, an intermittent tributary. Although some ammonia enters the San Miguel River from other effluent waste sources in the area, seepage from the ponds appears to be a major source of contamination. Concentrations of ammonia in samples of river water obtained upstream from the plant ranged from the detectable limit to 0.18 mg/l in April 1974, whereas samples taken about 5 mi (8 km) downstream contained 3.2 to 3.8 mg/l. Ammonia contents of individual grab samples at the downstream site have been as high as 41 mg/l. Although such high concentrations have been determined intermittently, a study by Union Carbide in 1974-75 (R. L. Miller, written communication, 1977) reportedly shows that the river supports an abundant and diverse aquatic community even below the seepage area from the ponds. Alternative methods of pH control or lining of the ponds would help reduce the contamination of the river water.

Chemical Wastes (SIC 28)

In the Rocky Mountain Arsenal and adjacent areas in Colorado, the disposal of chemical wastes in unlined ponds from 1943 to 1957 has caused severe contamination of shallow ground water.[8] Liquid wastes from the manufacture and the destruction of chemical warfare agents, and also from the production of pesticides and herbicides, have affected ground-water quality over an area of about 30 sq mi (70 sq km). Initially, wastes were conveyed to storage lagoons by ditches or sewers. Since 1957, disposal has been by pipeline or tank truck to an asphalt-lined reservoir with a capacity of 240 million gal (912,000 cu m). The injection of wastes into a deep disposal well drilled to basement rock was discontinued when it was found to be a cause of minor earthquakes in the Denver region.

Several agencies have been engaged in a study of the contaminants and their sources since 1954. Excessive concentrations of sodium, fluoride, arsenic, chlorate, and chloride (up to 4,000 mg/l, Cl) have been noted in the shallow aquifer and have caused extensive damage to crops and livestock. Other contaminants include herbicides and the insecticides aldrin, endrin, and dieldrin, some of which may have infiltrated to the aquifer from the periphery of the asphalt-lined reservoir or from leaking sewers. Moreover, a deeper bedrock aquifer may have been degraded locally by the downward migration of contaminated water through defective well casings.

The concentration of contaminants in the shallow aquifer has been reduced in recent years by dilution from irrigation return water and canal seepage; many of the abandoned wells have been returned to service. Evidence of contamination still persists, however, and plans have been made to study the feasibility of rehabilitating the entire area.

Wastewater and Meat Processing Wastes (SIC 201)

A rendering plant located near San Angelo, Texas, uses eight unlined lagoons to dispose of saline process water, and to a lesser extent, of domestic sewage and boiler blowdown.[9] Seepage from the lagoons has contaminated shallow ground water with ammonia, nitrite, nitrate, and organic nitrogen. Ammonia concentrations in water from nearby wells have been as high as 104 mg/l; nitrite concentrations reached 27 mg/l in 1975. Seepage from the ponds infiltrates the Leona Formation, a fairly permeable water-table aquifer that crops out in the area. Background concentrations of ammonia and nitrite in the aquifer are generally low. Excessive nitrate concentrations, however, are common and appear to be related to the return of irrigation waters or to contamination from feedlots or other sources. The company has been requested to line the wastewater lagoons, which will help alleviate or eliminate the problem of ground-water contamination.

Radioactive, Chemical, and Sanitary Wastes (SIC 28)

At the Test Reactor Area of the Idaho National Engineering Laboratory near Idaho Falls, ponds are used to dispose of low-level radioactive wastes, chemical wastes, and sanitary wastes.[10)] Since 1952, seepage from three radioactive waste ponds and from a chemical waste pond has created separate relatively small bodies of shallow perched ground water in the surface alluvium, at depths of about 50 ft (15 m). Downward migration also has created a second perched-water zone, at about 150 ft (46 m), in fine-grained water-bearing sediments interbedded with the basalt bedrock. This deeper perched ground-water body is centered under the area of the disposal ponds and was about 6,000 ft (1,830 m) long and 2,500 ft (760 m) wide in 1972. Some of the perched water percolates downward through openings in the basalt and interbedded sedimentary layers to the Snake River Plain aquifer, at depths of about 450 ft (137 m).

Average discharge to the radioactive waste ponds was about 200 million gal/yr (757,000 cu m/yr) from 1952 to 1973. The total content of radionuclides averaged 1,700 Ci per year from 1971 to 1973; the majority of these have a short half-life and are of little consequence. Chromium-51, however, was determined in a water sample from the main perched-water zone in 1972, indicating relatively rapid seepage from the ponds. Other radionuclides were present in the following concentrations:

Tritium	353 pCi/ml
Cobalt-60	6.4 pCi/ml
Strontium-90	0.817 pCi/ml

The concentrations of these radioactive constituents in the perched water change relatively rapidly, according to the nature of the wastes that are being discharged to the ponds. With the exception of strontium-90, concentrations generally meet established standards for drinking water. Cesium-137 has never been detected in water samples from the perched-water zone, although it is being discharged to the waste ponds in quantities exceeding those of strontium-90; apparently cesium is strongly adsorbed by clays and other minerals during seepage from the ponds. Similarly, strontium apparently is being adsorbed during its downward passage to the Snake River Plain aquifer, because water samples from wells tapping the aquifer in the Test Reactor Area have not contained detectable amounts of strontium. Evidence of contamination of the Snake River Plain aquifer by seepage from the radioactive waste ponds is indicated, however, by the relatively high concentrations of tritium in water from deep wells in the area. A plume of high tritium content, slightly in excess of 150 pCi/ml, extends southward from the disposal ponds.

A disposal pond for the chemical (non-radioactive) wastes has been in use in the Test Reactor Area since 1962. The discharged waters, about 50 million gal/yr (190,000 cu m/yr), contain high concentrations of sulfate and sodium, with minor amounts of sulfite, phosphate, and chloride. High specific conductance determinations in water samples from the main perched-water zone, in excess of 3,000 micromhos/cm, are indicative of increased TDS, largely due to seepage from the chemical waste pond. Relatively high specific conductance determinations in water samples from the Snake River Plain aquifer may be due to seepage from the disposal pond. It is more likely, however, that they reflect the injection of non-radioactive wastes directly into the aquifer through a deep well in the Test Reactor Area. The degree of contamination and the movement of contaminants in the perched and regional ground-water bodies are being closely monitored.

Case Histories With Costs of Remedial Actions

To fully evaluate the economic implications of instituting controls or remedial actions for the large number of impoundments that are believed to be causing ground-water contamination in the nation would be a formidable task. First, most impoundment sites have never been studied in sufficient detail to determine whether or not they actually seep. Second, the fact that seepage may be detected in some cases does not necessarily establish the severity of that ground-water contamination threat. Third, the need for and the type of remedial action cannot be ascertained without a detailed evaluation of the rate and quantity of the seepage, the composition of the escaping fluids, rates and directions of ground-water flow, and the use or potential use of the receiving aquifer as a source of water supply. Finally, operators of many impoundments simply may not have access to any other waste-disposal alternatives that are either technologically or economically feasible.

For the reasons noted above and because only scanty cost data were available for case histories involving remedial actions, the present study has addressed mainly the basic technologies and costs of controlling contamination from impoundments (see Section VIII and Section XII, Appendix D). As a general indication, however, four case histories of contamination from leaky impoundments in different hydrogeologic environments have been evaluated in some detail to provide specific field examples of economic and technological implications.

Las Vegas-Henderson Area, Nevada

General Background. Case-history data in the Las Vegas-Henderson, Nevada, area provide a fairly comprehensive picture of a long-term multi-source contamination problem for which a multi-phased solution has been proposed. The general location of the area is shown on Figure 9. The contaminated water, much of which is derived by seepage from industrial waste impoundments and to some extent from municipal waste impoundments, has moved through the upper part of the ground-water system into Las Vegas Wash, a tributary of Lake Mead. Lake Mead is a major reservoir on the Colorado River which supplies about 52 percent of the total water used in the Las Vegas Valley. Of the total water use, about 42 percent is from ground-water resources, and about 6 percent is from recycled treated sewage effluent, which is used for agricultural and golf-course irrigation and for cooling water. The main center of ground-water withdrawal for public supply is more than 10 mi (16 km) northwest of the area of heavily contaminated ground water.

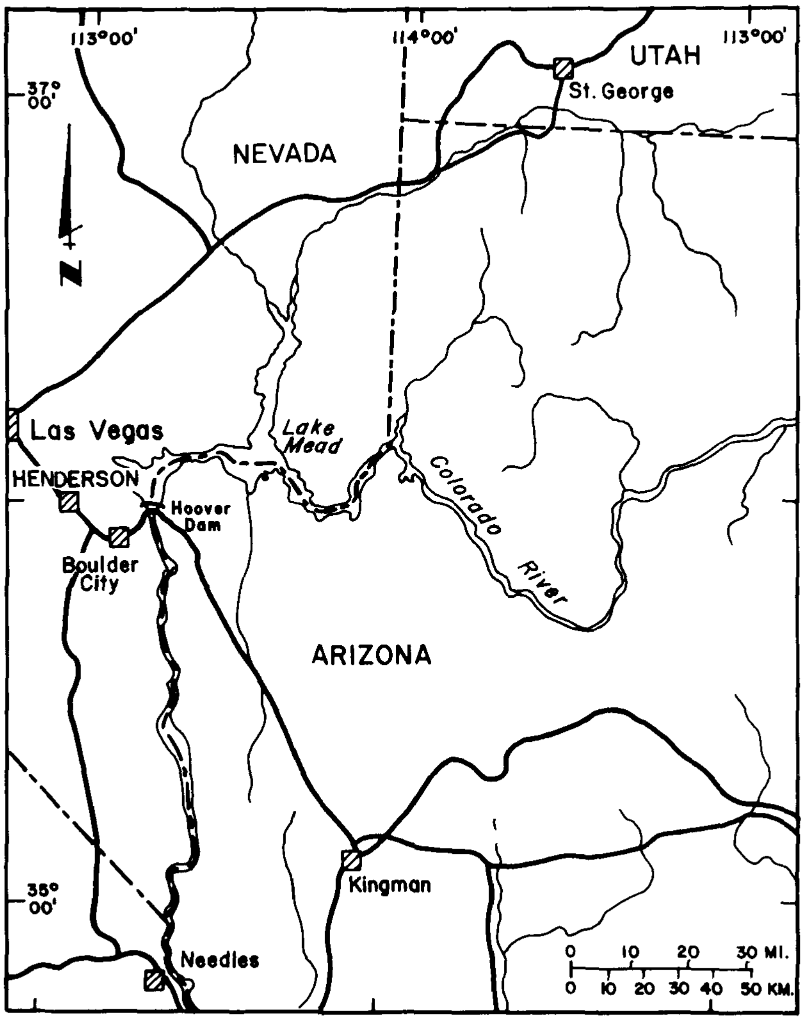

Figure 9. General location of the Las Vegas-Henderson area in southeastern Nevada.

The Desert Research Institute has made a number of detailed studies[11-14] of the hydrogeologic conditions in the Las Vegas Wash area, including establishment of an extensive network of ground-water and surface-water monitoring stations. Most of these studies were sponsored by EPA, who also made several independent studies.[15,16] The U.S. Geological Survey has described the general ground-water conditions[17] and currently maintains water-level,[18] stream-gaging, and chemical-sampling stations in the Las Vegas Valley. The U.S. Bureau of Reclamation has developed plans to control the salinity of the Colorado River. Planning reports have been prepared by engineering consultants for a number of industrial and municipal waste-disposal systems in the Las Vegas-Henderson area.

A major industrial complex, housing several companies engaged chiefly in metal refining and manufacture of chemical products, adjoins the Henderson area. Other waste-generating facilities in the area include four sewage-treatment plants, several sand and gravel pits, and two power plants.

Topography, Drainage, and Climate. Las Vegas Valley is typical of many valleys in the Basin and Range Province of the southwestern United States. The valley is wide and flat and slopes southeasterly from an altitude of about 2,000 ft (610 m) above msl (mean sea level) at Las Vegas to about 1,200 ft (370 m) at Lake Mead. Mountains composed of igneous and sedimentary rocks rise steeply along the borders of the valley and coalescing alluvial fans slope gently from the mountains toward the valley floor.

Las Vegas Wash, a shallow, narrow stream that trends southeasterly across the study area and drains into Lake Mead, is the principal surface drainage feature. Originally, Las Vegas Wash was an intermittent stream, but it presently contains water in the middle and lower reaches throughout the year, mainly due to surface and subsurface inflow of industrial and municipal waste effluents. Precipitation averages about 4 in (10 cm) per yr and occurs mainly in the summer and early fall. Evaporation is about 72 to 80 in (180 to 200 cm) per yr.

Hydrogeologic Framework. The hydrogeologic framework of the Las Vegas-Henderson area consists of a bedrock-walled valley partly filled with unconsolidated deposits (Figure 10). The valley-fill materials consist of beds and lenses of sand, gravel, silt, and clay having a maximum total thickness of several thousand feet (about 800 m) or more. The valley walls are composed of relatively impermeable igneous and sedimentary rocks.

The valley fill is divided into three major hydrogeologic units. The uppermost unit is a largely unconfined aquifer (also referred to as the near-surface aquifer), which is composed of sand and gravel and contains the water table. The water table is at depths ranging from about land surface near Las Vegas Wash to as much as 50 ft (15 m) below the land surface elsewhere in the valley. Beneath the near-surface aquifer is the Muddy Creek Formation, a confining unit, which is composed of silt, clay, and fine sand. Several artesian aquifers are interfingered with confining beds in parts of the valley, especially north and west of the Henderson area. One of these, known as the middle artesian aquifer, is tapped for public supply at depths of about 200 to 500 ft (60 to 150 m) by wells of the Las Vegas Valley Water District (LVVWD), about 13 mi upgradient from the Las Vegas Wash. The LVVWD supplies ground water to the city of Las Vegas and water from Lake Mead to the cities of Las Vegas and North Las Vegas.

The artesian aquifers are recharged by infiltration of precipitation at and near outcrop areas on the sides of the valleys and by slow leakage of ground water from the overlying near-surface aquifer in places where the hydraulic gradient is downward. The near-surface aquifer is recharged throughout the study area by infiltration of water from precipitation, lawn sprinkling, agricultural irrigation systems, leaky sewers and mains, and seepage from unlined surface impoundments.

The regional flow pattern in the horizontal dimension is from high altitudes on the water table along the flanks of the upland areas to low altitudes in the vicinity of Las Vegas Wash (Figures 10 and 11). The

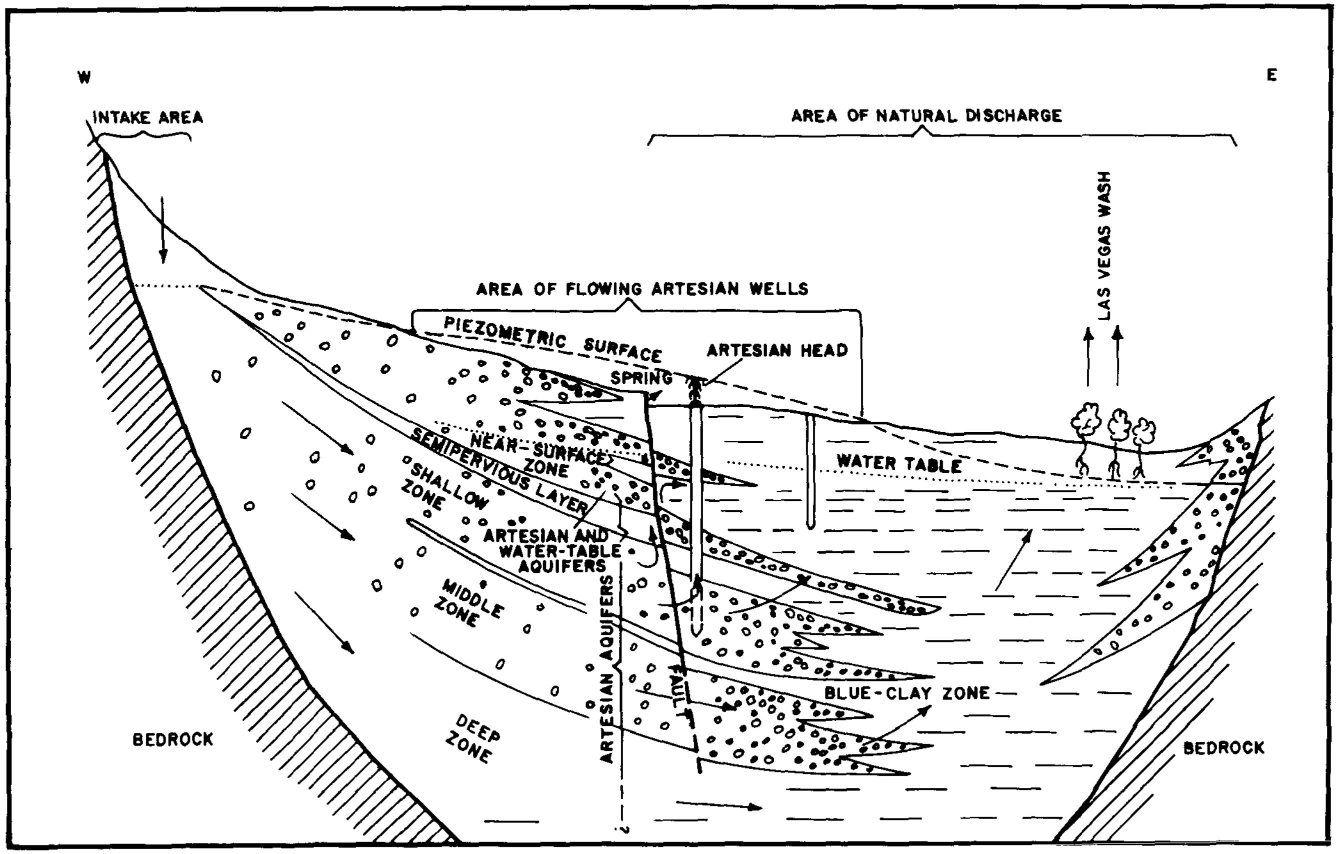

Figure 10. Hydrogeologic section across Las Vegas Valley, showing aquifers, confining beds, and ground-water flow pattern, 1945-1950 conditions. 17)

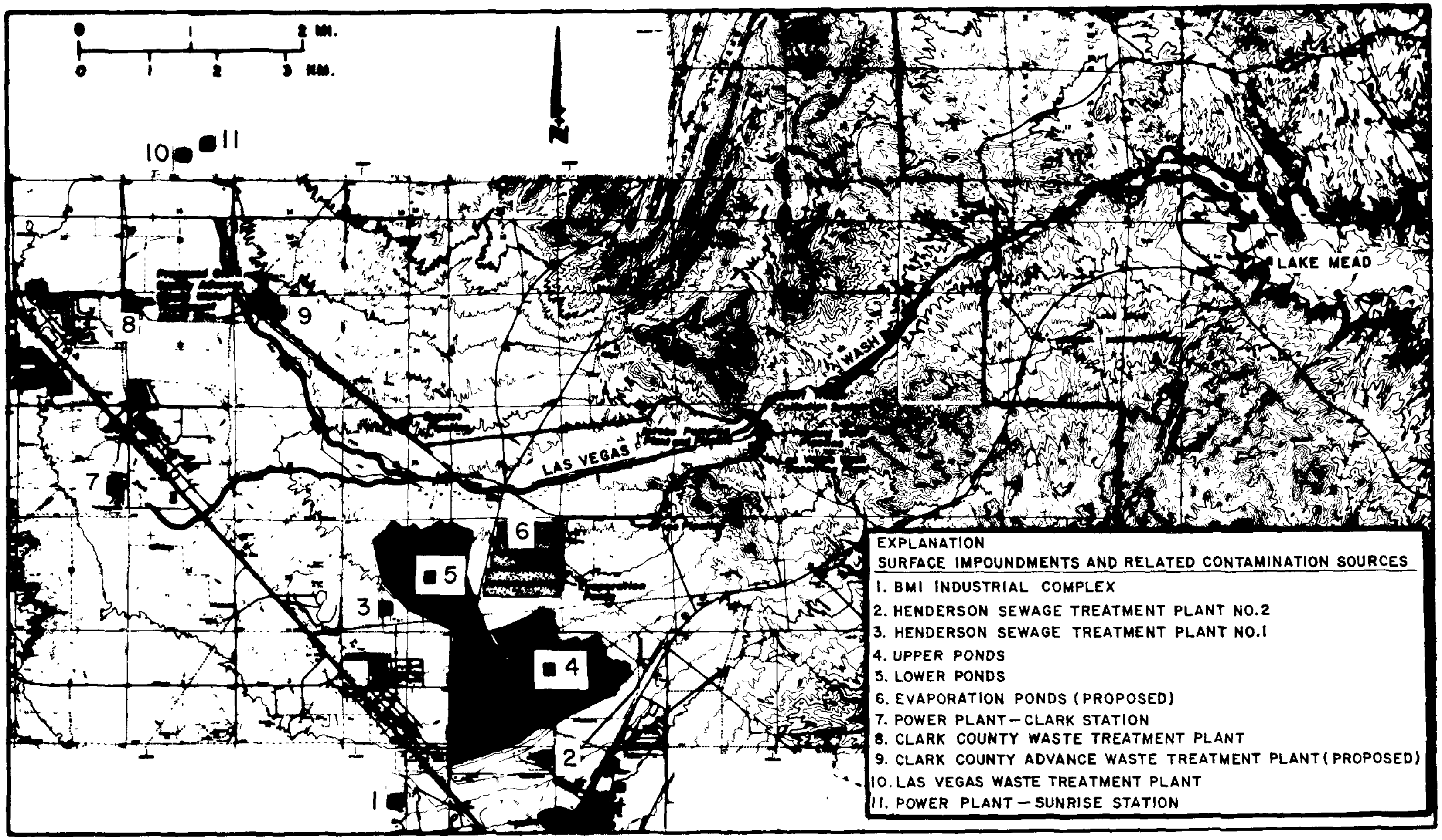

Figure 11. Surface impoundments, other sources of contamination, and proposed remedial facilities for abating contamination of the Las Vegas Wash area, Nevada. (Adapted in part from U. S. Bureau of Reclamation.)

general flow pattern in the vertical dimension is downward from recharge areas along the bordering highlands to discharge areas in the lowlands, where water from the shallow and underlying deep aquifers seeps into the Las Vegas Wash (Figure 10 shows hydrologic conditions in the period 1945-1950). The flow pattern has been altered over the years in that the potentiometric surface is no longer above the land surface except in a few local areas, and the water table now is at or near the land surface in the Las Vegas Wash.

Water Quality. The natural water quality in the study area ranges from moderately to highly mineralized, depending on geographic location and depth of the aquifers. The water-table aquifer in most of the area is generally too mineralized or contaminated for use as a public-supply source. In the parts of the underlying artesian aquifers that are tapped for public supply, the average content of TDS is about 300 mg/l, hardness about 240 mg/l, and chloride about 5 mg/l.

Lake Mead water is more mineralized than the average ground water developed by public-supply systems. In 1973, Lake Mead water had the following concentrations: TDS, 745 mg/l; hardness, 330 mg/l; and chloride, 92 mg/l. The salinity of the Colorado River at Hoover Dam reportedly is increasing and, as one remedial measure, plans have been developed to control the salinity by eliminating or reducing seepage and discharge of contaminated water from impoundments and other nutrient-rich sources in the Las Vegas Valley.

Although the present study is mainly concerned with contamination from surface impoundments, it is important to note that in the Las Vegas Wash situation, other potential and known sources of contamination affect the quality of both the surface water and the ground water. These sources include the following:

1. Leaky sewers.
2. Leaky water mains.
3. Lawn sprinkling.

4. Spreading of sewage sludge to fertilize parks and golf courses.
5. Spray irrigation of sewage effluent for golf-course irrigation.
6. Disposal of storm runoff from streets and industrial areas into basins.
7. Leaky storage tanks.
8. Spills of contaminated fluids in commercial and industrial areas.
9. Particulate emissions from smoke stacks.
10. Septic tanks and cesspools.

Surface Impoundments. A major source of contamination of the shallow ground water and of Las Vegas Wash in past years, and to a lesser extent presently, has been seepage of contaminated water from scattered surface impoundments. Table 9 gives a summary of the significant features of selected existing and proposed impoundments in the study area. These impoundments extend roughly along a line from Las Vegas southeasterly to Henderson (Figure 11); all are south and west of the Las Vegas Wash. The impoundments are used for holding, percolation, evaporation, biological treatment, and retention of waste fluids at four sewage treatment plants, two power plants, and at and near a major industrial park.

Some seepage of contaminated fluids also probably occurs from unlined impoundments at municipal waste-treatment plants owned by Clark County and the city of Las Vegas, but the volume is thought to be negligible. Most of the effluent discharged from these plants moves directly through streams or unlined ditches into Las Vegas Wash, but some may also seep down into the shallow aquifer. Some cooling water and boiler blowdown water at the Clark and Sunrise stations of the Nevada Power Company also may seep into the underlying shallow aquifer locally from unlined impoundments; some is lost by evaporation; some is discharged directly to Las Vegas Wash by means of small streams; and some is recycled. Part of the cooling water used at the Nevada Power Company plants consists of recycled treated sewage effluent obtained from municipal waste-treatment plants.

Table 9. CHARACTERISTICS OF SELECTED IMPOUNDMENTS IN THE LAS VEGAS-HENDERSON AREA, NEVADA

Map No.[a]	Name	No. of Ponds	Nature of Lining	Total Area (ac)	Total Area (ha)	Depth (ft)	Depth (m)	Type of Effluent	Remarks
1	City of Henderson Sewage Treatment Plant No. 2	-	Unlined	--	--	--	--	Domestic sewage	Started in 1942; discharges to Upper Ponds.
2	Upper Ponds	Multiple cells	Unlined	950	(385)	3	(0.9)	Inorganic and organic chemicals	Used extensively 1942-76 for evaporation-percolation. Only small part in service for sewage disposal.
3	Lower Ponds	Multiple cells	Unlined	430	(174)	3	(0.9)	Various industrial wastes; now mainly domestic sewage	Used extensively 1942-71. Only small part in service for sewage disposal and cooling water evaporation-percolation.
4	City of Henderson Sewage Treatment Plant No. 1	2	Unlined	5±	(2±)	6	(1.8)	Domestic sewage	Started in 1958. Oxidation ponds after Imhoff tanks; discharge to Lower Ponds.
5	BMI Industrial Complex	10-15	Lined	27	(11)	6	(1.8)	Process wastes	Evaporation-percolation ponds. Cooling water discharged to Las Vegas Wash.
6	Nevada Power Company - Clark Station	1	Unlined	--	--	6	(1.8)	Cooling water and boiler	Evaporation pond and discharge to Las Vegas Wash via unlined ditch.
7	Clark Co. Sewage Treatment Plant	1	Unlined	--	--	--	--	Domestic sewage	Storage lagoon and Duck Creek discharge to Las Vegas Wash.
8	Clark Co. Advanced Waste Treatment Plant (Proposed)	2	Lined	--	--	16	(4.9)	Domestic sewage	Holding ponds.
9	City of Las Vegas Waste Treatment Plant	5	Unlined	3	(1)	--	--	Supernatant effluent from sludge digestors	Evaporation-percolation pond.
10	Do.	1	---	--	--	--	--	Domestic sewage	Chlorine contact pond.

[a]See Figure 11.

The city of Henderson operates two secondary waste-treatment plants. One plant contains two unlined holding ponds with ultimate discharge of effluent to a nearby series of percolation-evaporation ponds (Lower Ponds. The effluent from the other plant discharges directly to the Upper Ponds. Originally, the pond system for the Henderson industrial park consisted of some 1,380 acres (559 ha) of unlined percolation-evaporation ponds referred to as the Upper and Lower Ponds (Figure 11). The original area of the ponds was designed for evaporation with no infiltration. In actual practice, only about 20 percent of the area of the Upper Ponds has ever received wastewater, as most of the water is lost by seepage.

The ponds were first used by the U.S. Army during the early 1940's for disposal of wastes from the manufacture of magnesium products. About 1946, the site was converted into an industrial park, and several chemical companies and a titanium milling plant have been in operation at the site since that time. These companies produce a variety of inorganic and organic chemicals and use substantial amounts of water for cooling and processing.

Most of the wastes from the industrial park were discharged formerly to the Upper and Lower Ponds. In recent years, however, as a result of a series of studies by the Desert Research Institute and by EPA which indicated that contaminants were entering the near-surface aquifer from the ponds and were seeping into Las Vegas Wash, a series of actions have been taken to control contamination from these sources. In 1971, discharge of wastes to the Lower Ponds was essentially stopped except for treated sewage effluent from the city of Henderson Sewage Treatment Plant No. 1 (Figure 11) and cooling water from the industrial park. In addition, in compliance with NPDES permit requirements by EPA, virtually all discharge of wastes to the Upper Ponds has ceased, except for inflow of cooling water and municipal wastes from the city of Henderson Sewage Treatment Plant No. 2. Small lined ponds and other treatment facilities have been constructed in the industrial park in recent years to replace the old pond system.

Contaminants in Impoundments. The composition of the impounded fluids provides a clue to the potential contaminants in the ground water in the study area. For descriptive purposes the impounded fluids are classified as follows: (1) domestic secondary effluent, (2) cooling and boiler-blowdown water, and (3) process wastes.

Domestic secondary effluent is mainly from trickling-filter types of sewage-treatment plants, except for one of the two plants at Henderson (Table 9). The effluent generally has a high TDS content and nutrients such as phosphate and nitrate that contribute to algal growth. Mean concentrations of selected constituents in the effluent from two sewage-treatment plants (STP's) in the study area in 1971 are given below:

Constituent	Clark County STP Effluent (mg/l)	Henderson STP Effluent (mg/l)
Chloride	302	622
Sulfate	447	603
Nitrate as N	5.7	---
Phosphate as P	22	20
Dissolved solids	1,494	2,409

Cooling and boiler-blowdown water is discharged from two power plants and from the industrial park. Water from the power plants has relatively high TDS contents (about 3,000 to 4,000 mg/l) and is similar in overall composition to secondary effluent from the Las Vegas and Clark County STP's from which it is derived. Formerly, cooling water from the chemical plants in the industrial park was mixed with industrial wastewater before discharge. However, the cooling water is now discharged separately to the Upper and Lower Ponds and is believed to be largely free of harmful constituents, although the TDS content is high.

Owing to numerous operational changes, it is difficult to characterize the past and present composition of the industrial waste and process waters from the Henderson industrial park. A few analyses indicate that at times the chemical contents have ranged as follows: pH about 1.5 to 12; nitrate, 2 to 256 mg/l; and TDS, about 3,000 to 25,000 mg/l.

Other substances presently or formerly used in manufacturing processes or reported in the waste streams from the industrial park include: sodium chlorate, benzene, sulfuric acid, chlorine, ammonia, caustic soda, magnesium, chloride, copper, zinc, lead, chromium, phosphorus, iron, calcium, sulfate, phosphoric acid, boron, boron trichloride, boron tribromide, thiophenol, DDT, Imidan (an insecticide), and other organics.

Movement of Contaminants in Ground Water and Surface Water. Above-normal concentrations of TDS have been reported both in ground water from observation wells and in water at various sampling points in Las Vegas Wash and its tributaries.[11,12] The dissolved solids consist of high concentrations of chloride and nitrate and low to moderate concentrations of chromium, iron, lithium, lead, strontium, and zinc. Most of the contaminants are attributed to waste streams from municipal and industrial sources. Figure 12 shows a plume of nitrate-rich ground water in the near-surface aquifer in 1971, extending downgradient a distance of 3 to 4 mi (5 to 6 km) from the Henderson industrial park to Las Vegas Wash. The plume is attributed mainly to seepage of industrial effluent containing high concentrations of nitric acid used in leaching titanium ore and, to a lesser extent, nitrate in sewage-treatment plant effluent. The high loads of nitrate of as much as 1,700 lbs/day (770 kg/day) and of TDS of as much as 300,000 lbs/day (136,000 kg/day) in Las Vegas Wash in past years are attributed largely to seepage of contaminated water from the industrial ponds.[11,12]

The unlined surface impoundments in the area have permitted substantial seepage of contaminated water into the near-surface aquifer, which acts as a conduit for the movement of contaminated water laterally into Las Vegas Wash. Continued downgradient movement of the contaminated water poses a potential threat to the water quality of Lake Mead. In parts of the study area, contamination of the near-surface aquifer has probably resulted also from seepage of contaminated water through the bottoms and

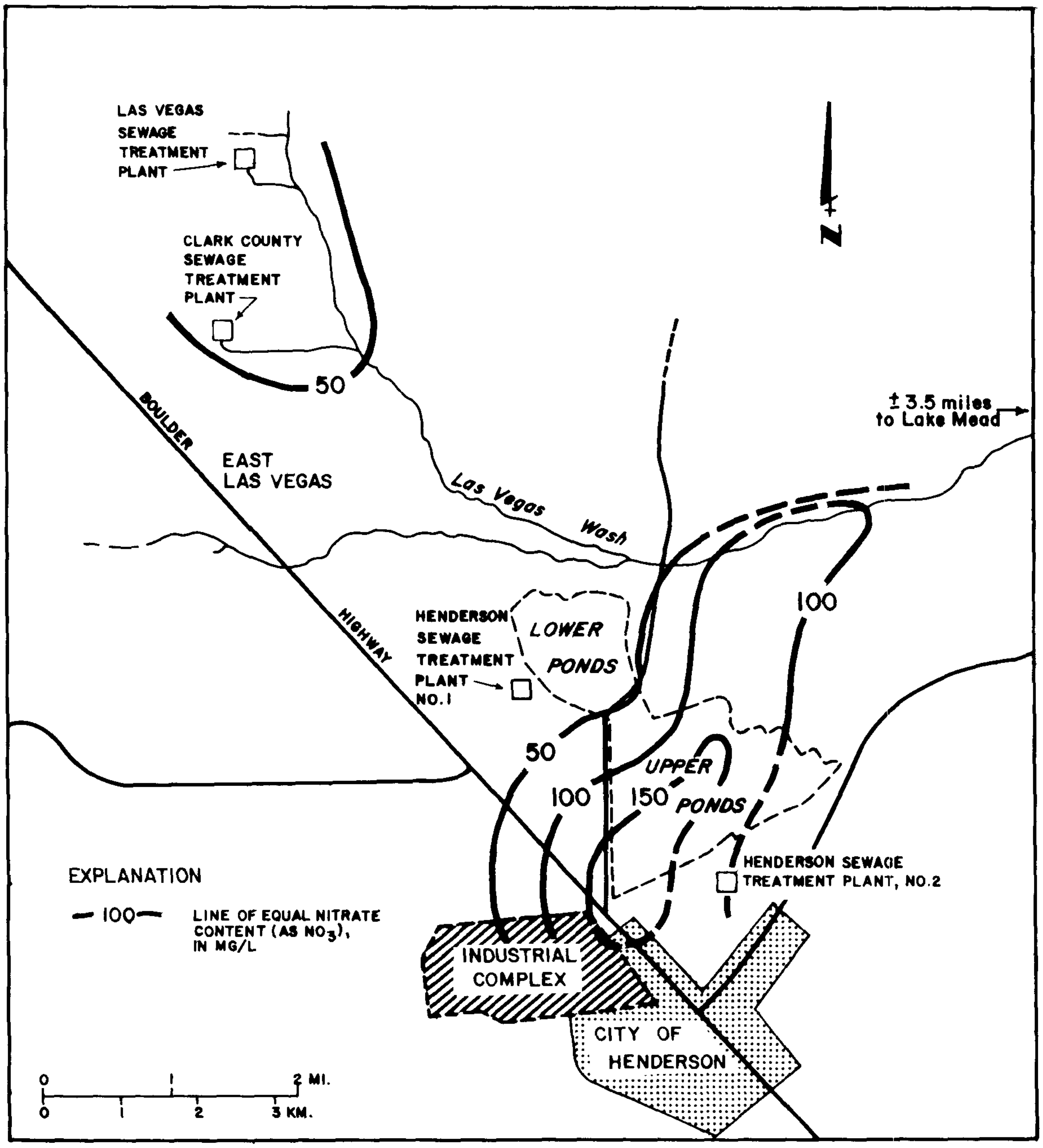

Figure 12. Plume of nitrate-contaminated shallow ground water near Henderson, Nevada.[11)]

sides of unlined ditches and canals that convey municipal and industrial effluents to discharge points.

Remedial Actions and Costs. Under consideration at present are several plans to abate contamination in the Las Vegas Wash area. These include: (1) upgrading of the existing municipal sewage-treatment system in the city of Henderson to an approved secondary treatment status; (2) improvement of the city of Las Vegas and Clark County municipal sewage-treatment facilities; (3) improvement of waste-disposal facilities at the Henderson industrial park; and (4) implementation of a regional salinity control plan.

The key elements of the alternative waste-treatment plans for the city of Henderson[19)] are summarized below:

Plan 1 - Construction of an activated-sludge treatment plant of about 8-mgd (30,000 cu m/day) capacity, irrigation reuse of 53 percent of the treated effluent for golf courses and other public greenbelts, and discharge of excess treated secondary effluent to the Clark County Advanced Waste-Treatment Plant.

Plan 2 - Similar to above, except that the excess effluent would be discharged to 85 acres (34 ha) of unlined seepage ponds near the Lower Ponds area (Figure 11).

Plan 3 - Construction of two activated-sludge treatment plants, irrigation reuse of 79 percent of the treated effluent, and discharge of excess effluent to 65 acres (26 ha) of unlined seepage ponds near the Lower Ponds (Figure 11).

For economic reasons, the disposal ponds in Plans 2 and 3 above are designed for seepage rather than evaporation. The evaporation concept was ruled out because it would have required about 850 acres (340 ha) of lined ponds at an approximate cost of $27,000 per acre ($67,000 per ha) of pond. This would have added an additional 17 million dollars to each of the estimated capital costs for Plans 2 and 3 shown in the table below (adapted from URS Co., 1977)[19]:

	Estimated Capital Costs (Millions of dollars)	Estimated Operating Costs in Year 2000 (Millions of dollars)
Plan 1	13.7	1.3
Plan 2	12.5	0.41
Plan 3	14.9	0.54

Plans for regional treatment of municipal wastes in the study area also include improvement and expansion of existing secondary waste-treatment plants owned by the city of Las Vegas and the Clark County Sanitation District and construction of an AWT (advanced wastewater-treatment plant). The proposed AWT plant would receive and treat secondary effluent from existing city of Las Vegas and Clark County waste-treatment plants. This effluent would be renovated by removal of phosphate and reduction in colloidal and suspended solids, TDS, and some organic substances. The AWT treatment process includes lime and alum coagulation, flocculation, clarification, filtration, and chlorination. The initial capacity of the AWT plant would be 90 mgd (340,000 cu m/day), with a potential capacity for an additional 45 mgd (170,000 cu m/day) by 1990.

A number of alternatives have been considered for disposal of the tertiary effluent from the AWT plant. Part may be discharged to Las Vegas Wash to maintain the flow; part may be discharged through a bypass pipe downgradient from a proposed Bureau of Reclamation facility designed for the collection and treatment of underflow from the Las Vegas

Wash (Figure 11); and part may be used for irrigation and cooling. The estimated cost of construction of the AWT plant is 50 to 60 million dollars, part of which would be financed by EPA and part by local governments.

The two principal sources of industrial wastes in the Henderson-Las Vegas area are power-plant cooling water and process wastes from the industrial park. As indicated previously, the power plants presently receive secondary treated effluent from nearby municipal plants for use as cooling water. Conceivably, the power plants could construct small on-site facilities to treat the secondary effluent for removal of phosphate and suspended solids. The treated water would then be recycled through cooling towers in order to reduce the volume of discharge to Las Vegas Wash.

At the industrial park, where most of the industrial wastes are generated, EPA has required that a number of actions be taken by several companies, under NPDES compliance procedures, to prevent discharge of contaminants into ground water and Las Vegas Wash. The most recent actions include essentially stopping further discharge of industrial wastewater to the unlined Upper and Lower Ponds (except for cooling water), additional treatment and recycling of water and wastes, use of cooling towers, and construction of a number of additional lined evaporation ponds for disposal of waste fluids within the industrial park complex. Detailed cost estimates for these remedial actions were not available, but combined estimates for two of three major companies in the industrial park are summarized as follows:

Remedial Action	Estimated Capital Costs (Millions of dollars)
Construction of lined ponds (10 to 15)	1.80
Construction of cooling towers (2)	0.40
Process changes and recycling of wastes	.94
Total:	3.14

No information was obtained on remedial actions by other companies, but the total expenditure for pollution control at the industrial park is estimated to be 3.5 to 4 million dollars. Operating costs are unknown but may be as much as $100,000 per yr or more.

The U.S. Bureau of Reclamation, which has the responsibility for protecting and improving the quality of the Colorado River, has devised a regional plan to help achieve these objectives. The plan, one of several that the Bureau (1976) is working on, is designed to control the salinity of the Colorado River by reducing the load of dissolved solids contributed to the river from irrigation return flows, from diffuse natural sources such as saline geologic formations, and from point sources such as flowing wells, springs, and municipal and industrial effluent discharges.

The plan for the Las Vegas Wash area involves the collection of nearly all of the ground-water underflow at a selected downstream point in Las Vegas Wash before it reaches Lake Mead (Figure 11), and to dispose of it by evaporation or desalting. Theoretically, this would permit the eventual removal from the near-surface aquifer of older contaminated water and water from the remaining sources of waste discharge such as municipal effluents and cooling water.

The Bureau of Reclamation plan includes the following features:

1. A subsurface interception facility composed of a cement grout cutoff wall to be installed across the Las Vegas Wash at a narrow point in the channel northeast of the city of Henderson to seal off most of the underflow.
2. A collection system consisting of perforated pipes installed in the alluvium just upstream from the cutoff wall. The underflow would move through the pipes to a sump where the water would be pumped either to a series of solar evaporation ponds or to a desalting plant. The initial underflow is estimated to be about

5 cfs (0.14 cu m/s), which would be increased to about 20 cfs (0.57 cu m/s) by the year 2,000.

3. A solar evaporation unit consisting of 5 ponds of 25 acres (10 ha) each, located in the vicinity of the former industrial ponds. The evaporation ponds most likely would be lined to prevent seepage.
4. A desalting plant, probably of the reverse-osmosis type, would be located near the interception facility. The plant would be built as part of a second-stage construction operation and would have a capacity of about 20 cfs (0.57 cu m/s). Most of the fresh water produced by the desalting plant would be discharged into Las Vegas Wash downgradient from the plant and would ultimately reach Lake Mead. Brine and sludge from the desalting operation would be disposed of in the evaporation ponds.
5. The final feature of the Bureau of Reclamation plan is a 72-in bypass pipeline to carry water from the municipal waste-treatment plants or AWT plant in the northern part of the area to a discharge point downgradient from the proposed interception facility. Some discharge from the AWT plant would be diverted into Las Vegas Wash near the municipal plants to maintain the ecologic balance in the Wash.

The estimated capital costs for the Las Vegas Salinity Control Unit (Bureau of Reclamation, oral communication, 1977) are as follows:

Stage	Facility		Estimated Capital Costs (Millions of dollars)
I	Interceptor facility		7.2
	Lined evaporation ponds (land, lining, and construction)		20.6
	Bypass pipeline		4.2
		Subtotal:	32.0
II	Desalting Plant		24.5
		Total:	56.5

Grants Mineral Belt, New Mexico

General Background. The Grants Mineral Belt was among the earliest uranium discoveries and developments in the United States. Formerly, the principal occupations in the Grants Mineral Belt were ranching and farming; forestry industries and tourism were secondary. In Valencia and McKinley Counties of northwestern New Mexico (Figure 13), there are now five uranium mills in operation or under construction, which have helped to make New Mexico foremost in the mining and milling of uranium and associated minerals in the United States.[20)] Mining-related businesses supplying equipment, materials, and services have expanded in the Grants Mineral Belt, as has the building industry, which requires construction materials of all kinds. An excellent account of the early impact upon the populace and its water supplies is given by Gordon.[21)]

Hydrogeologic Conditions. The bedrock and alluvium of the Grants Mineral Belt range in age from Pennsylvanian to Holocene.[21,22)] The dominant structural feature is the Chaco Slope, developed on the north flank of the Zuni Uplift. The relationship of the stratigraphic units is shown in Figure 14.

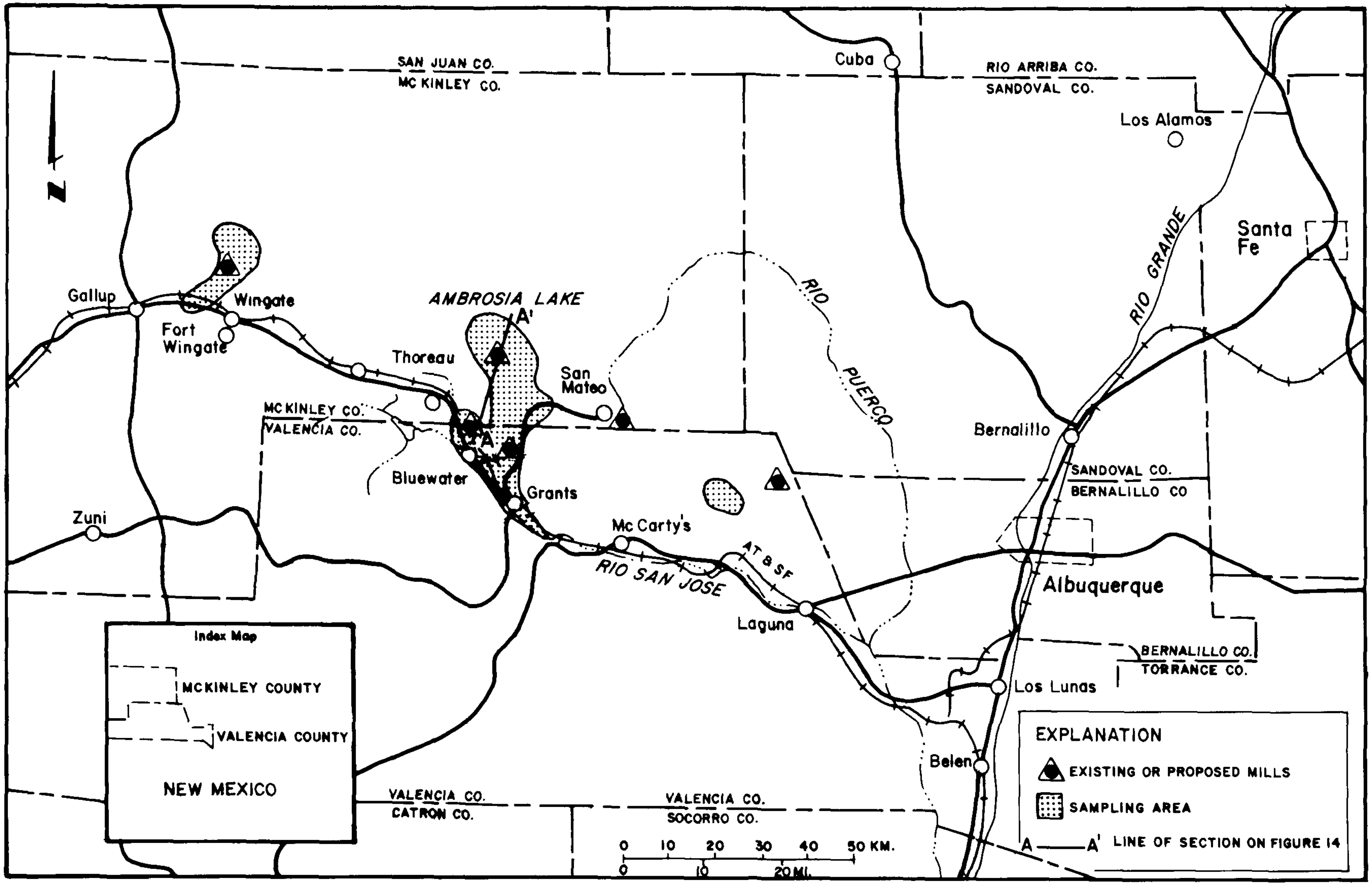

Figure 13. Grants Mineral Belt in northwestern New Mexico showing mill sites and sampling areas of previous investigations. 23)

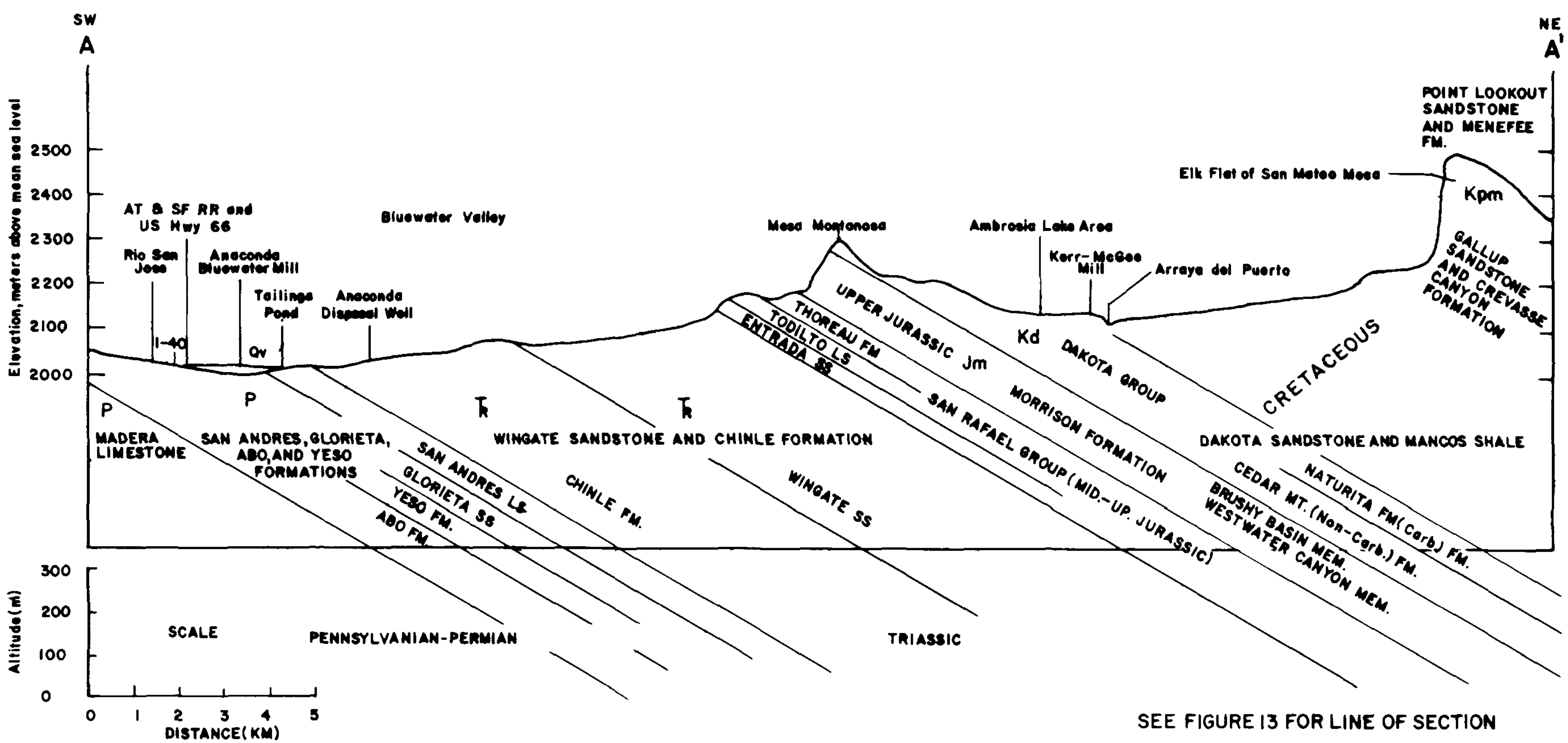

Figure 14. Hydrogeologic section A-A' through Ambrosia Lake showing water-bearing units in the Grants Mineral Belt Area.[23)]

The principal aquifers, from land surface down, are: (1) valley-fill alluvium and related Holocene basalt flows; (2) the Westwater Canyon Member of the Morrison Formation; and (3) the San Andres Limestone. Minor aquifers are the sandstones of the Dakota Group and sandy beds within the Chinle Formation.[23)] Salt water occurs in the limestones and sandstones of the Yeso and Abo Formations of Permian age at depths of about 940 ft (290 m) to 1,420 ft (460 m). These formations have been used by one mining company to dispose of wastewater by deep-well injection.[24)] Plans are under consideration to abandon the injection-well scheme and to enlarge a nearby tailings pond complex as a substitute method of handling wastes.

Prior to the development of the uranium mines, there were no perennial streams in the Grants Mineral Belt.[21)] Presently, because of the large quantities of ground water being pumped from the mines for dewatering purposes and discharged to the nearest drainage courses, most of the principal streams flow continuously. Nevertheless, ground water remains the main source of supply for communities, private domestic supplies, and irrigation and stock watering. As a general rule, the valley-fill alluvium and related basalts are dependable sources of ground water along the broad valleys of the Rio San Jose and the Rio Puerco (Figure 13). According to Kaufmann and others,[23)] "numerous shallow domestic wells south and southwest of a uranium processing mill north of Milan also tap the shallow unconfined aquifer. The principal bedrock aquifers are the San Andres Limestone and the Westwater Canyon Member of the Morrison Formation." These bedrock aquifers supply most of the water used by the mills.

Ground-Water Contamination. Ground-water contamination resulting from the mining and milling of uranium in the Grants Mineral Belt is documented in reports of investigations by EPA's Office of Radiation Programs and National Enforcement Investigations Center[23,25,26)] and by the State of New Mexico.[27)] Of particular interest is the situation near a mill in the Grants area in the southern part of the Ambrosia Lake District. This mill uses a carbonate leach to extract uranium from the ore, whereas other mills in the Grants Mineral Belt utilize an acid leach. The carbonate leach is thought to be highly effective in dissolving selenium as well as uranium, and it is the selenium that has caused some community health concerns to develop.[26)] It is important to emphasize that radium (Ra-226) is not the only or even the main ground-water contaminant associated with uranium mining and milling. Selenium can be toxic and must also be kept out of underground drinking-water sources where its infiltration would raise concentrations above acceptable levels (EPA's standard is 0.01 mg/l for community supplies).

The mill site is about 4 mi (6.4 km) north of Grants (Figure 13). The mill itself and its tailings ponds are upgradient from two subdivisions (Figure 15) as well as from irrigated farm lands. Nearly all wells in the area are developed in the water-table aquifer which receives some seepage from tailings ponds near the mill. The depth to the water table is about 50 ft (15 m).

Chavez,[27)] who investigated the potential for ground-water contamination at the mill site, found that in less than 2 yr, after the mill began operations, the Ra-226 concentration in the water-table aquifer rose from its normal range of about 0.1 to 0.4 pCi/l to as much as 9.5 pCi/l in some wells (EPA's standard for Ra-226 in drinking water is 5 pCi/l). At test well "D" (Figure 15), the Ra-226 content, which was 17.4 pCi/l in 1964, has not been above 5 pCi/l in the last 10 yr. Moreover, a company official reports that background concentrations of Ra-226 in sampling wells upgradient from the mill currently range from 0.8 to 3.1 pCi/l. Sampling of wells in the area and interpretation of water-level contours indicate a downgradient movement of contaminants from the tailings ponds and particularly from the abandoned pond southwest of the mill. The plume of contamination is believed to be irregular in shape and is not advancing along a broad front but is preferentially following zones of high permeability in the water-table aquifer.[28)] The NMEIA (New Mexico Environmental Improvement Agency) reports that the Ra-226 content of recent samples from the water-table aquifer has apparently

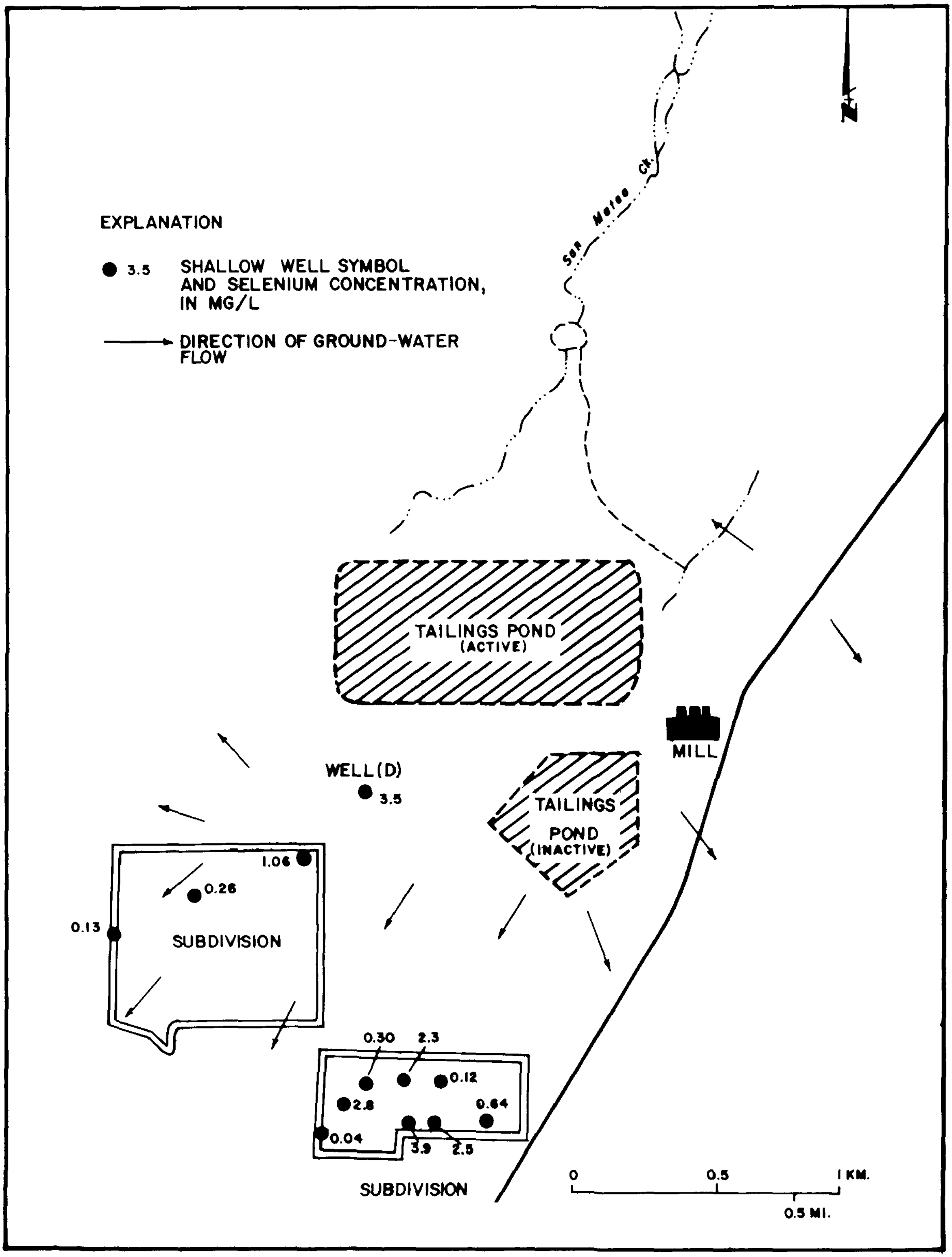

Figure 15. Selenium concentration and general direction of ground-water flow in the shallow aquifer in the vicinity of a uranium mill near Grants, New Mexico.[23)]

stabilized at less than 1 pCi/l throughout the subdivision areas (written communication, 1978).

Kaufmann and others[28)] state that "total uranium in well "D" at the south margin of the larger tailings ponds (Figure 15) is about 500 pCi/l, compared with 10 to 20 pCi/l in wells of comparable depth but located about twice the distance downgradient from the mill. For comparison, seepage from the mill tailings pile contains 52 pCi/l of Ra-226 and 101,000 pCi/l (150 mg/l) of U-natural." The authors conclude that, although high concentrations of radium and uranium seep into the alluvium (water-table aquifer) near the ponds, the radium and uranium ions are adsorbed by clays at a relatively short distance from the mill and apparently are no threat either to the deep aquifers or to the water-table aquifer in the nearby subdivisions.

This is not the case with selenium. As shown in Figure 15, selenium concentrations ranging from 0.04 to 3.9 mg/l have been determined at individual domestic shallow wells in the subdivisions. Well "D", close to the tailings pond, shows as much as 3.5 mg/l selenium, or 350 times the recommended maximum permissible level of 0.01 mg/l in public drinking-water supplies.[29)] The concentrations shown are not the latest available but are reportedly representative of recent analyses.

Kaufmann and others[28)] note that "although the background level for selenium is not fully defined, the deeper aquifers (Chinle, San Andres) contain 0.01 mg/l, whereas the seepage collection ditches and the shallow monitor well "D" contain 0.92 and 3.5 mg/l, respectively. Data collected in the course of the study showed that selenium concentrations in ground water throughout the Grants Mineral Belt were generally 0.01 mg/l or less. Prominent exceptions include the foregoing wells and seepage adjacent to the mill.* Elsewhere, mine and ion-exchange plant effluents averaged 0.027 and 0.15 mg/l of selenium, respectively, at the

*Company reports that selenium concentrations in samples from background wells upgradient from the mill range from 0.08 to 0.12 mg/l.

time of sampling. As a result of widespread selenium contamination, a cooperative State-industry program is underway to provide alternate potable water supplies for the local populace."

Cost of Controlling Ground-Water Contamination. Remedial operations, particularly in regard to the selenium contamination of the alluvial water-table aquifer, are currently underway, but no specific information relating to the ultimate costs of the joint investigation by the company and the NMEIA are readily available. A company official has estimated that costs may be on the order of $250,000 to $300,000. The entire cleanup operation will take some years to complete. Details of the operation are given in the "Ground-Water Protection Plan," an agreement between the company and NMEIA dated August 18, 1976.

According to the Plan, aquifer pumping tests will be run to determine the hydraulic properties of the alluvium and water samples will be taken from private and company wells in the area. A line of 20 collection wells paralleling the south and west sides of the tailings pond has already been installed and is operating, with the contaminated water pumped out of the aquifer being recycled through the mill's processing system. Water pumped from the San Andres Limestone is injected through 6 injection wells into the alluvial aquifer downgradient from the 20 withdrawal wells, for the purpose of flushing out the selenium-contaminated water and diluting it in order to restore the water quality of the alluvial aquifer to normal. During the period of remedial action, the company is furnishing free bottled drinking and cooking water to residents whose wells may be contaminated.

Brokaw and Peshtigo Area, Northeastern Wisconsin

General Background. Wisconsin is one of several States where problems of ground-water contamination stemming from discharge of sulfite liquors from pulp mills have been studied in some detail. In past years, most liquid and pulp sulfite wastes were simply discharged into nearby streams or lakes. If the dilution and assimilative capacities of the receiving water were great enough, the wastes were carried away. As mills became larger and more numerous, the amounts of sulfite waste liquors exceeded the capacity of the receiving waters to handle the wastes. Consequently, laws were passed in Wisconsin and in other States to prevent discharge of the wastes to surface water. This led many companies to begin disposal of their sulfite liquors into unlined surface impoundments designed to permit seepage of the wastes underground, as long as existing laws did not forbid such disposal.

In the manufacture of sulfite pulp, chips of coniferous woods (usually those of low resin content) are cooked under pressure and at high temperature in a watery solution of calcium, magnesium, or ammonium bisulfite, containing an excess of sulfuric acid. Byproducts of the sulfite pulping process are cymene, which includes any of three liquid hydrocarbons and spent sulfite process liquor, most of which is discharged to the environment because it has little or no known economical use. The spent liquor itself, which contains appreciable amounts of lignin, acidity, and TDS, also has a high BOD, which ranges from about 15,000 to 40,000 mg/l. The liquor has a dark color and pungent odor, and foams when dispersed in open bodies of water.

Of 579 municipalities in Wisconsin, 549 obtained (1960) their water supplies from aquifers; also, about 93 percent of the rural homes in Wisconsin have their own domestic supply wells and most use ground water as their source for irrigation and farm-animal supply.[30)] Known sites in Wisconsin experiencing ground-water contamination from surface impoundments containing spent sulfite liquor include (Figure 16) Brokaw, Rothschild, Peshtigo, Niagara and Neenah[30,31)] (Smith, Thomas; and Brant, Gary; personal communication, 1977). The situations at Brokaw and Peshtigo described below are among the best documented case histories.

<u>Ground-Water Contamination at Brokaw</u>. Brokaw is a mill town on the Wisconsin River approximately 8 mi (13 km) north of Wausau, the county seat of Marathon County. The population is about 400. From 1953 to 1957, the paper mill at Brokaw continuously discharged sulfite waste liquors into a 6-acre (2.4 ha) percolation pond on a large island

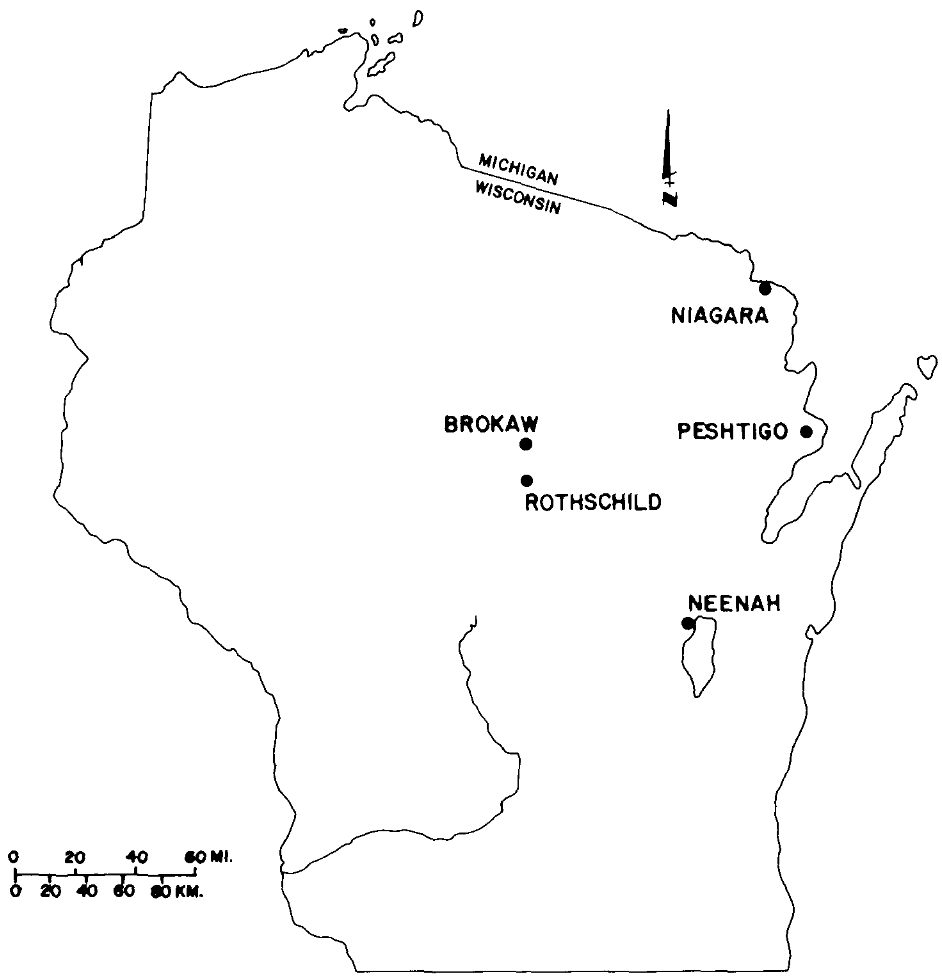

Figure 16. Location of selected incidents of ground-water contamination from paper mill wastes in northeastern Wisconsin.

in the Wisconsin River (Figure 17), during which time nearby water-supply wells became polluted. It was believed, at the time when the waste disposal began, that the spent liquor would be biologically destroyed by soil bacteria as it percolated through the earth materials beneath the pond floor and would be further clarified and made non-objectionable by filtration during seepage down to the water table. However, according to Ruedisili,[30)] "a few years of continuous checking showed that the spent liquor -- of high specific gravity and moving to lower strata -- was not changed in composition. It appeared to be concentrating in the deeper sections of the aquifer and moving toward and along the main channel of the Wisconsin River. Company officials became concerned that this polluted ground water would be objectionable for potable and industrial uses even with very dilute concentrations of sulfite liquor. Observations showed that the liquor was slightly acid, high in BOD (16,000 mg/l) and dissolved organic material, had a characteristic pungent odor, and foamed when dispersed in surface waters. Therefore, in October 1964, the Wisconsin Committee on Water Pollution and the State Board of Health requested that the company prevent further contamination of the ground water and determine the feasibility of removing the spent sulfite liquor from the ground."

"A company study determined that a barrier well system would be the best means of prohibiting the further migration of the liquor within the aquifer (migration of 3,300 ft (1,000 m) downstream in 11 years). This could be accomplished by placement of either a pumping barrier or a barrier caused by continually recharging fresh water to the aquifer. Because of the expense and difficulty of obtaining uncontaminated water, the possibility of permanently maintaining a fresh-water barrier was ruled out."

"The company then utilized a high-capacity "withdrawal" (dewatering) well and a barrier (interceptor well) for removal and control of the underground pool of spent sulfite liquor. Initially, the barrier well was used for test purposes to determine increases or decreases in liquor concentrations in the ground water. The withdrawal well pumped

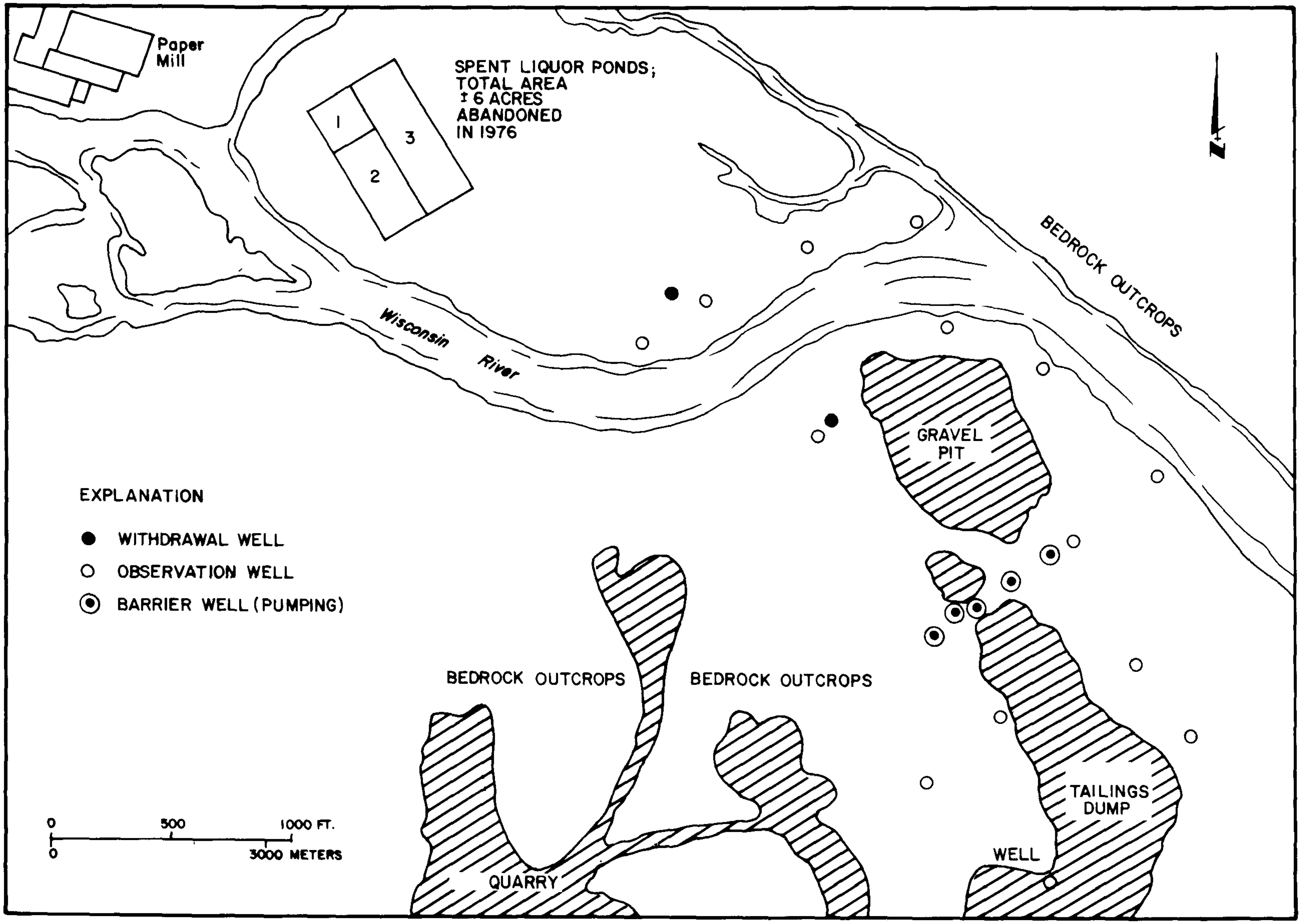

Figure 17. Paper mill spent liquor disposal site, Brokaw, Wisconsin. 32)

contaminated water from the ground and discharged it into the Wisconsin River. Because the effects of adding contaminated ground water to the Wisconsin River could not be predicted without continuous monitoring, a comprehensive program of systematic water-level and water-quality observations was established in 1964." In subsequent years, four more pumping wells were installed as barrier wells to prevent further movement of the liquor, and two more withdrawal wells were installed to remove the highly concentrated spent liquors closer to the original ponding operations (Figure 17).

"Results of the barrier well system have shown that the wells can be pumped only from November to April every year, because of the inability of the river to assimilate this contaminated water. Since the operations began, production of water and waste liquid from these wells has been much lower than expected. They were constructed to pump 1,500 gpm, (95 l/s) but have been operated at only 500 gpm (32 l/s). At this present (1972) pumping rate, computations by company chemists have shown that the barrier wells are removing less than 2.2 ponding-days equivalent of liquor per month. As there were a total of 1,488 days of ponding spent liquor, the magnitude of the problem of removing the liquor from the aquifer only by the barrier wells can be seen. Similarly, water-quality analyses have shown that the spent liquor in the water pumped, measured in lignin, was reduced from an initial concentration of 17,200 mg/l to 3,000 mg/l in 3 days and after 10 days dropped to 2,120 mg/l, stabilizing at approximately this level. Results of the withdrawal program have further revealed that a water-table gradient has been established toward the barrier well system and is beginning to control the further migration of the waste liquor; it will continue to do so if the average yield of the barrier wells is maintained at approximately 500 gpm (32 l/s)."

According to a paper mill official at Brokaw (oral communication, April 1977), capital costs amount to about $453,000. These include the construction of the 6-acre (2.4 ha) ponds; installation of five observation and monitoring wells (which subsequently became barrier pumping wells, complete with 1,500-gpm (8,175 cu m/day) pumps powered by 50-hp (51 hp) natural-gas engines); two centrally located withdrawal wells with the same size, construction, and pumps as the barrier wells; and upgrading of the monitor system. No real-estate costs are included in the capital costs.

In 1976, the company abandoned the percolation ponds and began to use an in-house treatment plant that evaporates 89 to 95 percent of the spent sulfite liquor and burns the residual. Some wastewater, including digester blowdown stack waste, is stored temporarily in new 1.5 million gal (5,700 cu m) tanks for later secondary treatment and eventual release of the treated effluent directly into the Wisconsin River.

Ground-Water Contamination at Peshtigo. According to Hackbarth[31] and Ruedisili,[30] a problem similar to that at Brokaw has developed at Peshtigo, involving paper mill spent liquor wastes. Beginning in 1955, spent-liquor wastes were disposed of into percolation ponds and ditches. The spent liquors seeped from these facilities into the water-table aquifer, a valley-fill deposit composed of Pleistocene sand and gravel, including lenticular layers of silt and clay overlying a bedrock covered by a blanket of dense, impermeable, clayey till. Unlike the valley walls and bedrock of granite at Brokaw, made permeable by joints and cracks, the dolomitic bedrock at Peshtigo is essentially impermeable; therefore, at Peshtigo the spent sulfite liquor remains within the valley fill and does not move at depth into and through the bedrock as it does at Brokaw.

In the 18 years of disposal into ponds at Peshtigo (1955-1973), the spent liquor has passed downward into the water-table aquifer, with no intervening zone of aeration between the bottom of the percolation ponds and the water table. Thus aerobic treatment is impossible. Wisniewski[33] reports that the clean, fine quartz sand in which the ponds are dug has very little adsorptive capacity. Little, if any, of the lignin is adsorbed as the dense waste liquor of high specific gravity percolates downward to the base of the water-table aquifer.

Hackbarth[31)] also reports that the spent sulfite liquor seeps downward to the bottom of the water-table aquifer and concentrates near the disposal sites. He says "in many instances the Folin-Denis values approach those of the applied spent sulfite liquor (about 75,000 mg/l)." He goes on to say "...the spent sulfite liquor is not affecting a much larger area than that on which it was applied. There does not appear to be cause for worry about lateral movement to water wells ...the existence and position of the till layer is very critical to this operation. If the till were buried deeper, it is conceivable that the spent sulfite liquor would not discharge into the river but would move under it (parallel to the river trend) and influence the whole flood plain farther downstream (as it has as Brokaw)."

Hackbarth concludes that an area covering about 0.75 sq mi (1.9 sq km) has been contaminated to a depth of 75 ft (23 m) below land surface by the spent sulfite liquor, but that the plume of contamination is essentially stabilized in its present position. He estimates that, of the 292 million gal (1.1 million cu m) disposed of in the infiltration ditches and ponds, some 187 million gal (708,000 cu m) has seeped laterally or run overland at times into the Peshtigo River, thus leaving some 105 million gal (400,000 cu m) as a residual mound at depth in the water-table aquifer. As discharged from the ponds, the spent liquor has received secondary treatment including neutralization, filtration of solids, and some dilution.

From 1971 to 1973, experimentation was undertaken using spraying from tank trucks over a vegetated area of about 43.5 acres (17.6 ha). Such disposal is environmentally acceptable but is a cumbersome and time-consuming means of handling the spent sulfite liquor; furthermore, it does not function well, if at all, during freezing weather. Installing, operating, and maintaining a rainbird-type sprinkling system was judged to be too expensive, and, in 1973, a new treatment plant was built to evaporate about 57 percent of the spent liquor, leaving a burnable pulp as a residual. Other plant fluid wastes are piped to the City of Peshtigo's waste-treatment plant before discharge to the Peshtigo River.

The cost for construction of the evaporator and separating plant was $2.5 million. Operation and maintenance costs for the plant run about $1 million/yr. Final treatment of 4.2 mgd (16,000 cu m/day) of mill wastewater at the Peshtigo treatment plant costs another $0.5 million/yr, according to a company official.

South Farmingdale Area, Long Island, N.Y.

General Background. The South Farmingdale area in western Long Island, N.Y., is largely residential, has a population of about 540,000, and has a water-supply demand of about 108 mgd (410,000 cu m/day). It contains more than 1,000 light industries and commercial establishments. No surface-water supplies are available; consequently, the area is totally dependent upon ground water for public supplies. Some ground-water contamination has already occurred locally by infiltration of synthetic organic chemical compounds, metal-plating waste, sewage, and other substances. The general location of the area is shown on Figure 18 and a detailed map is shown on Figure 19. The area straddles the Nassau-Suffolk County boundary and extends from about the middle of the Island to Great South Bay on the south.

Because of known or potential threats of contamination of parts of the Upper Glacial (Water-Table) and underlying Magothy Aquifers, numerous studies of water-quality problems have been made by the Nassau County Health Department, Nassau County Department of Public Works, Suffolk County Department of Environmental Control, Suffolk County Water Authority, and the New York State Department of Environmental Conservation. Each of these agencies has also supported cooperative studies with the U.S. Geological Survey.

Water-Quality Problems. The study area, which is largely unsewered, includes about 50 industrial point-source discharges, such as pits, ponds, lagoons, and septic systems, and numerous storm-water basins (Figure 19). Many of these point sources discharge a wide variety of liquid wastes into the ground; others discharge to streams or the wastes are removed by commercial haulers.

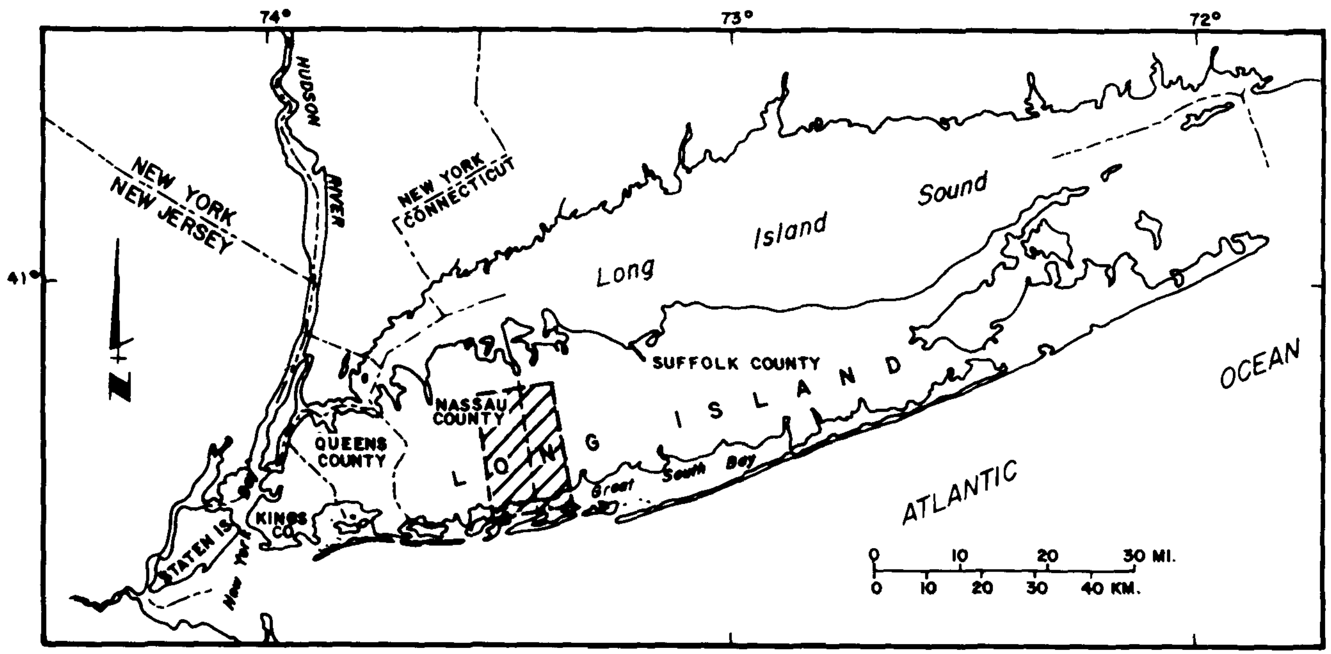

Figure 18. Map of Long Island showing area examined for surface-impoundment problems.

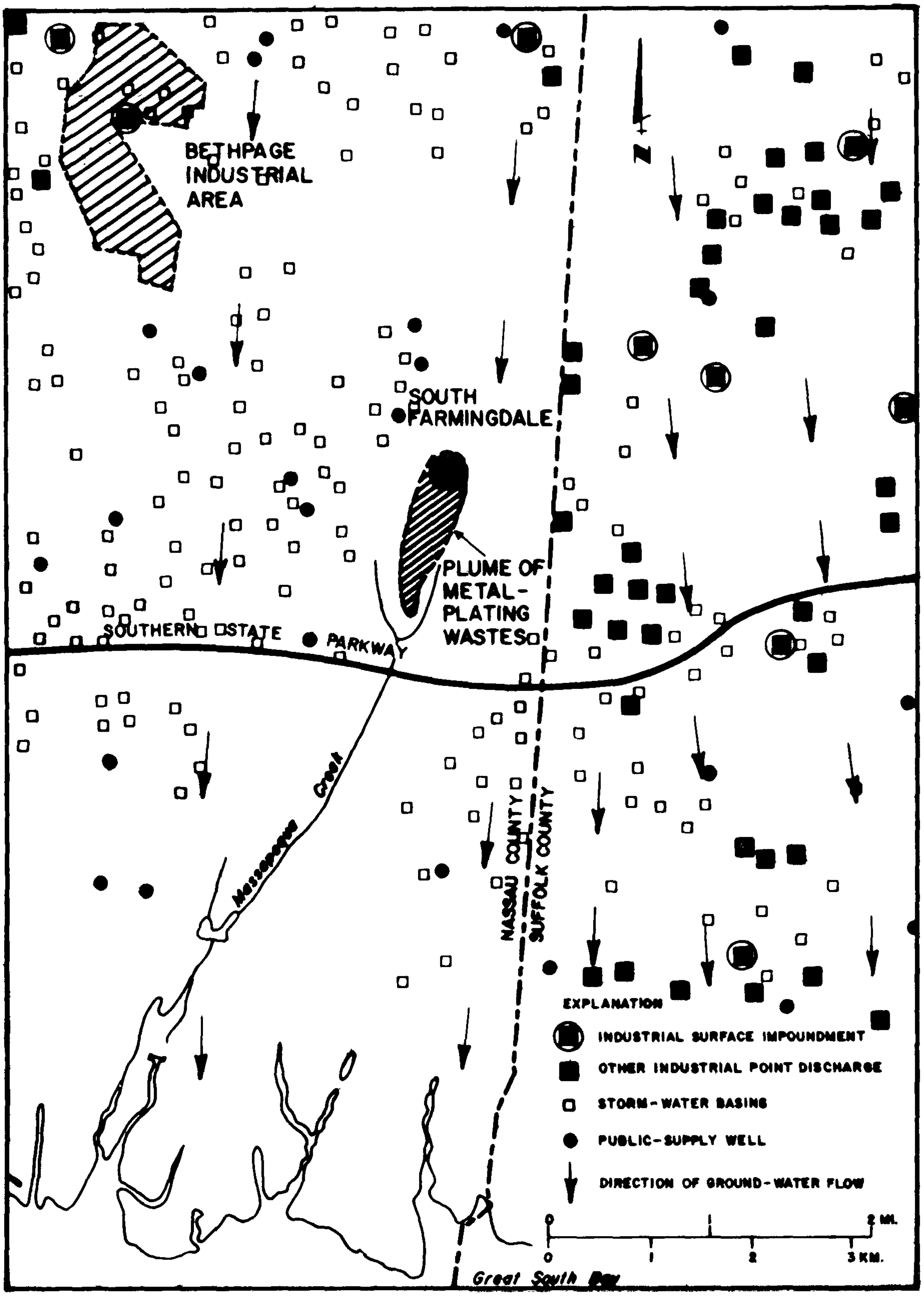

Figure 19. South Farmingdale area in western Long Island, N. Y., showing plume of metal-plating wastes, location of industrial surface impoundments, other industrial point discharges, storm-water basins, and public-supply wells.

The wastes include ammonia, incinerator blowdown and quench-water wastes, metal-plating waste fluids, and organics such as methylene chloride, vinyl chloride, polyvinyl chloride, chloroethylene, benzene, toluene, chloroform, carbon tetrachloride, phenols, and other organic chemicals. Additionally, because the area is largely unsewered, millions of gallons (thousands of cu m) of domestic wastes containing detergents and other sewage contaminants are discharged directly into ground water through tens of thousands of cesspools and septic tanks.[34-36] Central sewer systems, now under construction in both southeastern Nassau County and southwestern Suffolk County, will eventually eliminate the need for most domestic septic systems.

The area also has hundreds of unlined storm-water basins[37,38] (Figure 19), which receive highly polluted street runoff that seeps into the underlying Water-Table Aquifer through the bottoms and sides of the basins. The runoff has an average pH of 5.6 and contains oil, grease, other organics, and inorganics, including nitrate and phosphate. In addition, during the winter months, runoff containing high concentrations of chloride from road deicing salts also seeps into the aquifer through the basins. Trace amounts of heavy metals, including arsenic, cadmium, chromium, lead, mercury, nickel, and zinc, which have been detected in runoff to the storm-water basins, also are of concern.

Urbanization of the study area, beginning in the early 1940's, resulted in increasing contamination of the upper part of the Water-Table Aquifer, chiefly by effluents seeping from cesspools and septic tanks and by industrial and municipal wastes discharged into pits, ponds, lagoons, or on the land surface. As a result of the ground-water contamination, some shallow public-supply wells that tapped the Water-Table Aquifer were abandoned and deep public-supply wells were drilled into the underlying Magothy aquifer, the principal source of water supply. Recently, however, 9 public-supply wells and 8 industrial-supply wells, all withdrawing water from the Magothy aquifer in the Bethpage industrial park area (Figure 19), also have been taken out of service because of ground-water contamination.

Ground-Water Contamination from Plating Wastes. The first indication of contamination of the Water-Table Aquifer by plating wastes was noted in 1942 by the Nassau County Health Department[39] at an aircraft plant in South Farmingdale.[40] It was determined that chromic acid wastes from metal-plating operations had been discharged into unlined disposal basins at the plant site and had contaminated a nearby supply well. The owners were advised to shut down the well and to make no further use of the water. The approximate location of the disposal basins and of the associated plume of contaminated ground water is shown on Figure 19.

No further investigation of the chromium contamination was made until June 1945, when a series of shallow test wells were installed south of the aircraft plant. The chromium content of the water from the test wells ranged from zero to a trace. In 1948, the New York State Department of Health analyzed another set of samples from these test wells, along with samples from a shallow domestic well about 1,500 ft (460 m) south of the disposal basins. The results showed some copper, aluminum, and cadmium, as well as chromium in the water. Recognizing that the full extent of the contamination could not be assessed by resampling the few existing wells and aware of the potential danger to public-water supplies, the Nassau County Department of Health and Public Works made a joint investigation of the contaminated area in 1949 and 1950, which included the drilling and sampling of about 40 test wells.

Despite the completion of a waste-treatment unit for chromium removal in 1949, discharge of effluent containing cadmium and other metals was continued at the disposal basins. After 1.2 mg/l of cadmium was determined in a sample of treated effluent from one of the basins in 1953, a new test-drilling program was begun in that year to determine the extent of cadmium contamination in the ground water downgradient from the disposal basins.

In 1962, the U.S. Geological Survey, in cooperation with the Nassau County Departments of Health and Public Works, made a detailed investigation of the extent, chemical composition, and pattern of movement of the contaminated water.[40)] This investigation included the drilling and sampling of about 100 test wells and also extensive sampling of a nearby stream, Massapequa Creek, for cadmium and hexavalent chromium.

Figure 19 shows the general location of the plume of contaminated ground water with respect to public-supply wells, the Bethpage industrial area (a recently discovered source of organic contaminants from impoundments), and other impoundments. Figure 20(A) is a block diagram showing the shape and extent of the plume in relation to the local hydrogeologic system. The plume was about 4,200 ft (1,280 m) long and averaged about 750 ft (230 m) wide in 1962. Figure 20(B) is a hydrogeochemical section across the south end of the plume in 1962, showing the distribution of lines of equal concentration of hexavalent chromium. The volume of contaminated water in the plume is estimated to be 195 million gal (741,000 cu m). Part of the contaminated ground water is discharged naturally into Massapequa Creek and the remainder is moving slowly downgradient in the Water-Table Aquifer. Intermittent sampling suggests that little expansion of the plume has taken place since 1962.

As long as the plume remains in the Water-Table Aquifer, under present pumping conditions only a minor threat exists to the quality of water in the underlying Magothy Aquifer. However, a number of steps could be taken to alleviate the potential threat of significant downward movement of the contaminated water as a result of increased pumping from the Magothy Aquifer. One alternative would be to remove the plume by pumping out the contaminated water, provided that further discharge of metal-plating wastes to the impoundments were stopped. However, the costs would be very high if the waste fluids had to be treated before recharge to the ground-water system or had to be stored in lined holding ponds before removal by scavengers.

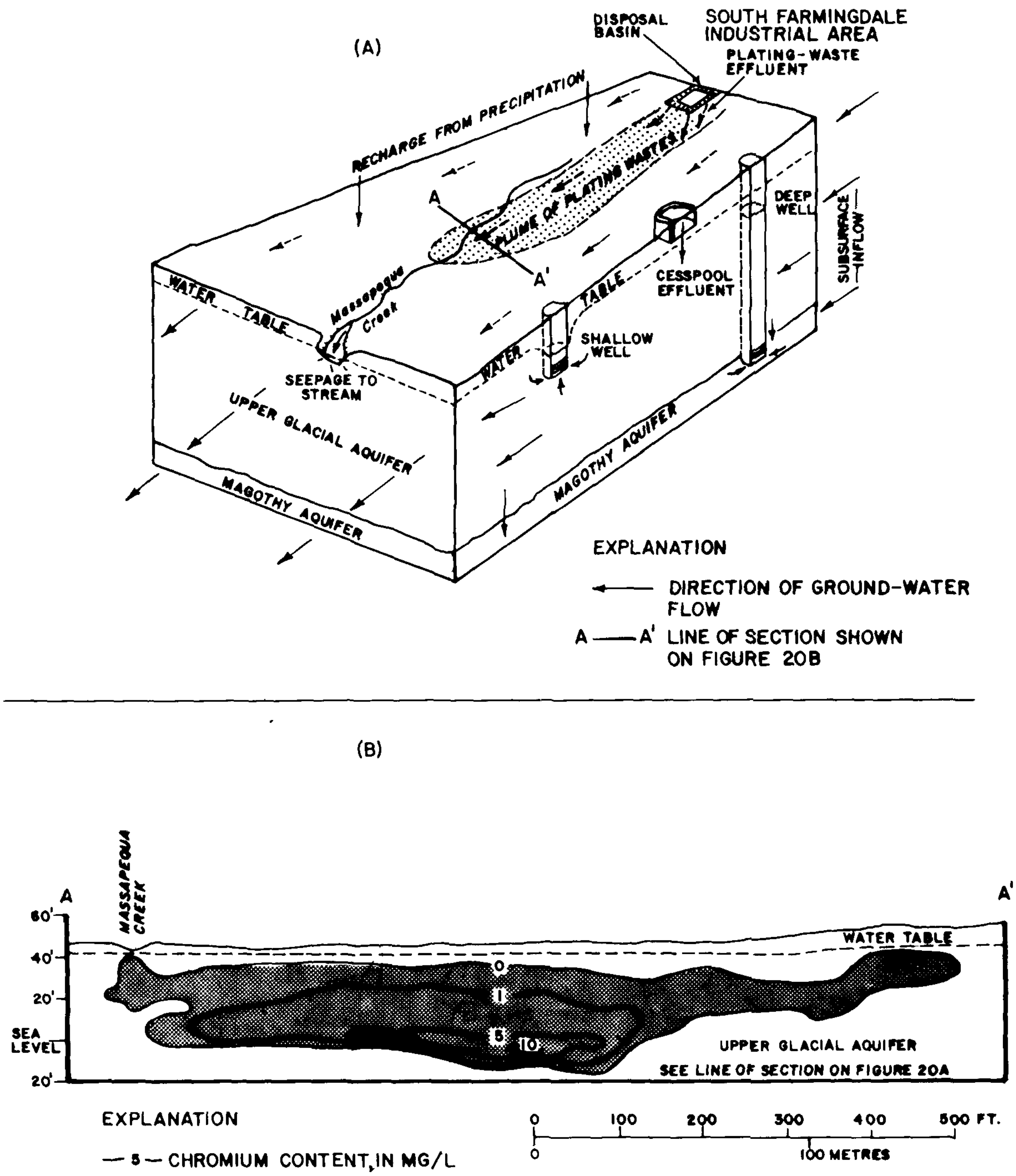

Figure 20. Block diagram (A) showing the aquifer system and areal extent of plume of plating wastes in South Farmingdale, Nassau County, N. Y., and downgradient section (B) showing vertical distribution of hexavalent chromium content in 1962.[40]

Status of Remedial Actions. Only the plume of contamination caused by the plating wastes at South Farmingdale has been investigated intensively thus far, at a cost believed to be considerably in excess of $100,000. Most likely, there are individual plumes of contaminated ground water associated with many of the other impoundments in the area, as well as with other sources of contamination such as cesspools, leaky sewers, spills, and dumps. Nothing has been done yet to define their dimensions or chemical composition, owing to the large expenditures that would be required.

Except for removal of heavy metals, mostly chromium, in small treatment plants at the site of the plume at South Farmingdale and in the Bethpage industrial area, little or no treatment is given to wastes in other surface impoundments and no treatment is given to street runoff in the numerous storm-water basins. At some industrial establishments, scavengers are used to haul away wastes for disposal elsewhere. However, the basic problem of how to safely dispose of other industrial wastes, which cannot be discharged into municipal sanitary-sewer systems in the area, still exists.

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SECTION VIII

TECHNOLOGICAL CONTROLS

CONTAMINATION-PREVENTION TECHNIQUES

Direct Methods

A number of direct methods are available that will prevent contaminated fluids in an impoundment from coming in contact with uncontaminated ground water. Some of these methods are feasible only during the construction of new impoundments; others may be applied to new or existing impoundments. Although many variations and combinations of these techniques are potentially applicable, it is believed that the eight techniques summarized below cover the range of currently available technology for preventing or controlling ground-water contamination.

Alternative 1 - Installation of an Impermeable Membrane

One of the commonly used methods for preventing ground-water contamination from impoundments is the installation of an impermeable membrane that seals off the bottom and sides of the impoundment. The membranes most typically used are made from synthetic materials such as butyl rubber, polyvinyl chloride, polyethylene, polypropylene, and nylon.

Usually, an impermeable membrane must be installed during the construction of an impoundment, particularly if the function of the impoundment is to hold sludge or solid materials. The only way to install an impermeable membrane in an existing impoundment is to remove the impounded material, install the membrane, and then replace the material on top of the membrane--an exceedingly difficult, costly, and environmentally risky operation. If the function of the impoundment is the treatment of wastewater, it is sometimes possible to drain the impoundment during a period when no wastewater is generated (such as during a plant maintenance shutdown) and to install the membrane. If, however, the installation delays production or if it requires a plant shutdown that would not be otherwise scheduled, the resulting costs could make the use of this alternative economically prohibitive for many plants.

Alternative 2 - Installation of a Layer of Impermeable Material

Bentonite clay is most commonly used to form a layer of impermeable material on the bottom and sides of an impoundment. It is usually pumped in as a thick slurry and allowed to compact either by subsidence or by mechanical means. Although clay is not totally impermeable, it does have one advantage over membrane liners in that it will not deteriorate with age. Also, being plastic in nature, it tends to be self-sealing should the layer be punctured.

As in the case of impermeable membranes, bentonite layers are usually installed during the initial construction of an impoundment. If an impoundment is already filled with a solid or sludge, those materials would have to be removed first in order to install the bentonite layer. This procedure is just as difficult as the installation of an impermeable membrane.

In theory, it should be possible to install a bentonite layer in a wastewater impoundment without first emptying it of fluids. However, bentonite slurries usually do not settle very rapidly, and if the wastewater impoundments are aerated lagoons, it is doubtful that a sufficiently dense layer could be established on the bottom, because of the turbulence caused by aeration. The wastewater-treatment system would, in all likelihood, have to be shut down in order to produce the quiescent conditions necessary for the bentonite to compact. For these reasons, in-situ installation of bentonite or other slurry-like layers in most operating wastewater-treatment impoundments is not likely to be feasible because of costs and physical problems.

Alternative 3 - Collection of Contaminated Water Seeping from Impoundment

A number of collection systems can be used to intercept contaminated ground water at points near the actual boundary of an impoundment when it is not feasible to install an impermeable membrane or a layer of impermeable material in an existing impoundment that is already filled with wastes. The contaminated water is either returned to the impoundment or treated to remove the objectionable contaminants prior to reuse or discharge. The three most commonly used collection systems are infiltration galleries, wellpoint systems, and conventional wells.

Infiltration Galleries. An infiltration gallery consists of a gravel-packed trench with a horizontal perforated pipe along the trench bottom which connects to a vertical casing and pumping system. Infiltration galleries may be useful in places where geologic conditions make it difficult for standard wells to intercept all the contaminated ground water. For example, in areas where the soil consists primarily of hard dense material, such as glacial till, and the ground water is transmitted largely through lenses of sand, dewatering by conventional screened wells is difficult, and an infiltration gallery may be used.

The trench for an infiltration gallery is excavated with various types of equipment, depending on the depth required to collect contaminated ground water. Where the aquifer is shallow or the ground water to be pumped is only in the upper part of the aquifer, the trench may be excavated using a scraper and/or backhoe. The scraper removes the top 1 or 2 yds (about 1 or 2 m) of soil above the water table. The backhoe excavates to depths of about 12 yds (11 m) below the ground surface. For deeper trenches a clamshell or dragline may be used.

During excavation below the water table, the side slopes of the trench tend to slough into the excavation unless special precautions are taken. One solution would be to place a biodegradable drilling mud in the trench to keep the slopes intact. The gravel pack and the horizontal collecting pipe can be placed in the trench while it is filled with drilling mud. After several days, the mud largely degrades or breaks down and flushes out.

Wellpoint Systems. A standard wellpoint system is useful in dewatering part of an aquifer where depths to be dewatered are less than 25 ft (8 m) below land surface. The system consists of a line of screened wellpoints connected to riser pipes, a common header pipe, and a centrifugal pump. Under corrosive conditions, such as in the pumping of acid ground water or water containing high concentrations of dissolved salts, polyvinyl chloride (PVC) wellpoints and headers are used. The wellpoint spacing, header size, and pump size are all determined by the soil transmissivity and resulting ground-water flow rates.

In most soils, wellpoints are jetted into place, using a high pressure jet pump to hydraulically loosen the soil and flush the displaced soil to the land surface. In cases where the soils consist of fine sand or silt, a large-diameter hole may be jetted into the ground 2 ft (0.6 m) deeper than the wellpoint, to permit placement of a 12-in (30.5 cm) diameter sand wick around the wellpoint for increased pumping efficiency. Where the soil is very stiff or cemented, or where the wellpoint is placed in rock, predrilled holes may be required.

Normally, labor for installing wellpoint systems involves a 4 or 5 man trained crew. Major dewatering firms will provide the trained crew on a contract basis. Once the wellpoint system is installed for permanent dewatering of contaminated ground water, labor mainly involves checking the pump once a day for lubrication, clogging, and repair. Standby pumps are always included in the design of the system.

Wells. A series of individual conventional wells can be used to dewater the ground-water reservoir to any depth, provided submersible pumps are installed. Each well is drilled at spacings dependent on the soil conditions and the corresponding ground-water flow rates. As water from each well is pumped, a water-level cone of depression forms; the series of wells is designed to have overlapping cones of depression to provide a uniform lowering of the water table.

For permanent dewatering, the individual wells should have a diameter of at least 4 in (10.16 cm) to accommodate a submersible pump. Each well is drilled and cased, and the screen is packed in a gravel envelope. Usually, the gravel packing extends 10 to 15 ft (3 to 5 m) above and below the well screen.

The use of a conventional well is more costly than installation of well-points, in that it requires a large diameter hole, larger casing, gravel, and a pump. Typically, mud-rotary drilling is employed for well graded soils, where a drilling fluid such as bentonite slurry is required to keep the drill hole open during installation. In areas with stiff soils and boulders, cable-tool drilling is commonly used. Cable-tool drilling requires more time for each hole drilled.

In each of the above techniques, the water drained from the assembly of collection points is combined into a single contaminated waste stream which, depending upon the specific conditions, can either be returned to the impoundment or treated prior to discharge.

Alternative 4 - Return of the Collected Water Back to the Impoundment

Subsequent to the collection of contaminated water emanating from an impoundment, as described in Alternative 3 above, the treated water may be discharged to a surface stream, recharged into the aquifer, or simply returned to the impoundment. Although costly and difficult, returning collected water to an impoundment is an attractive alternative, in selected locations, because it may not require extensive wastewater treatment.

Return of collected water back to an impoundment is feasible only where it does not cause the level of fluids to rise and eventually overflow the banks of the impoundment. The likelihood of such overflow depends on the relative volumes of material entering and leaving the impoundment. The relationship must be considered both in terms of intermittent buildup (such as during severe rainstorms) and long-term average accumulation.

Wastewater-treatment impoundments present a somewhat special case, because many such impoundments operate in a flow-through condition with the water level in the impoundment being maintained by mechanical means, such as overflow weirs or control valves. Evaporation and rainfall, therefore, have very little effect on the water level in many wastewater-treatment impoundments. Even in areas of net positive rainfall, pumping collected water back into a wastewater-treatment impoundment will not cause it to overflow its banks, but will merely increase the wastewater flow rate from the impoundment. If the water that is collected and returned to the impoundment is not a significant percentage (say less than 10 percent) of the normal wastewater flow through the impoundment, then pumping the collected water back into the impoundment will usually be feasible.

Alternative 5 - Physicochemical Immobilization of Waste Material

A number of proprietary techniques are currently available that are intended to convert waste slurries, sludges, and other semi-liquid materials into a solid and more chemically stable mass that is less prone to leaching. All of these techniques involve some method of mixing the waste material with an immobilizing agent that can be composed of either an inorganic cementitious or an organic polymeric substance.

Inherent in the process is the movement or transfer of material. If the immobilization is performed directly as the waste is generated, the task is merely one of mixing the waste stream with the immobilizing agent and depositing it in an appropriate impoundment. If, on the other hand, the intent is to immobilize the entire body of waste already deposited in a large impoundment, the overall task is far more difficult and costly. The waste material must either be agitated while the immobilizing agent is added; or it must be pumped from the waste impoundment, mixed with the agent, and then redeposited either in the original impoundment or into a new impoundment especially designed to store the immobilized waste. If the waste to be immobilized is nonpumpable or otherwise difficult to agitate, this technique can be difficult to apply. The larger and deeper the waste impoundment, the more difficult it is to uniformly mix the waste and the immobilizing agent. In spite of these limitations, physicochemical immobilization can be a feasible technique for preventing or alleviating ground-water contamination from selected impoundments.

The waste and the immobilizing agent must be chemically compatible if an immobilized material of long-term stability is to be formed. Therefore, it is usually necessary to perform tests on the specific wastes prior to employing this technique.

Alternative 6 - Ground-Water Cutoff Wall

The feasibility of employing a ground-water cutoff wall is heavily dependent on local hydrogeologic conditions, and it is unlikely that this alternative can be used at many existing impoundment sites. Nevertheless, it is described here to show what might be done in special situations.

The cutoff wall can be a partial barrier, blocking off the upstream portion of an impoundment that is built in a narrow channel bounded by essentially impermeable materials, or it can encircle the entire impoundment, essentially forming a complete impermeable barrier. The extent of encirclement required depends entirely on the physical features of each impoundment and the hydrogeologic conditions at and near the impoundment. It is important to note that although a partial cutoff wall (one that forms an upgradient barrier) can prevent surface water from contacting waste material in the impoundment, it does not necessarily prevent contaminated water from leaving an impoundment and eventually causing ground-water contamination. That is, liquid seeping through the bottom and sides of the impoundment will eventually reach the water table and move in the direction of the hydraulic gradient; this could cause the aquifer downstream from the impoundment to become contaminated. Two general types of cutoff walls, the slurry trench cutoff and the grout cutoff, are discussed below.

Slurry Trench Cutoff. Slurry trench cutoffs have been used in dam construction for about 40 years. More recently, they have been used in construction of underground walls. Wall depths of as much as 150 ft (46 m) have been reported (Saylorville Dam in Iowa). Slurry wall thicknesses have ranged from 24 in (0.6 m) to 96 in (2.4 m). The trench construction usually involves excavation, filling with bentonite clay slurry, and backfilling with indigenous soils.

Excavation involves removing soil to bedrock level or to the depth of the uppermost impermeable soil layer. The top portion of the trench is excavated with scrapers while the lower portion requires a dragline bucket or clamshell. The width of the trench is dependent on the size of the excavation equipment. Typically, a 5-ft-wide (1.5 m) trench is cut, although special clamshells are capable of excavating a 2-ft-wide (0.6 m) trench. Narrower widths are desirable for underground structures where the trench is backfilled with concrete. However, where soil is used for backfilling, wider trenches are more typically excavated.

During excavation, the vertical walls of the trench are supported by the bentonite slurry. The slurry is added to the trench at a rate compatible with the excavation rate, so that the trench always remains filled to above water-table elevations. The excess fluid pressure of the slurry supports the vertical walls of the trench and forces fine slurry particles into the voids of the indigenous soil material to form an impermeable seal.

Only "Wyoming" bentonite is used in slurry trench construction. This is a high swelling sodium base bentonite. The slurry is normally placed to attain a final level of at least 2 ft (0.6 m) above the water table, so that no overflow occurs. Also, at least 3 ft (0.9 m) of soil above the final trench is required to allow the movement of overland equipment and to prevent the loss of bentonite slurry moisture to evaporation. The trench is backfilled with materials extracted from the trench and graded by bulldozers. In some cases, selected borrow material is required to obtain a well-graded backfill that will be secure from piping effects and will minimize settling.

Grout Cutoff. Grout cutoffs are less commonly used as impermeable barriers than slurry trench cutoffs because it is difficult to insure that a continuous grout curtain is formed. Grouting is used to seal fractures that may exist in underlying bedrock, but it generally is not recommended for cutoffs in soil.

The technique involves drilling holes at selected intervals and injecting the grout solution so that it flows laterally to form a continuous curtain wall. Silicate grouts are normally used in sandy soils having grain sizes above 0.1 mm. In coarser soils, both bentonite and cement grouts can be used. Chemical grouts are used mostly in fine-grained soil, such as silt.

Due to serious construction difficulties, high costs, and uncertain degree of protection, slurry trenches and grout cutoff walls are more applicable to existing impoundments filled with waste materials than to proposed new impoundments. Finally, as noted previously, the feasibility of using ground-water cutoff walls is highly dependent on local hydrogeologic conditions. For this reason, a cutoff wall must be viewed as a specialized rather than a generally applicable technique.

Alternative 7 - Capping of the Impoundment Surface

Capping an impoundment surface prevents rainwater from percolating down through the waste material and eventually reaching the ground water. Capping involves placing an impermeable barrier on top of the waste material. Depending on the physical features of the impoundment, the barrier can either be an impermeable membrane or a layer of impermeable material such as bentonite clay. In some cases it may be feasible to apply physicochemical immobilization to the upper surface of the wastes in the impoundment. The choice of the specific method depends a great deal on the mechanical properties of the wastes. Capping is usually only applicable to existing inactive impoundments (filled and no longer receiving waste material), which contain either solid material or highly dewatered sludge.

Capping is not applicable to impoundments containing fluids because where a waste is already in a fluid form, it is capable of seeping through the bottom and sides of an impoundment regardless of whether or not there is a cap over it. Also, capping is ineffective in preventing ground water from coming in contact with and dissolving impounded waste material during a rise in the water table.

Alternative 8 - Treatment of Contaminated Water

If it is not possible to prevent the generation of a contaminated waste stream, and if the stream cannot be returned to the impoundment from where it originated, then it normally must be subjected to wastewater-treatment processes for removal of objectionable contaminants before it can be disposed of into the physical environment. The type of treatment depends on the overall chemical composition of the waste, the specific contaminants to be removed, and the required composition of the treated effluent. In actual applications, treatability studies and engineering evaluations are usually performed first in order to select the wastewater-treatment process configuration that will consistently produce the required effluent.

In this study, it was not the intent to custom design a treatment system for each of the specific types of wastewater emanating from individual impoundments. However, an effort has been made to match the general characteristics of the impoundment wastewater with correspondingly general types of wastewater-treatment processes. Although literally hundreds of configurations could be generated from the various types of standard wastewater-treatment and associated sludge-handling equipment available, six basic process modules have been defined in this study for use in preparing cost estimates. The modules, used in various combinations depending on the nature of the wastewater to be treated, represent by function the most commonly used types of wastewater-treatment systems. The modules are described below as follows:

Equalization. Equalization is the use of a holding basin to damp out variations in wastewater flow and composition. An equalization basin is typically installed between the point of collection of the wastewater and the treatment system proper. Many equalization basins are mildly agitated to insure proper mixing of the incoming and stored wastewater.

For those impoundments that produce contaminated water largely as the result of precipitation percolating down through a mass of solid waste, wastewater flow rates and compositions can vary considerably, making equalization a necessity. Equalization is also especially desirable when biological treatment is to be used, because biological treatment systems cannot tolerate major variations in wastewater composition. It is reasonable to assume that many systems that require collection and treatment of contaminated water from impoundments would employ some form of equalization.

Biological Treatment. Biological treatment is a general term referring to a whole family of treatment processes designed to remove organic material from wastewater by means of biochemical oxidation, using naturally occurring microorganisms. In biological treatment, the organic content of the waste serves as the food source for the microorganisms, which then convert the waste into carbon dioxide, water, and cell mass. The cell mass forms a solid material which can be readily separated from the wastewater as a wet sludge. The effectiveness of biological treatment depends on the biodegradability of the waste, that is, the degree to which microorganisms are able to use the waste as a food source. Many organic wastes, particularly those containing synthetic organic compounds in high concentrations, are only marginally biodegradable. Some are even toxic to biological treatment systems. Due to the nature of microorganisms and the kinetics of biochemical reactions, the efficiency of removal of organic matter, usually expressed as BOD, is seldom greater than 95 to 97 percent for most biological treatment systems.

The general biological treatment system used for cost estimates in this report is a long-detention time activated-sludge system that is equipped with the normally used sludge-handling and dewatering equipment consisting of thickening and vacuum filtration units. Such a system is capable of handling a wide variety of wastewater containing biodegradable materials.

Activated Carbon Adsorption. Adsorption is a very complex physicochemical surface phenomenon in which chemical species in solution or colloidal form preferentially migrate and become attached to the surface of the adsorptive material. Granular activated carbon is the most commonly used adsorbent for wastewater treatment, primarily due to its pore structure which contains a very large adsorptive surface. In applying carbon adsorption to wastewater treatment, the wastewater is pumped through a bed of carbon contained within a vessel. When the adsorptive capacity of the carbon has been exhausted, the carbon is removed and then subjected to a thermal regeneration process which volatilizes and oxidizes the adsorbed material and reactivates the adsorptive surfaces in the carbon. The regenerated carbon is then returned to the vessel and put back into service. A certain percentage of carbon (4 to 12 percent) is lost during each regeneration, so replacement carbon must be regularly supplied.

Activated carbon adsorption is often used for the removal of organic matter that is partly or totally refractory to biological treatment and to effect further removal of organic matter. The activated carbon system in the cost module consists of a complete adsorption system plus provisions for carbon regeneration.

Heavy-Metals Removal. Heavy metals present in wastewater can either be in solution or in the form of solid particles. Due to the filtering action of soil, the heavy metals of principal concern with respect to ground-water contamination from impoundments are those that are in the soluble phase.

A variety of processes are available for removing heavy metals from wastewater. The most widely used processes are precipitation and settling. Most heavy metals exhibit very low solubility under alkaline conditions, and the addition of lime, soda ash, or other alkaline substances to a wastewater containing heavy metals will cause a large fraction of the metals to precipitate from solution as complex metal hydroxides and carbonates. Metallic sulfides are also quite insoluble, and hydrogen sulfide or sodium sulfide are sometimes used in metal-removal processes. The precipitated metallic compounds initially form very fine colloids which must be agglomerated into larger particles before they can be settled out and removed as a sludge. For this reason, coagulants such as alum and synthetic organic polyelectrolytes are often added to the wastewater along with the alkaline substances.

Conventional solids recirculation clarifiers are generally used for the settling of the metallic precipitates. The precipitated material is removed from the clarifier as a wet sludge and usually is subjected to dewatering by means of centrifugation, vacuum filtration, or filter pressing prior to ultimate disposal. Depending on the metals to be removed, the efficiency of the specific process configuration, and the presence of certain interfering organic substances (which can form metal-organic complexes that are difficult to precipitate), it is possible to produce an effluent with metallic ion concentrations of as low as 0.5 to 2.0 mg/l. In addition to removing heavy metals, alkaline precipitation can also be used for the removal of phosphate and fluoride ions.

The ultimate disposal of metallic hydroxide and metallic carbonate sludges deserves careful consideration. When these substances are exposed to even mildly acidic conditions (pH 4 to 5), a significant amount of metals can be resolubilized and potentially cause renewed contamination problems.

Dissolved-Solids Removal. Wastewater contains a wide range in type and concentration of TDS. Depending on the chemical composition of the wastewater, some of the dissolved-solids constituents may consist of man-made contaminants, and others may consist mainly of naturally occurring dissolved inorganic salts. To some extent, the previously described biological treatment, carbon adsorption, and heavy metals-removal processes do remove a certain amount of TDS, but the removal is intended for specific chemical constituents.

The removal of dissolved solids is usually directed toward wastewater containing high concentrations (over 5,000 mg/l) of inorganic dissolved solids, such as the ions of sodium, potassium, calcium, chloride, sulfate, and bicarbonate. Removal of such highly soluble species is exceedingly difficult and relatively expensive. Technology similar to desalination technology must be employed, and the disposal of the salts removed from the wastewater can be a significant problem.

For the purpose of calculating costs for the removal of high concentrations of dissolved solids, evaporation techniques have been selected in this study. Vapor recompression evaporators are to be considered for the smaller systems, while multi-stage flash evaporators are more applicable to larger systems. Both types of evaporators can effect a 30:1 concentration ratio. The concentrated brine from either system is then sent to a wiped film evaporator where the final portion of water is evaporated, leaving a salt residue. The salt residue, which is still highly soluble, must be disposed of in a protected disposal site such as another lined impoundment.

Treated Water Discharge System. After being treated, the water may be discharged into either a surface-water body or back into the aquifer. The choice usually depends on the proximity of the nearest stream. Water can be returned to aquifer systems through an injection well, by seepage from a lagoon, or by landspreading. For the purpose of providing cost estimates, it is assumed that a surface-water discharge system consisting of a pumping station plus a generous length of sewer pipe is to be employed.

Indirect Methods

The following two techniques can be used in places where a ground-water supply is already extensively contaminated. These techniques would not be acceptable generally as a control strategy for the installation of a new impoundment.

Alternative 9 - Development of a New Source of Water Supply in an Uncontaminated Area

Even after the source of contamination is removed, it may take many years for contaminated ground water to be flushed out naturally from an aquifer so that it no longer affects nearby water-supply wells. During that period, the users of the contaminated ground water may have no other choice than to obtain a supply of water elsewhere. Often, this requires construction of an entirely new water-supply system consisting of a well field, a water-treatment plant (if needed), a water-storage reservoir, and water-transmission lines.

Alternative 10 - Treatment of Contaminated Ground Water Prior to Use

In places where the level of ground-water contamination is not prohibitively high, it may be possible to install additional treatment steps at a water-treatment plant to reduce the concentration of contaminants to an acceptable level. The type of treatment will, of course, depend on the specific contaminants that must be removed. If the levels of contamination exceed the ability of the treatment steps to reduce them to an acceptable degree, this technique cannot be used. It is usually not feasible to treat highly contaminated water supplies, partly due to economics and partly due to the inability of assuring a continuous supply of water that meets drinking-water standards.

COST RELATIONSHIPS

General Approach

Capital and operating cost relationships are explained in detail in Section XII, Appendix D for each of the contamination-prevention techniques previously described. The cost relationships are in modular form, so that if combinations of two or more techniques are required, the capital and operating costs for the combination are merely the sum of the capital and operating costs of the individual components. The costs are given as a function of the characteristic size. Depending on the specific prevention technique, these are given in terms of impoundment horizontal surface area, area of an impoundment's underground perimeter, or (for wastewater treatment alternatives) in terms of the volumetric flow rate of contaminated water to be treated.

Because the costs given in Appendix D are general rather than site-specific, certain bases and assumptions have been used to reflect the physical factors most likely to be encountered in typical situations. The costs for the construction-intensive alternatives, such as liners and cutoff walls, are not heavily influenced by economy-of-scale effects (above a certain minimum size). For example, once equipment is mobilized, the cost of installing a layer of bentonite clay becomes a rather linear function of the area that must be covered. However, the cost of a sophisticated wastewater-treatment system such as a complete carbon adsorption and regeneration unit is quite equipment-intensive. That is, both its capital and operating costs are strongly influenced by economy-of-scale effects in that a large system can treat a unit of water much less expensively than a small system. For this reason, some of the costs have been expressed simply in terms of cost per unit of size, and others are presented in the form of non-linear cost curves.

Cost Implications

It was not feasible in this study to attempt to develop overall cost estimates for coping with leaky impoundments on a national basis because of the wide variability in hydrogeologic settings, dimensions of impoundments, the nature of the impounded wastes, and the lack of specific information on the number of impoundments that require remedial actions. However, an example of how costs could be determined for a single hypothetical leaky impoundment, using the cost modules, is given at the end of Appendix D. It was assumed that the impoundment contained a heavy metals-bearing sludge and that both a ground-water collection system and a treatment unit would be needed to alleviate the ground-water contamination problem. The estimated total capital investment for the control system is $638,000.

Obviously, the cost of remedial actions for each leaky impoundment would have to be estimated on a site-specific basis. Nevertheless, it seems clear that the cost of implementing remedial actions for large numbers of leaky impoundments on a national basis would be very high. It should also be kept in mind that impoundments that permit seepage to ground water are only one of many potential sources of ground-water contamination. Consequently, a national effort to completely protect the quality of ground water against all forms of contamination undoubtedly would be many times greater than that for impoundments alone.

SECTION IX

STATE REGULATORY CONTROLS

AGENCY ORGANIZATION AND AUTHORITY

Legislative Basis

Most of the numerous State agencies (Tables 10 and 11) responsible for the protection of ground-water quality have promulgated regulations relating to surface impoundments, largely on the basis of liberal interpretations of the intent of State law rather than on specific statutory directives. In general, the emphasis to date has been mainly on control of impoundments associated with point-source discharges to surface waters, through issuance of State or Federally administered NPDES (National Pollution Discharge Elimination System) permits.[1)] In addition, some type of permit or certificate, generally with only minimum requirements for ground-water quality protection, if any, is issued in many States for various types of non-discharging impoundments, such as evaporation or seepage ponds. Moreover, virtually no control or surveillance is exerted over abandoned impoundments. Passage of Federal laws such as SDWA (Safe Drinking Water Act, P.L. 93-523) and its amendments and RCRA (Resource Recovery and Conservation Act, P.L. 94-580) is beginning to stimulate new regulatory responses from State legislatures and agencies.

State laws in a number of States give the principal regulatory agency the authority to deal directly with any activity potentially endangering ground-water quality. For example, the Maryland statute directs the Maryland Water Resources Commission to regulate activities likely to pollute,[2)] and Pennsylvania's Clean Streams Law mentions the need to control potentially polluting activities.[3)] In each case, the responsible agency has proceeded to develop fully operational wastewater discharge control programs designed to protect both surface-water and ground-water quality.

Similarly, the Michigan Water Resources Commission has issued regulations to protect ground-water quality from contamination by seepage from surface impoundments, despite the fact that the Michigan Water Resources Commission Act does not specifically mention ground water except by definition of the waters of the State. However, the law explicitly directs the Commission to act through the requirement that the Commission "have control over any waters of the State and the Great Lakes."[4] A summary prepared by the Commission, describing its responsibilities under the act, interprets this to mean "control of pollution of any surface or underground waters of the State and the Great Lakes."

In Montana, by contrast, existing controls over discharges to pits, ponds, and lagoons stem directly from State law. The Montana Revised Code (Sec. 69-4804) specifies that the law, including permit requirements, applies to "drainage or seepage from all sources including that from artificial privately owned ponds or lagoons, if such drainage or seepage may reach other State waters in a condition which may pollute the other State waters."

Institutional Framework

Institutional responsibility for control of surface impoundments by States is distributed among a wide range of agencies, depending on the types of wastes and methods of discharge. For example, in many States, the Health Department has primary responsibility for the regulation of municipal waste discharges impacting public-water supplies, and a broader based environmental agency administers regulations to control industrial and other waste discharges. The mechanism for interagency coordination is usually through a policymaking resources commission or board composed of representatives of various State agencies, including Oil and Gas Boards, Mining Departments, Water Resources Agencies, Parks Departments, and Agriculture Departments.

In Indiana, the State Board of Health has reorganized the procedures and responsibilities of its Water Pollution Control Division to provide a specific method of coordinating projects that require the input of several Sections.[5] The Permits and Approval Section has been designated as the unit responsible for issuing NPDES permits, confined feedlot approvals, land-application approvals, and construction and operation permits. A total of 11 staff positions are assigned to this category. The technical aspects of facilities approval are handled by a staff of six sanitary engineers in a Construction Plan Review Section. The Facilities Inspection Section is responsible for investigating water-pollution complaints and making other inspections required by water-pollution control laws and regulations; this section is designed to operate with 15 staff members. Legal support is provided to the Water Pollution Control Division by four staff attorneys.

Passage of the Oklahoma Controlled Industrial Waste Disposal Act in 1976 created the Controlled Industrial Waste Management Section within the State Board of Health.[6] Responsibilities of this Division include development of rules and regulations for the management of wastewater processing facilities and disposal sites. Applicable regulations proposed after passage of the law provide increased control over types of wastes that may be discharged and the design of land-disposal sites, including impoundments.

The Waste Management Section is required to prepare "for adoption by the State Board of Health a list of materials designated as controlled industrial wastes," together with rules, regulations, and minimum standards for the processing and disposal of these materials. Generally, if the wastes to be controlled are toxic and/or hazardous, a permit is required for the construction of processing facilities for disposal of these wastes.

The Waste Management Section will also issue operating permits for the facilities, with the permittee responsible for provision of liability insurance of not less than $100,000 and not more than $500,000. The actual amount of the insurance for each facility must be equal to twice the value of real property situated within 1 mi (1.6 km) of the facility or site. The Waste Management Section is also instructed by the law to require monitoring systems and liners for any ponds associated with disposal of controlled wastes.

Montana is representative of those States that have recently passed legislation or are developing rules and regulations, governing disposal of hazardous wastes and control of facilities receiving these materials. Generally speaking, laws of this type are applicable to many kinds of industrial wastewater discharges to impoundments because the materials are defined as "solid or hazardous wastes" without reference to consistency. As of July 1, 1977, the Montana Solid Waste Management Act will govern the disposal of solid or hazardous waste and will require permits for all phases of operational facilities. The new law requires the Department of Health and Environmental Sciences to: (1) obtain the approval of local health offices before issuance of disposal permits; (2) establish and operate hazardous waste-management facilities for treatment and storage of wastes and spills; (3) establish monitoring procedures; and (4) protect public health.[7] This law and the previously discussed Oklahoma statute illustrate the manner in which some States are responding to Federal waste-management requirements.

The Idaho Department of Health and Welfare published regulations applicable to surface impoundments in January 1977,[8] which, following hearings, were withdrawn by the State Legislature. At present, the Department is seeking to reinstate the less stringent 1973 regulations and is proceeding with a permit system for impoundments based on the Idaho Environmental Protection and Health Act.

In Montana, the Board of Health and Environmental Services writes regulations to be administered by the Water Quality Bureau, but the Department of National Resources is primarily responsible for allocation and administration of water rights. Historically, some of the activities controlled by this Department may affect the regulations of the Water

Quality Bureau, requiring close liaison between the two units. The Mining Department in the Montana State Lands Office writes regulations pertinent to mining operations and confers with the Waste Quality Bureau prior to issuance of a discharge permit or in the event of water-quality problems.

Permitting Systems

Waste impoundments may be permitted under Federal or State controls or a combination of both. However, a review of State permit systems shows a wide range in requirements from very generalized to very detailed. Twenty-eight States (Table 10) have been authorized by EPA to administer NPDES permit programs for controlling waste discharges mainly to navigable waters. States on the non-approved list also have developed some form of State discharge permit system applicable to control of wastewater impoundments. Although they lack EPA authorization to administer and enforce the program, a number of these States including Texas, Utah, and Maine are active participants in the program. States without NPDES authorization commonly operate a State Pollutant Discharge Elimination System (SPDES) similar to the Federal system.

One of the principal results of the NPDES approach to water-pollution control has been the provision of structural uniformity to those State statutes and regulations which have been amended to incorporate the requirements of the Federal program. The Federal Water Pollution Control Act applies to "navigable waters." State laws, however, typically apply to all waters of the State, including ground water. The lack of clear direction as to the applicability of the NPDES program to ground water resulted initially in many States confining discharge requirements to those facilities having a direct impact on surface-water quality.

In a "Water Quality Strategy Paper" issued in 1974,[9)] the EPA addressed the lack of provision for ground-water protection in the existing NPDES procedure. The strategy identified specific controls on activities affecting ground water and advised that EPA would establish ground-water

Table 10. SUMMARY OF STATE, INSTITUTIONAL, AND REGULATORY CONTROLS FOR MUNICIPAL, INDUSTRIAL, AND AGRICULTURAL IMPOUNDMENTS

State	Principal Regulating Agency[1]	Types of Waste Impoundments and Controls				
		Discharging - NPDES[2] Administered by		Non-Discharging[3]		
		EPA	State	Municipal[4]	Industrial[4]	Agricultural[4]
Alabama	Water Improvement Comm.	X		P	P	P
Alaska	Dept. Environmental Conservation	X		P	P	P
Arizona	Dept. Health Services, Bureau Water Quality Control	X		AR	AR	AR
Arkansas	Dept. Pollution Control and Ecology	X		P	P	P
California	State Water Resources Board		X	P	P	P
Colorado	Dept. Health, Water Poll. Control Div.		X	P	P	P
Connecticut	Dept. Environmental Protection		X	P	P	P
Delaware	Dept. Nat. Resources and Env. Control		X	P	P	P
Florida	Dept. Environmental Regulation	X		P	P	P
Georgia	Dept. Nat. Resources, Env. Protec. Div.		X	P	P	P
Hawaii	Dept. Health, Env. Protec. and Health Services Div.		X	AR	AR	AR
Idaho	Dept. Health and Welfare, Env. Div.	X		P	P	P
Illinois	Env. Protection Agency	X		P	P	P
Indiana	Board of Health, Water Poll. Control Div.		X	P	P	P
Iowa	Dept. Environmental Quality	X		P	P	P
Kansas	Dept. Health and Env., Div. Env.		X	P	P	P
Kentucky	Dept. Nat. Resources and Env. Protec.	X		P	P	P
Louisiana	Stream Control Comm.	X		P	P	AR
Maine	Dept. Env. Protec., Bureau Water Quality Control	X		O	O	O
Maryland	Dept. Nat. Resources, Water Resources Admin.		X	P	P	P
Massachusetts	Water Resources Comm.	X		P	P	P
Michigan	Dept. Nat Resources		X	P	P	P
Minnesota	Pollution Control Agency		X	AR	AR	P
Mississippi	Air and Water Poll. Control Comm.		X	P	P	P
Missouri	Dept. Nat. Resources Div. Env. Qual.		X	P	P	AR
Montana	Dept. Health and Environmental Sciences		X	P	P	P
Nebraska	Dept. Environmental Control		X	P	P	P
Nevada	Dept. Human Resources		X	P	P	P
New Hampshire	Water Supply and Poll. Control Comm.	X		P	AR	AR

Table 10 (Continued). SUMMARY OF STATE, INSTITUTIONAL, AND REGULATORY CONTROLS FOR MUNICIPAL, INDUSTRIAL, AND AGRICULTURAL IMPOUNDMENTS

State	Principal Regulating Agency[1]	Types of Waste Impoundments and Controls				
		Discharging - NPDES[2]		Non-Discharging[3]		
		Administered by EPA	Administered by State	Municipal[4]	Industrial[4]	Agricultural[4]
New Jersey	Dept. Environmental Protection	X		AR	AR	AR
New Mexico	Water Qual. Control Comm., Env. Improv. Agency	X		P	P	P
New York	Dept. Env. Conservation, Div. Pure Waters		X	P	P	P
North Carolina	Dept. Nat. and Econ. Resources		X	P	P	P
North Dakota	Dept. Health, Env. Health and Eng. Serv.		X	P	P	P
Ohio	Environmental Protection Agency		X	P	P	P
Oklahoma	Water Resources Board	X		P	P	P
Oregon	Dept. Environmental Quality		X	P	P	P
Pennsylvania	Dept. Env. Resources, Bureau Water Qual.	X		P	P	P
Rhode Island	Div. Water Supply and Poll. Control	X		P	N	N
South Carolina	Dept. Health and Environmental Control		X	P	P	P
South Dakota	Dept. Environmental Protection	X		P	P	P
Tennessee	Dept. Public Health, Water Qual. Control	X		P	P	P
Texas	Dept. Water Resources	X		P	P	P
Utah	Dept. Soc. Serv., Div. Health, Bureau Water Quality	X		P	P	P
Vermont	Agency Env. Conservation, Env. Eng. Div.		X	P	P	P
Virginia	Water Control Board		X	P	P	P
Washington	Dept. Ecology, Office Water Programs		X	P	P	P
West Virginia	Dept. Health	X		AR	AR	AR
Wisconsin	Dept. Nat. Resources, Div. Env. Protec.		X	P	P	P
Wyoming	Dept. Env. Qual., Water Qual. Div.		X	AR	AR	AR

1 Coordinates with Departments of Health and Water Resources in many States.

2 Permitted as individual impoundments or as parts of larger systems discharging to streams; under National Pollution Discharge Elimination System administered by EPA or State, Includes municipal and industrial types and feedlots.

3 No discharge to streams; generally under State control; includes feedlots under a certain capacity; and seepage, evaporation, holding, and storage types of impoundments.

4 AR, Agency review; N, none; O, other; P, permit or certificate.

criteria for water-treatment works it funded. In addition, EPA set forth a policy which explained its determination to:

1. Provide States with the maximum incentive to establish ground-water regulatory programs on their own, including monitoring procedures.

2. Structure NPDES permit inputs to require dischargers changing to a land-disposal procedure to submit to conditions designed to minimize damage to underground water.

3. Adhere closely to the Federal Water Pollution Control Act requirement that any area-wide planning process to control disposition of residual waste generated in the area, including surface and subsurface disposal, provides for protection of ground-water quality.

The impact of the EPA strategy on State permitting requirements for non-discharging impoundments is unclear. However, review of State regulations shows that the States generally are moving toward increased control of these facilities as they become more aware of their potential for ground-water contamination. A useful approach is through promulgation of rules and regulations requiring the issuance of discharge permits that incorporate ground-water quality parameters based on the requirements of The Safe Drinking Water Act. For instance, in New Mexico a discharge plan requires: "A description of methods and conditions, including any monitoring and sampling requirements, for the discharge of effluent or leachate which may move directly or indirectly into ground water."[10] The requirement for a ground-water discharge plan is applicable to both industrial and municipal discharges, and the permit application is specific with regard to technical data to be submitted.[11]

Delaware, which administers the NPDES program, has developed its regulations to include prohibition against discharge of any pollutant from a point source, either directly or indirectly, into "surface or ground water"[12] without a permit from the Department of Natural Resources. All waste-treatment impoundments are included as activities requiring construction and operation permits. The State regulations also include the NPDES provision prohibiting any discharge of liquid wastes which is in conflict with areawide waste-treatment management plans approved under the Federal Water Pollution Control Act.

The Indiana Stream Pollution Control Board requires a special permit for the operation of "ground adsorption systems," defined as "any lagoon or subsurface adsorption field where underground percolation occurs and from which there is no discharge of runoff." The program, administered by the Board's Division of Water Pollution Control, was established to "effectively control water-pollution control facilities and their discharges that are not controlled under the Federal National Pollutant Discharge Elimination Program created under the Federal Water Pollution Control Act Amendments of 1972."[13]

Owners and operators of any ground adsorption system that does not discharge to a waterway must obtain a ground adsorption permit. However, if the system discharges to a waterway, the applicant is instructed to apply for an NPDES permit.

Michigan's Discharge Permit Application requires the applicant to stipulate the distance between existing private and municipal wells and the proposed waste-treatment facility. The State water-pollution control law requires every industrial or commercial entity which discharges liquid wastes into surface water or ground water to have these facilities supervised by a certified operator. The applicant is advised that he will be required to submit an application for certification of the operator prior to start of the proposed facility.[14]

The Wisconsin Pollutant Discharge Elimination System (WPDES) establishes effluent limitations, monitoring requirements, and other protective measures as a condition of issuance of a permit to construct a surface impoundment. The Wisconsin Department of Natural Resources can also impose a number of additional limitations, on a case-by-case basis, as part of the requirements for issuance of a permit. These include options to: (a) require monitoring of parameters other than those stipulated by the permit application, (b) increase frequency of ground-water sampling, and (c) impose more stringent limitations on the quantity or concentration of substances discharged through impoundments.[15] Wisconsin is also authorized by EPA to administer the NPDES program.

Permit systems developed by many States generally give some recognition to the importance of the following items:

1. Protecting ground water from contamination. The permit requirements, however, differ from State to State with regard to the type and amount of detailed information to be supplied in an application and the degree of surveillance and control to be exercised by regulatory agencies.

2. Evaluating the location of ponds with respect to water supplies and other facilities subject to contamination based on consideration of soil porosity and rock formations.[16] Specific design requirements may include infiltration tests and soil borings to determine surface and subsurface soil characteristics in the immediate area of a pond. Soils must be relatively impermeable or linings may be required to prevent excessive liquid loss due to percolation or seepage.

3. Permitting use of shallow sludge-drying lagoons only where the soil is reasonably porous and the bottom of the lagoon is located at least 18 in (46 cm) above the maximum level of the water table. Grading of surrounding areas to prevent surface water from entering the lagoon is also recommended.[17] Pennsylvania requires that geologic evaluation of the site satisfy a set of State "geocriteria." Impoundments are not

permitted unless it can be shown that they are "...structurally sound, impermeable, protected from unauthorized acts of third parties, and maintain a 2-ft (0.6 m) freeboard."[18)]

4. Constructing embankments and dikes with impervious materials compacted sufficiently to form a stable structure, accompanied by removal of vegetation from the area. State regulations generally apply to both municipal and industrial impoundments, with specific physical construction details added. Discharge of industrial wastewater usually involves listing of constituents of the wastes as part of the permit application.

Personnel and Enforcement

Although the rules and regulations appear to provide for some measure of ground-water quality protection in many States, the pollution-control agencies are commonly confronted with workloads far beyond the capacities of their present staffs. Insufficient financial resources is a common complaint. In most agencies, geology and engineering are the principal professional disciplines of pollution-control employees, with support provided by technicians skilled in a variety of field, laboratory, and office tasks. Pennsylvania's Bureau of Water Quality Management is an example of a well organized staff that includes 16 geologists involved in ground-water protection and pollution investigation. Eleven of these staff members work out of regional offices.

Few State pollution-control agencies are able to assign staff personnel to work exclusively on surface impoundments and thereby maintain adequate surveillance over these facilities. For instance, North Dakota reported 60 informal actions involving discharges to impoundments since July 1975. The organizational chart for the State shows 1 person responsible for discharge permits and 12 staff members assigned to water-pollution control. An additional seven professional employees are assigned to waste treatment. The work assignment in this State also typifies the situation in many other agencies where staff members assigned to a specific division or bureau are required to work on more than one State program element. A review of selected State organizational charts during 1976-1977 shows the following ranges in sizes and types of staffs:

Arizona. Three persons in enforcement and two more assigned to implementation of "The Safe Drinking Water Act."

Colorado. Four professional staff members assigned to the Division of Monitoring and field studies. There are 14 engineers in the engineering section, and 3 engineers whose responsibilities involve water-quality management planning.

Connecticut. Twenty persons assigned to enforcement out of a total staff of 70.

Kansas. Three professional staff members assigned to enforcement. Twelve district engineers and technicians located throughout the State.

Maryland. Six persons assigned to enforcement and a permit staff of 7 persons, whose duties are directly related to a specific element in the State's waste-management and water-supply program.

Minnesota. Twenty persons assigned to various phases of water-quality enforcement.

New Jersey. Forty-three staff members, mostly engineers, assigned to the compliance monitoring and enforcement division.

Oregon. Six professional staff members assigned to duties in the Office of Waste Water. The organizational chart indicates assignment of one person to the Water-Quality Division and one person responsible for ground-water supplies.

Typically, State regulations provide a number of opportunities for public hearings, including the decision to promulgate or amend regulations; provision for protests against permitting restrictions or denial of permits; and hearings called at the discretion of the agency to respond to public protest concerning the siting or operation of a particular facility. The range in procedures is discussed in more detail in the section "Controls by Selected States."

The legal procedures for dealing with violations of regulations differs slightly from State to State. A letter of warning or request to "show cause" usually follows informal contact with the alleged violator. If this approach fails, the agency is authorized to invoke regulatory requirements for remedial actions, usually in staged fashion, with a deadline set for final compliance. Actions of this type may involve the office of the State Attorney General and may result in fines ranging from $1,000 to $25,000 per day for each day the violations persist, or the courts may order imprisonment and/or a fine. Some States revoke operating permits for repeated violations or failure to comply with corrective orders.

TECHNICAL DESIGN CRITERIA

Municipal and Industrial Impoundments

Examples of specific impoundment design guidelines or requirements by selected States are summarized below. In many States these requirements relate mainly to construction or operational standards that have little or no bearing on prevention of ground-water contamination.

Missouri. The "Guide for the Design of Municipal Waste Stabilization Lagoons in Missouri" stipulates that:

> "The ability to maintain a satisfactory water level in the lagoons is one of the most important aspects of design. Removal of coarse top soil and proper compaction of subsoil improves the water-holding characteristics of

the bottom. Removal of porous areas, such as gravel or sand pockets, and replacement with well-compacted clay or other suitable material may be indicated. Where excessive percolation is anticipated, sealing of the bottom with a clay blanket, bentonite, asphalt, or other sealing material should be given consideration. A maximum percolation rate of 0.25 in/day (0.6 cm/day) for the finished lagoon floor is included in the specifications for construction."[19]

Tennessee. The "Outline of Engineering Requirements" calls for: (a) location of wastewater oxidation ponds and lagoons 1,000 ft (305 m) or more from homes, main roads, and business establishments; (b) prohibition of entry of surface water into impoundments; (c) a minimum top width of 8 ft (2.4 m) for embankments; (d) preference for circular or square design; (e) 2 ft (0.6 m) of freeboard for ponds of 3 acres (1.2 ha) or less, and at least 3 ft (0.9 m) of freeboard for ponds over 3 acres (1.2 ha); and (f) prefilling of the lagoon prior to operation and installation of a water-level gage.[20]

New Hampshire. (a) Minimum normal liquid depth in impoundments to be maintained at 3 ft (0.9 m), maximum depth at 5 ft (1.5 m), and lowering of depth during winter operation before formation of ice; (b) aerated lagoons must be designed to remove 85 percent of BOD under winter conditions; (c) ponds must be rectangular in shape, and (d) a buffer zone of uninhabited land must be maintained for 600 ft (183 m) in all directions from the pond edge.[21]

Washington. Guidelines for settling ponds stipulate: (a) each impoundment must provide 1 1/2 hrs of detention time at maximum backwash rate, plus storage space for solids, and (b) sludge entering dewatering ponds should not consist of more than 8 to 10 percent solids.[22]

Minnesota. "Criteria for Sewage Stabilization Ponds" specifies that: (a) the permeability of the pond seal must be as low as possible and seepage loss should not exceed 500 gal/acre/day (4.7 cu m/ha/day); (b) specifications for siting and construction are based upon a testing program; (c) ground-water monitoring wells or lysimeters are required around the perimeter of pond site; and (d) monitoring is determined on a case-by-case basis depending on proximity of private water supplies and on maximum ground-water levels.[23)]

Oil and Gas Impoundments

Regulation and surveillance of discharges to impoundments of wastewater associated with the extraction of oil and gas on private or State lands are usually part of the responsibility of a State Oil and Gas Board or Commission (see Table 11). Generally, the degree to which these boards are required to cooperate with State water-pollution control agencies is dictated by the operational rules of the State Water Resources Commission or other water-pollution control policymaking unit. Commonly, the Oil and Gas Commission or Board is represented in the membership of the policymaking unit, which provides a means of coordination with other agencies in matters relating to control of water pollution. Typical coordinating agencies are the Geological Survey, the Health Department, and the Department of Water Resources.

Nearly all oil- or gas-producing States (Table 6) allow storage pits and ponds for handling produced water; requirements range from temporary or emergency use only to evaporation use only. Most States stipulate that the impoundments must be constructed in a clayey soil or have a lining of some type. Generally, however, the regulations are not specific with regard to the type of lining required. Permit provisions relating to lining are decided on a case-by-case basis and generally are dictated by the results of soil borings. Louisiana is one of the few States that does not have a general requirement for lining.

The following summary, by selected States, illustrates the range of regulatory requirements for impoundments associated with oil and gas extraction:

Table 11. SUMMARY OF STATE, INSTITUTIONAL, AND REGULATORY FRAMEWORK FOR IMPOUNDMENTS[1] ASSOCIATED WITH OIL AND GAS EXTRACTION

State	Principal Regulating Agency	Cooperating Agencies	Type of Impoundments and Control[2]: Brine Disposal Pits and Ponds	Separator Pits and Ponds	Emergency Pits and Ponds	Remarks
Alabama	Oil and Gas Board	Water Improvement Comm.	NA	NA	P	Evaporation pits allowed with impervious lining only.
Alaska	Dept. Nat. Resources, Oil and Gas Conservation Div.	Dept. Health; Dept. Env. Conservation	-	-	P	
Arizona	Oil and Gas Comm.	Dept. Health	AR	AR	AR	Evaporation pits allowed in impervious soil only or where lined.
Arkansas	Oil and Gas Conservation Comm.	Dept. of Pollution Control and Ecology	P	N	N	
California	Dept. Conservation, Oil and Gas Div.	State Water Resources Bd., Dept. Fish and Game	P	-	-	Evaporation pits with impervious lining and percolation pits in certain areas, by permit.
Colorado	Dept. Nat. Resources, Oil and Gas Conservation Comm.	Div. Game, Water Pollution Control Comm., Div. Water Resources, Geological Survey	P	NA	P	Storage pits must be lined.
Florida	Dept. Env. Regulation	Dept. Nat. Resources	NA	NA	NA	Temporary storage or disposal allowed in pits under permit.
Idaho	Dept. Lands, Bur. Minerals	------	P	-	-	No record of oil and gas production.
Illinois	Dept. of Mines and Minerals, Div. of Oil and Gas	Mining Board, Pollution Control Board	P	-	-	Evaporation pits with impervious lining or soil.
Indiana	Dept. Nat. Resources, Oil and Gas Division	Bd. Health, Stream Pollution Control Board, Geol. Survey; Industrial Waste Section	P	P	P	Water-flooding storage ponds under permit; evaporation pits with impervious lining only.
Kansas	State Corporation Comm. Oil and Gas Conserv. Div.	Dept. Health; Geological Survey	P	P	AR	Brine to be disposed of after shutdown of impoundment.
Kentucky	Dept. Mines and Minerals Oil and Gas Div.	Dept. Fish and Wildlife; Water Pollution Control Comm.	N	N	N	
Louisiana	Dept. Conservation	Geological Survey	AR	AR	AR	Liners not required.
Maryland	Geological Survey	Dept. Water Resources	N	-	-	No oil and gas production.
Michigan	Dept. Nat. Resources, Oil and Gas Section	------	AR	-	P	No oil storage allowed in earthen ponds.
Mississippi	Oil and Gas Board	Air and Water Pollution Control Comm.	P	P	P	Salt-water disposal pits must be impervious. Permits renewed at least every two years.
Missouri	Oil and Gas Council	Geol. Survey; Div. of Commerce and Industry; Public Service Comm.; Water Pollution Board, Univ. Missouri	N	N	N	State Geologist acts as administrator for Oil and Gas Board.
Montana	Dept. Nat. Resources and Conserv., Oil and Gas Div.	Board Health; Water Resources Board	P	-	-	Evaporation pits allowed under permit where soil is impervious or liner is used.

Table 11 (Continued). SUMMARY OF STATE, INSTITUTIONAL, AND REGULATORY FRAMEWORK FOR IMPOUNDMENTS[1] ASSOCIATED WITH OIL AND GAS EXTRACTION

State	Principal Regulating Agency	Cooperating Agencies	Type of Impoundments and Control[2]: Brine Disposal Pits and Ponds	Separator Pits and Ponds	Emergency Pits and Ponds	Remarks
Nebraska	Oil and Gas Conservation Comm.	Dept. Health; Geological Survey	P	P	P	Unlined pits allowed only where soil is impervious.
Nevada	Oil and Gas Conservation Comm.	------	AR	AR	AR	Evaporation pits allowed in impervious soil only.
New Mexico	Oil Conservation Comm.	Environmental Improvement Agency; Dept. of Fish and Game; Dept. of Agriculture	P	NA	AR	Disposal in impervious lined pits may be allowed. Temporary emergency disposal for 30 days may be authorized.
New York	Dept. Env. Conservation, Bur. Mineral Resources	Div. of Quality Services; Div. of Pure Water	P	P	P	Storage ponds must be approved, SPDES-State permit program.
North Dakota	Indus. Comm., Geol.Surv.	------	P	-	N	Storage ponds allowed if impervious and under permit.
Ohio	Dept. Nat. Resources, Oil and Gas Div.	------	NA	NA	-	Storage ponds must be impervious.
Oklahoma	Corp. Comm., Oil and Gas Conserv. Div.	Dept. Pollution Control	P	P	AR	Earthen pits allowed for storage or disposal if constructed with impervious linings or seals.
Oregon	Dept. Geology and Mineral Industries	------	P	P	P	No commercial oil and gas production.
Pennsylvania	Dept. Env. Resources, Oil and Gas Div.	Dept. Health	P	P	P	
South Dakota	Oil and Gas Board	Dept. Health	P	AR	-	Evaporation pits allowed, if impervious.
Tennessee	Oil and Gas Board	Dept. Health	AR	-	-	Brine disposal into pits allowed, if approved. Remove oil.
Texas	Railroad Comm., Oil and Gas Div.	Dept. Water Resources, Dept. Parks and Wildlife; Dept. of Health	P	P	P	Evaporation pits with impervious lining only. Emergency pits unlined except where a problem may exist.
Utah	Dept. Nat. Resources, Div. Oil and Gas Conservation Div.	Water Pollution Comm.; Geological Survey	P	P	-	
Virginia	Dept. of Labor and Industry, Div. Mines and Quarries	Water Control Board	-	-	-	No oil storage allowed in earthen ponds.
Washington	Oil and Gas Conservation Comm.	Dept. Ecology	P	-	-	No record of oil and gas production.
West Virginia	Dept. Mines, Oil and Gas Div.	Dept. Nat. Resources, Div. Water Resources	-	-	-	No earthen pits allowed for ultimate disposal of salt water.
Wyoming	Oil and Gas Conservation Comm.	Dept. Environmental Quality	AR	AR	AR	Oil storage in earthen pits allowed only during emergency.

1 Mainly holding, storage, evaporation, and seepage types. Discharging impoundments generally prohibited, except under NPDES permit.
2 AR, Agency approval; N, no rules; NA, not allowed; P, permit or certificate.

Alabama. Alabama Oil and Gas Board Rule B-36 requires disposal of salt water and other fluids in an approved underground formation "as soon as practical or economically feasible after production is established in any field." Temporary storage is allowed in impervious pits.

Colorado. Storage pits must be lined. Permits are required for all pits except those used for temporary storage and disposal of substances produced in the initial completion and testing of wells. Provision exists for the establishment of special field or area rules; in this situation, all existing pits within the field or area have 180 days to comply with the standards set by the Oil and Gas Conservation Commission.[24)]

Illinois. Geological and engineering data are required in applications for permits for new impoundments. Sites must be underlain by clay hardpan. Old pits must have continuous walls to prevent flooding.[25)]

Indiana. Salt water or other wastes may be collected in pits underlain by impervious materials for one year. The Division of Oil and Gas in the Department of Natural Resources has the authority to allow storage beyond one year if it can be shown that pollution of surface water and ground water will not occur. Waste liquids must be kept at least 12 in (30 cm) below the top of the pit. The Department may order that production be discontinued, after a hearing, if the discharge is not properly impounded.[26)]

Michigan. General rules governing oil and gas operations, administered by the Michigan Water Resources Commission, require the State Geologist, acting as Supervisor of Wells, to approve all disposal facilities. Rule 602 calls for underground disposal of brines and use of earthen pits or ponds only with approval of the Supervisor.

Nebraska. Facilities requiring a "Retaining Pit Permit" stipulate that the pit should not be located within a natural surface drainage channel, should have an impervious foundation and sides, and should have a storage volume of at least three times the average daily inflow of fluids.[27)]

Feedlot Impoundments

State regulations governing animal feedlot operations typically are more stringent than the NPDES requirements for a point-source discharge.[28] State permitting usually applies to both large and small operations and, in some States, is based upon considerations of the ratio of animals to land area. Retention impoundments are the principal form of waste treatment. Most States can require additional treatment as a condition of permit issuance or renewal.

Iowa's feedlot regulations exemplify those of States with detailed regulatory provisions. This State, for example, makes a regulatory differentiation between permit requirements for open feedlots and for fully or partially enclosed confined operations, and requires that an open feedlot have a permit if beef cattle population exceeds 100 and lot area per animal is less than 600 sq ft (54 sq m). Confined feeding facilities are classified by the number of different species whose waste is discharged to a lagoon or holding basin, and a permit is necessary for beef cattle populations exceeding 20. The Iowa regulations also provide that, regardless of size, land-carrying capacity, or other specific provisions, all feedlots are subject to inspection if it is determined that a water-pollution problem may exist. Permits are required for new operations and expansion of existing facilities. A separate permit must be granted prior to construction, installation, or modification of a waste-storage and disposal system for a permitted facility. Information called for on the permit application includes an aerial photograph of the facility or construction site, which must show building and lot area, lagoons or waste-holding pits, direction of surface drainage from the site, location of wells and dwellings within 1,000 ft (300 m) of the site, adjacent land owned, and land area set aside for waste disposal.[29]

The Minnesota feedlot permit application requires similar site location details and also data concerning geologic conditions, soil types, ground-water elevations, and particulars about the effluent to be discharged. Minnesota prohibits location of a new livestock feedlot and its waste facilities within a floodway, within 1,000 ft (300 m) of a public park, in areas subject to the formation of sinkholes, in areas draining into sinkholes, or within half a mile of a concentration of 10 or more private residences.[30)]

Nebraska prohibits the location of a livestock waste pond within 100 ft (30 m) of any well used for domestic purposes, or within 1,000 ft (300 m) of a municipal water-supply well unless the operator can demonstrate that the pond will not result in contamination of ground water.[31)] Kansas regulates confined operations with 300 or more cattle, swine, sheep, or horses, housed at any one time, or any animal-feeding operation of less than 300 head using a lagoon for waste disposal. Retention ponds receiving animal wastes must "be capable of containing 3 in (7.5 cm) of surface runoff from the feedlot area, waste-storage areas, and all other waste-contributing areas."[32)]

The guidelines of the California State Water Resources Control Board for protection of ground water from disposal of animal wastes stipulate that a regional board may set requirements for discharges exceeding a 10-yr 24-hr storm. Retention ponds must be protected against overflow from stream channels during 20-yr peak stream flows for existing facilities and 100-yr peak stream flows for new facilities. Special sealants for retention ponds usually are not required where the ponds are constructed on sandy loams and finer textured soil materials such as silt and clay.[33)]

CONTROLS BY SELECTED STATES

This section contains descriptions of the regulations of several representative States applicable to the control of impoundments. Selection of States has been guided in part by an attempt to include those whose programs combine elements which, when taken together, provide a broad picture of the wide range in State regulatory controls and institutions.

California

Strong orientation toward local autonomy is the principal feature of California's water-management laws and regulations. Although the State Water Resources Board is the primary agency responsible for protection of water resources, nine regional water-quality control boards have broad discretionary powers, enabling them to develop locally specialized regulations. These regional boards have the authority to impose more stringent conditions, but must adhere to the requirements of the State Water Resources Board for disposal-site and waste classification.

The State Water Quality Control Act, the NPDES regulations, and the system of site and waste classification for disposal of wastes on land[33)] provide a legal basis for control of impoundments. The classification system, developed in response to a legislative instruction requiring regional water-quality control boards to approve sites suitable for the disposal of wastes on land, is based upon the geologic and hydrologic features of the disposal area and the capability of the site to protect surface-water and ground-water quality. Wastes are categorized according to the threat that they pose to water quality. The NPDES program developed in California incorporates this classification system, with the term "disposal site" defined as any place used for the disposal of solid or liquid wastes. The definition does not include any part of a sewage-treatment plant or point-of-discharge of sewage effluent or land drainage from pipes or ditches into waters of the State.

Neither the State Water Quality Control Act nor the NPDES regulations contains a specific definition of an impoundment. However, the definition of "waste" and "water-quality control," reinforced by the site and waste classification system, is construed to include impoundments.[34)]

"Waste" includes sewage and all other waste substances, liquid, solid, gaseous, or radioactive, associated with human habitation, or of human or animal origin, or from any producing, manufacturing, or processing operation of whatever nature prior to, and for the purposes of disposal. "Water-quality control" means the regulation of any activity or factor which may affect the quality of the waters of the State and includes the prevention and correction of water pollution and nuisance.

The disposal-site classification system includes three basic classes of sites:[35)]

1. Class I Disposal Sites - These are sites where ground-water and surface-water quality must be protected for all time against any hazard to public health and wildlife resources resulting from the disposal of wastes. The geologic framework of sites in this category must be capable of preventing infiltrating liquids from contaminating ground water or surface water. These sites must not be located over zones of active faulting or where other forms of geological change would impair the ability of natural features or artificial barriers to withhold contaminants from water. Leachate and subsurface flow into the disposal area must be contained within the site unless "other disposition is in accordance with requirements of the regional board." Manmade physical barriers such as liners must be installed and maintained in such a manner as to guarantee that waste, leachate, or gases will not contact usable water. These sites are subject to limits on the type and quantity of material entering the site, the concentration of material in the waste disposed of, and the volume present or remaining on the site after evaporation of fluids. A subdivision of this classification places a limit on the amount and type of Group 1 (see beyond) wastes that may be disposed of at such sites if the threat of inundation is greater than a 100-yr flood.

2. Class II Disposal Sites - These sites are divided into two subclasses, principally depending upon the depth to the water table. Class II-1 sites are those where geologic conditions prevent lateral and vertical infiltration of potentially contaminating fluids. At Class II-2 sites, such conditions may not exist, but a regional board may rule that use of artificial barriers, the depth to ground

water, or some other factor assures adequate protection for ground water beneath and adjacent to the site. At these places, the disposal area must be protected from washout and flooding and other potentially contaminating events such as infiltration of wastewater during site preparation and construction activities. Liquid wastes may not be discharged at separate ponding areas at these sites unless specific approval is granted by the regional board.

3. Class III Disposal Sites - These sites are judged suitable for the disposal of essentially insoluble, nondecomposable, inert solids such as demolition materials containing less than 10 percent of wood and metal, plasterboard, tires, and industrial wastes such as clay products, glass, inert slags and tailings, and scrap rubber. As these materials are thought to be least harmful to ground water, the siting requirements are the least stringent, and even marshy areas or pits and quarries may be found to be acceptable.

According to the State regulations, wastes may be solid, semi-solid, or liquid and may have characteristics requiring special handling, such as those relating to oils, acids, caustics, or toxic substances. These substances are divided into three major groups which in turn are further subdivided on the basis of municipal, industrial, or agricultural origin. The characteristics of these groups are described as follows:

1. Group 1 Wastes - These consist of, or contain, toxic substances which could significantly impair the quality of usable waters. The amount of the substance to be disposed of, its critical concentration in the receiving water, and its physical and chemical behavior must be considered. Toilet wastes, paint sludges, pumpings from grease traps, drilling muds, and chemical fertilizers are cited as examples of waste where quantity may be the factor determining categorization as either Group 1 or Group 2.

Saline fluids from water or waste-treatment and reclamation processes, community incinerator ashes, and toxic chemical toilet wastes are specified as examples of Group 1 wastes of municipal origin. Industrial wastes in this group include: brines, toxic or hazardous fluids such as spent cleaning fluids, petroleum fractions, chemicals, acids, alkalines, phenols, spent washing fluids, substances from which toxic materials can leach such as process ashes, chemical mixtures, and mine tailings and rotary drilling mud containing toxic materials. Group 1 agricultural wastes include pesticides and chemical fertilizers.

2. Group 2 Wastes - These consist of or contain chemical or biologically decomposable material that does not include toxic substances. Municipal and industrial wastes in this category include food-preparation or processing wastes, rubbish such as paper, cardboard, tin cans, cloth and glass, and inert construction and demolition materials. Sewage-treatment residues such as solids from screens and grit chambers, dewatered sludge, and septic tank pumpings are also included in this group. Provision exists for regional boards to place limitations on sludges if the water content is higher than 30 percent, or in the event that these sludges are judged to present a threat to water quality. Moist sludges require that the disposal site include barriers against leachate infiltration or be situated in an extremely dry region. Group 2 agricultural wastes include plant residues, manures, dead animals, and adequately cleansed pesticide containers.

3. Group 3 Wastes - These consist of materials which are entirely non-water soluble and nondecomposable inert solids including demolition wastes such as clay products, glass, inert slags, asbestos, and inert tailings and plastics. A discharger proposing to dispose of industrial wastes such as slag, tailings, or other process residues as Group 3 wastes may be required to prove that the wastes are substantially inert.

Prior to the disposal of wastes at a site that is new, has been enlarged, or for which a change in waste discharge is planned, the operator is required to file a report of waste discharge with the regional board. This report, leading to site and waste classification, is judged incomplete unless it has been approved and certified by all local agencies with jurisdiction in the proposed area.[36]

The discharger must provide details of disposal-site construction and operation relevant to the protection of water quality, a description of the waste materials involved, a map showing the boundaries of the site and waste-disposal areas, a general description of operations, detailed hydrological and geological data for the area, a description of plans for control of drainage, leachate, and gasses, and a plan for anticipated land use after termination of disposal operations. Although specific data requirements vary slightly, depending on the sensitivity of the site to ground-water contamination and the contaminating potential of the wastes, the general philosophy is that "the larger the disposal operation or the greater the possibility that water-quality problems may be created, the greater the detail required."

The regional boards require a description of land use within 1,000 ft (300 m) of the proposed waste-disposal site and notification 90 days prior to discontinuing the use of the site. This notification must describe methods and controls to be used to assure protection of the quality of surface water and ground water during final operations and describe any proposed subsequent use of the land. A report must be prepared by or under the supervision of a registered engineer or a certified geologist. The property owner has a "continuing responsibility for correcting problems which may arise in the future as a result of this waste discharge or water applied to this property during subsequent use of the land for other purposes."[33]

Monitoring programs are established on an individual site basis and may require inclusion of any or all of the following measures:[35]

1. Monitoring of local ground water and surface water considered to be within the area of influence of a disposal site. This measure requires collection of baseline data to indicate original conditions or effects caused by sources unrelated to the disposal site. The regulations observe that "these data may be important to the discharger because it may offer a basis to discount claims of degradation of water quality which may be filed later by other parties."

2. Routine surveillance to include a review of the adequacy of on-site drainage systems and other conditions, including settlement problems which may cause ponding of water, the amount of water applied to the disposal area, and the depth of cover material.

3. Maintenance of records of the depth to ground water beneath the disposal areas, with installation of piezometers or small-diameter wells in the disposal site at critical locations.

4. Monitoring of the integrity of liners used for water-quality protection. Seepage collection drains and sumps within hydraulic barrier installations should have continuous fluid-level measuring facilities to provide data on the effectiveness of the barrier.

5. Monitoring point locations selected on the basis of the characteristics of local ground-water and surface-water hydrology and site design. Generally, the disposer is required to collect samples upgradient and downgradient.

6. Analysis of selected constituents of the waste, usually including pH, electrical conductivity or TDS, chloride, hardness, and total alkalinity. Specialized monitoring is required at more sensitive sites for materials containing hazardous substances or metals.

7. Establishment of an identification system for individual disposal areas within sites receiving hazardous or toxic wastes.

Colorado

Water-pollution control in Colorado is administered by the Water Pollution Control Commission within the Colorado State Department of Health. The agency is required to coordinate its activities and regulations with other State agencies such as the Department of Natural Resources, the Oil and Gas Conservation Commission, and the Geological Survey, depending on the issues involved. The Colorado Water Quality Control Act requires that the Commission "...develop and maintain a comprehensive and effective program for the prevention, control, and abatement of water pollution and for water-quality protection throughout the entire State."[37)]

The 11-member Commission consists of one member each from the State Board of Health, the Wildlife Commission, and the Water Conservation Board, and seven citizens appointed by the governor to include one member from each Congressional district.

The Oil and Gas Conservation Commission in the Department of Natural Resources is responsible for the disposal of wastewater produced during all phases of oil and gas extraction and storage. The agency has ruled that surface discharge is permissible only in areas where produced water has low salinity and that all storage pits must be lined. These conditions are basic requirements for permit consideration.

In 1976, the Water Quality Control Commission revised the Rules for Subsurface Disposal to incorporate an expanded definition of such systems to include: "...unlined lagoons or systems disposing of pollutants not more than 100 ft (30 m) below adjacent original ground surface."[38)]

Highlights

- The Colorado Water Quality Control Act specifies that "State Waters" include ground water for discharge permit requirements. Therefore, regulations require permits for all solid- and liquid-disposal sites throughout the State, including exfiltration ponds or sewage systems disposing of pollutants directly or indirectly under the surface of the ground when the system serves more than 20 people or has a design capacity exceeding 2,000 gpd (7.6 cu m/day).[39]

- The design report submitted as part of a permit application for impoundment systems must include ground-water monitoring plans. Monitor wells must be situated in "a pattern sufficient to monitor each dominant direction of ground-water movement away from the site, and determine ground-water movement." The report also calls for water sampling and analysis with quarterly reporting of nitrate and ammonia nitrogen, specific conductance, fecal coliform, BOD, and chloride, at each monitoring point. Each application is accompanied by specific details of the requirements.[40]

- Decisions concerning requirements for each monitoring program for impoundments are made on a case-by-case basis. The permittee must keep records for three years.

- All monitoring wells must be pumped for 10 minutes prior to sampling.

- Granting of a permit to "construct or operate" a subsurface disposal system is contingent upon a determination beyond reasonable doubt that "...there is no risk of significant migration (of pollutants) and the proposed activity is justified by the public need."

- Permit applications require data describing the area within a 2 mi (3.2 km) radius of the proposed impoundment system; sociological elements and wildlife of the area; the probable effects of the system on mineral resources; and surface water and ground water in the probable zone of influence of the system, including maps indicating vertical and lateral limits of surface and subsurface water supplies.

- Applicants for a permit must fully describe the "chemical, physical, radiological, and biological properties of wastes to be disposed of."

- No impoundment may be abandoned without approval from the Water Quality Control Commission, which is authorized to impose closure requirements.

- The State "Guidelines for Design of Feedlot Runoff Containment Facilities" stipulate that:

  "All runoff containment structures that will hold liquid must be sealed. Removal of porous top soil and proper compaction of suitable sub-soil improves the water-holding characteristics of the bottom. Removal of porous areas such as gravel or sandy pockets and replacement with suitable material may be required. Suitable materials for sealing may include a clay blanket, asphalt coating, or manure."

- Violations are handled in a variety of ways, with the first step involving the issuance of a notice of alleged violation of an order, permit, or control regulation. This notice is usually accompanied by a cease-and-desist order and may include a description of required corrective measures. A public hearing may also be ordered, at which time the decision will be made on what further action is necessary. The permit may be revoked, suspended, or modified, and a clean-up order issued. Failure to comply leads to the intervention of the Attorney General. Civil penalties of not more than $10,000 per day for each violation may be leveled against those who violate a permit, while criminal proceedings for abuses of water quality "committed knowingly or intentionally," such as operating without a permit or deliberately dumping pollutants into State waters, carry a maximum fine of $25,000.

Delaware

The two principal laws enabling regulation of the disposal of wastewaters to impoundments in the State of Delaware are the Environmental Protection Act and the Delaware Solid Waste Authority Act (1975). Regulations developed by the Department of Natural Resources and Environmental Control (DNREC), the Delaware Solid Waste Authority (created by the 1975 Act), and the State Board of Health provide for the control of all waste discharges within the State.

Highlights

- The State law has no specific legal definition for "impoundment" broad enough to include structures other than reservoirs. Ponds for the purpose of regulation are "...all natural and/or man-made lakes or other bodies of water fed directly by springs, ground water, tidal, or non-tidal streams."

- Discharge of any pollutant from a point source into surface water or ground water is prohibited without a permit. Facilities covered by the permit requirement include "any liquid waste-treatment system."[41)]

- Sec. 13 of Delaware Regulations Governing the Control of Water Pollution (1974) provides exemption from permitting for 20 activities including:

    1. Existing ditches used for the express purpose of draining water from the surface of the land.

    2. Uncontaminated stormwater discharge.

    3. Operation of any quarry, gravel pit, or borrow operation unless there may be a discharge directly or indirectly to surface water and/or ground water.

- There is a general provision for hearings either before permitting or in the case of suspected violation. Fact sheets prepared as part of the permit application procedure are available for public inspection. The permit commits the applicant to performance standards, applicable pretreatment requirements, and notification to the public of intent to initiate the discharge.

- All ditches and ponds associated with landfills must be lined with an impermeable liner, unless the applicant can prove to the Department's satisfaction that a natural soil liner is impermeable.[42]

- Record keeping is required for all disposal sites and there is provision for DNREC inspection of these records and access to permitted sites. For municipal wastewater impoundments, the State uses the 10-State Recommended Standards for Sewage Works as a basic guide but reserves the right to enforce stricter standards on a case-by-case basis.

- Imposition of civil penalties is provided for in situations where the Department considers that pollution is taking place in violation of State regulations.

Idaho

The Idaho Environmental Protection and Health Act, the Dredge and Placer Mining Protection Act, the Surface Mining Act, and the Oil and Gas Conservation Act all contain provisions for the control of discharges of wastewater to surface impoundments. Overall regulation of discharges from municipalities, industries, and agriculture is subject to the water-quality protection requirements of the Department of Health and Welfare. The Idaho Oil and Gas Conservation Commission has regulations dealing with the permitting and surveillance of disposal sites to avoid ground-water contamination. The State does not presently produce petroleum, so that the principal concern is with controls on processes associated with exploratory drilling.[43]

For purposes of administration, Idaho is divided into three regions: Region I - Coeur d'Alene, Region II - Boise, and Region III - Pocatello. Each region is staffed with seven technical experts whose activities are primarily concerned with water-quality control, and one professional staff member working with Section 208 programs in the regions.

Highlights

- The Department of Health and Welfare, the primary State environmental regulatory agency, promulgated "Waste Treatment and Discharge Permit Regulations (Jan. 1977)" following the required public hearings on the proposals. These regulations were subsequently withdrawn by the Legislature. While the State agency is seeking to reinstate the 1973 regulations, it is proceeding with a permitting system based upon the language of the Idaho Environmental Protection and Health Act, in lieu of updated standards or other regulatory guidelines.

- The rejected regulations offered a specific definition of "Infiltration-Percolation Basin" as being "any impoundment or depression in the land surface designed or utilized for the disposal of wastewater and sewage by infiltration and percolation into the soil." Similarly, a "Non-Overflow Lagoon" was "a sealed or unsealed impoundment designed or utilized for storage, stabilization, or disposal of wastewater and sewage without overflow." Neither definition is present in the 1973 Water Quality and Wastewater Treatment Requirements or the Environmental Protection & Health Act.

- The Act authorizes the Department of Health and Welfare and the Water Resources Division to issue permits for municipal, industrial, and agricultural impoundments, with most authorizations granted after case-by-case consideration.[44)] The permitting procedure for tailings ponds and settling ponds governed by the Idaho Surface Mining Act requires design of these facilities and their operation in accord with water-pollution protection requirements of the Department of Water Resources. Similarly, the Idaho Dredge and

Placer Mining Protection Act relates to the permitting and reclamation of this type of mining development, with impoundments considered as industrial facilities.

- The Idaho Oil and Gas Conservation Commission is charged with the permitting of drilling sites, technical review to avoid ground-water contamination, monitoring, and regulation of production to maximize recovery. "General Rules and Regulations" developed by the Commission preclude the production, storage, or retention of oil in open receptacles. Conditions for the disposal of brine or salt by evaporation require the use of impervious sites. Where the soil under the pit is porous and closely underlain by gravel or sand, impounding of brine or salt water is prohibited. Surface mud impoundments must be lined with an impervious membrane or other flooring and must be removed after drilling. The Commission has the authority to condemn improperly constructed impoundments or those where operations permit overflow of the wastes. All earthen pits must have a continuous embankment surrounding them, sufficiently above the level of the surface to prevent water from running into the pit.

- The applicant for a permit for all other surface impoundments controlled by the Department of Water Resources must guarantee that the waste materials will be restricted to the disposal site, provide for chemical sampling of the effluents, and determine the characteristics of the soil mantle at the site. The 1973 regulations specifically prohibit the use of any land treatment or disposal method which would create a ground-water mound, result in a salt buildup on another person's property, or create a health hazard.

- The Department of Health and Welfare requires that wastewater impoundments be installed in such a fashion as to avoid contamination of nearby wells. A provision exists for hearings to be held prior to permitting in the event that sufficient citizen interest is evidenced upon publication of the intent to issue a permit for a facility.

- Monitoring of discharges and record-keeping are required by the permit application, with specific approaches decided on a case-by-case basis. The enabling laws authorize Department personnel to inspect sites in the event that there is any reasonable doubt concerning the environmental acceptability of the impoundment. There is also provision for the issuance of pollution-abatement orders and the setting of civil penalties by the courts in cases of persistent violation.

<u>Maryland</u>

The Water Resources Administration in Maryland's Department of Natural Resources (DNR) has developed comprehensive ground-water protection regulations based upon State law, a system of aquifer classification, and Federal requirements. The agency coordinates its activities with the State Department of Health and Hygiene, which exercises primary supervision over the treatment and disposal of solid wastes and the health-related aspects of water supply. Legislation to consolidate virtually all State environmental programs, including those governing solid waste, under the DNR is presently being considered. The measure would transfer the Environmental Health Administration of the Health Department to DNR. Also under consideration is a revision of sections of regulations covering discharge permits and approvals.[45)]

The explanation of terms used both in State environmental law and in rules and regulations promulgated by DNR clearly demonstrates the intent to protect ground water from all forms of waste disposal, including transmission of wastewater to impoundments. For instance, discharge is defined by the law and subsequent regulations as the addition, introduction, leaking, spilling, or emitting of any pollutant to waters of the State or the "placing" of any pollutant in a location where it is "likely" to pollute. The term "disposal system" not only includes treatment works and disposal wells, but is extended to include "other systems." Ponds are cited as points of discharge of effluents and are included in the definition of "waters of the State" without any reference to the quality of influent.[46)]

The agency has a two-tiered approach to control of discharge, with some activities requiring permits and others requiring administrative approval of design and/or operation. The proposed revision of discharge regulations will give the agency increased authority to control activities, facilities, or systems which are not designed to discharge water, wastes, or wastewaters, but which may "cause" such discharge "directly or indirectly" into waters of the State. Further, a discharge permit may be required from any facility for which there is a "potential" discharge to waters of the State. Holding and treatment ponds or lagoons for wastes or wastewaters, mining activities, and animal feedlots are categorized in this fashion.[47)]

For purposes of administration, the State is divided into five regions with a specialist in charge of each. Permitting activity is under the supervision of a senior staff member individually responsible for wetlands, hazardous and industrial wastes, municipal discharges, water supply, and watersheds. Similarly, the technical services division is divided according to activity groupings for water quality, flood control, planning, and laboratory services. Each of the three subdivisions in the Water Resources Administration is headed by a chief administrator directly responsible to the Water Resources Administration director.[48)]

Highlights

- State ground-water quality standards recognize three classes of native ground-water quality: (a) high quality water, meeting or exceeding Federal drinking water standards; (b) intermediate quality water suitable for industrial and agricultural use or for possible use as a potable water supply after desalination; and (c) low quality (saline) water. Effluent limits, or allowable contaminant loads, are matched to aquifer types. For instance, nitrogen loading for land application of municipal wastes and a requirement for zero pollutant discharge for surface impoundments are features of the discharge requirements for potable ground waters or Type I Aquifers. Ground-water quality standards stipulate that: "The characteristics or constituents of water or wastewaters discharged into Type I Aquifers may not exceed, or cause the natural ground-water quality to exceed, mandatory recommended standards for drinking waters as established by the Federal government." For Type II Aquifers, the discharger must provide evidence that the discharge will not result in pollution of Type I Aquifers.[49)]

- The Maryland Ground Water Pollution Control and Prevention System supplements the State and NPDES requirements for surface-water discharge by requiring a permit "to discharge to underground waters and for approval of plans and specifications for a facility which may discharge." Infiltration-percolation basins, land application of wastewater, and industrial subsurface soil adsorption systems (drain fields, seepage pits, etc.) are categorized as facilities requiring a discharge permit. Holding ponds and lagoons for chemicals, wastes, or other materials are classified as "facilities which may discharge" and for which approval of plans and specifications is required by the Water Resources Administration.

- In the event that an existing discharge does not comply with requirements, the permittee must attest that facilities will meet requirements set forth in a compliance schedule developed by the Water Resources Administration and expressed in compliance periods. The discharger must submit a compliance report within 14 days following each compliance deadline.

- Satisfaction of State requirements leads to issuance of an NPDES surface-water discharge permit or a ground-water discharge permit in the event that a discharge may affect ground-water quality.

- A public hearing is required prior to permit issuance, with a hearing notice to be published at least once in a daily or weekly newspaper in the geographical area of the discharge, at least 30 days prior to the hearing.

- Discharge facilities (both municipal and industrial) must be operated by a Certified Superintendent whose qualifications meet the State's legal requirements (Article 43 Sec. 406-A of the Annotated Code of Maryland).

- Any discharge authorized by permit is subject to monitoring requirements imposed by the Administration at time of permit issuance, including the installation, use, and maintenance of monitoring equipment or methods. Each permit specifies the sampling and analysis requirements, including frequency and type of sampling and analysis. The permittee is required to retain monitoring records for three years and submit a monitoring report at periods stipulated by the Administration, but no less frequently than once a year. Permits are valid for 5 years.

- Regulations covering permit review, modification, suspension, or revocation entitle the Administration to modify permit provisions after notice and the opportunity for a public hearing. Revisions or modifications of a compliance schedule may be made for a variety of reasons, including events over which the permittee has no control, such as material shortages.[50)]

- In the event that a violation takes place, the Administration may issue a corrective order, require the alleged violator to appear before the Department to answer charges, or require a written report. Failure to comply may result in modification or revocation of a permit and/or civil or criminal penalties.

- The Geological Survey regulates disposal of brine wastes from the gas industry but must coordinate its activities with the Water Resources Administration. Surface discharge of brines is covered by NPDES, and although there are no specific rules regarding disposal of this wastewater, the State's aquifer classification and ground-water quality standards must be adhered to.

- The prevention of oil pollution, both above and below ground, is also covered by agency regulations, which prohibit the discharge, depositing, or draining of oil or other matter containing oil into the waters of the State, or in a manner contrary to promotion of State water-quality standards.[51)]

Massachusetts

At present, authority to control surface impoundments in Massachusetts is somewhat ambiguous due to the abolition in 1976 of the Department of Natural Resources in favor of consolidation of environmental management within a cabinet-level Executive Office of Environmental Affairs. The reorganization included transferring the Department of Environmental Quality Engineering and the Division of Water Pollution Control to the new department as separate but complementary agencies. Previously, the Division of Water Pollution Control had been the administering agency of the Water Resources Commission, a regulatory body created by the Massachusetts Clean Water Act. The Act authorizes the Division of Water Pollution Control to issue permits and establish monitoring, sampling, record keeping, and reporting procedures to control water pollution affecting the waters of the State, defined by the law to include lakes, ponds, impoundments, and ground water. The Division has authority to promulgate permitting regulations controlling discharges to ground water and to establish a formal permit system, but to date (1977) has not done so.[52)]

The State's system for controlling discharges to surface-water bodies (MPDES), taken in conjunction with regulations governing the disposal of hazardous wastes and regulations promulgated in 1976 by the Department of Environmental Quality Engineering to set minimum requirements for the subsurface disposal of sanitary sewage, incorporates limited controls over certain types of impoundments.

Highlights

- The State discourages the use of lagoons for treatment or disposal of municipal wastewater.[52)]

- In 1973, regulations requiring the licensing of hazardous-waste collection, storage, and disposal were promulgated by the Division of Water Pollution Control. Nearly 100 licenses, which inventory the type of hazardous wastes going to disposal sites, have been issued. The regulations stipulate methods for disposal of various types of hazardous materials, require licensing of sites, and ban discharge to land or to waters of the State.[53)]

- The requirements for subsurface disposal of sanitary sewage establish a permitting system to be administered by the Department of Environmental Quality Engineering. Construction of seepage pits in areas where the maximum ground-water elevation is less than 4 ft (1.2 m) below the bottom of the pit is prohibited. In situations where the soil consists of porous sand or gravel with a percolation rate of 0.5 in/min (1.3 cm/min) or less, the maximum ground-water level must not be less than 2 ft (0.6 m) below the bottom of the pit. The restrictions are based on measurements to be made during the period of the year when the water table is at its highest elevation. Percolation tests are required as a condition of permitting.

Nebraska

The Nebraska Environmental Protection Act stipulates pollution-control requirements for protection of the State's oil, land, and water resources and is the principal instrument under which the Department of Environmental Control (DEC) functions as the administering agency. Municipal and industrial surface impoundments are regulated by waste-disposal rules established by the Department and administered by its Water Pollution Division. The Agricultural Division is responsible for implementation of livestock waste regulations.[54)] At present, DEC activities relative to permitting and supervision of impoundments are the responsibility of 12 technical staff members and 2 attorneys. However, additional legal assistance is available from county legal staff and the Attorney General's office.[55)]

In 1975, the DEC promulgated rules and regulations governing the issuance of NPDES permits. These requirements, taken together with those developed pursuant to the Environmental Protection Act and restrictions on disposal of liquids and hazardous materials in landfills, provide an effective range of control.

Highlights

- Nebraska regulations require permits to cover wastewater surface impoundments, with the exception of uncontrolled discharges composed entirely of storm runoff. However, the NPDES rule granting this exemption provides for reversal in situations judged by the regulatory authority as being significant contributors to pollution. NPDES and State rules and regulations provide for public participation through hearing procedures and publication of notices. Significant features of the permitting procedure include:

    1. Provision for consultation between the divisions of the DEC concerning a permit application.

    2. NPDES provision for denial of a permit if the application is in conflict with discharge requirements of any approved Section 208 areawide waste-treatment plan under the Federal Water Pollution Control Act Amendments of 1972 or of NPDES constituent discharge requirements.

    3. Hearings to be held in conjunction with regulatory rule making or in the event that there is a contest over the granting of the permit.

- The design of all wastewater works in Nebraska is based upon the recommendation that they incorporate the features of the "Recommended Standards for Sewage Works" (1971 Revised Edition), prepared under the direction of the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers.

- Nebraska regulations prohibit the siting of livestock feedlot facilities within 100 ft (30 m) from a domestic well, 1,000 ft (300 m) from a municipal well, or in situations where they will contaminate ground water.[56)]

- Regulations provide for "right of entry" for inspection by authorized departmental personnel, reporting of pollution incidents by the facility operator, and reporting of the results of wastewater sampling for specific constituents.

- If a violation is judged to be an emergency, the violator is taken to court where the DEC will seek a mandatory injunction. In cases of less urgency, the procedure follows the administrative route of a warning to the violator, followed by a hearing. The person charged with the violations may file briefs and has a right to appeal. The law provides for the payment of fines of up to $5,000 per day for each violation.

New Mexico

The New Mexico Water Quality Control Act recognizes eight "constituent" agencies with responsibilities that are either directly related to the development, management, and protection of water supply and water quality or are affected by the availability of water for industrial, agricultural, recreational, or aesthetic purposes. The Act established a system by which each "constituent" agency participates in the formulation of rules and regulations through representation on the Water Quality Control Commission, which it established as the principal entity responsible for development of regulations. The members of the Commission represent the Environmental Improvement Agency (EIA), the Bureau of Mines and Mineral Resources, Department of Agriculture, Department of Game and Fish, Natural Resources Conservation Commission, Oil Conservation Commission, State Engineer, Interstate Stream Commission, and the State Parks Recreation Commission.[57)]

Passage of the Environmental Improvement Act (1971) transferred the responsibilities of the former Environmental Services Division of the Health and Social Service Department to EIA. This agency is responsible for the environmental management and enforcement of water-supply and water-pollution control rules and regulations. The Water Quality Division in EIA and the Engineering Office are the principal sections concerned with discharges to surface impoundments from all sources other than oil and gas extraction and storage. The Oil Conservation Commission is responsible for implementing State regulations and for issuing permits for discharges related to the oil and gas extraction. Permits covering coal surface mining are issued by the New Mexico Coal Surface Mining Commission.

In January 1977, the Commission promulgated amendments to existing water-quality control regulations designed to control discharges "onto or below the surface of the ground" and established standards limiting 27 constituents in ground water. Generally speaking, the amended regulations reflect the requirements of the Federal Safe Drinking Water Act by seeking to protect all ground water with an existing concentration of 10,000 mg/l or less of TDS, for present and future use as domestic and agricultural water supply. The need to protect ground-water quality from contamination due to the inflow of polluted surface water, and to differentiate between undesirable naturally occurring constituents and those reaching ground water from a variety of waste-disposal practices, is also acknowledged by the regulations.[58)]

The maximum ranges and concentrations in the ground-water standards do not preclude the use of water containing higher ranges and concentrations. In formulating the regulations, the Commission sought to confront issues surrounding the application of NPDES to semi-arid regions, principally the contention that the Federal system is designed primarily to protect water quality in streams where ground water is discharging to surface water.[59] EIA observed that "it would be ineffective and inappropriate to rely primarily upon this system (NPDES) to protect water quality in semi-arid regions where such surface-water bodies as there are in fact discharge to ground water."[60] In effect, the regulations provide the State with a discharge system for ground-water quality protection parallel to but separate from NPDES. From a procedural viewpoint, the mechanics for hearings, issuance of permits, and enforcement do not differ substantially from those established by other States, but the technical requirements are more specific in their intent to prevent contamination of ground water from infiltration of undesirable constituents from surface impoundments.

Highlights

- A discharge plan describing methods of discharge, existing conditions, monitoring and sampling programs, and a contingency plan designed to cope with failure of the discharge system is to be established prior to permitting of discharge of effluent or leachate which may move directly or indirectly into ground water. The plan also calls for identification of any bodies of water, water courses, and ground-water discharge sites within a 1-mi radius of the outer limits of the proposed discharge site. A lithological description of rock at the base of alluvium below the site, if available, as well as the depth to and TDS concentration of the ground water likely to be affected by the discharge, is also required.

- Exemptions from discharge plan requirements include sewerage systems used only for the disposal of household and other domestic wastes amounting to 2,000 gpd (7.6 cu m/day) or less of liquid wastes, leachate from solids disposed of in accordance with the State's solid waste-management regulations, effluent or leachate discharges from activities regulated by a coal surface mining plan approved and permitted by the New Mexico Coal Surface Mining Commission, and discharges regulated by the Oil Conservation Commission.

- The regulating agency may impose a full range of monitoring options, including monitoring of the vadose zone and continuation of monitoring after cessation of operation. The discharge plan must identify the types of data and stipulate periodicity of reporting. The discharger is required to retain monitoring records for 5 yr. Conformity of sampling and analytical techniques is required through either adherence to standardized methods established by the American Public Health Association, EPA, or the U.S. Geological Survey.[61)]

- According to an official of the New Mexico EIA, "A discharge plan is approvable if it demonstrates that neither a hazard to public health nor undue risk to property will result, and that ground-water quality standards will be met at any place of withdrawal for present or reasonably forseeable future use.

  Shortcut methods of showing that these requirements are met, which are acceptable under most circumstances, include criteria for seepage rates from impoundments and/or land application rates. These criteria include a limit for municipal, domestic, and animal waste discharges of 200 lb/acre/yr (220 kg/ha/yr) of nitrogen entering the subsurface from a leach field or surface impoundment, and a limit for industrial, mining and manufacturing operations of 0.5 acre-ft/acre/yr (1,540 cu m/ha/yr) of effluent entering the subsurface from a surface impoundment.[62)] It must be emphasized that dischargers are required to show that ground-water standards will be met at any place of withdrawal for present or forseeable future use. These shortcut criteria, which can be used at the discharger's option, are possible ways of showing this."

- The agency has the authority to modify a discharge plan, set a time limit for implementation of modification, or terminate the discharge if the modifications are not made. No plan may be approved for more than a 5-yr period.

The discharger is entitled to request a variance from regulatory requirements under certain conditions, including demonstration that there is no reasonable relationship between the economic and social costs and benefits (*including attainment of the ground-water quality* standards), and that the proposed discharge would not create a public health hazard.

Texas

The Texas Water Quality Act of 1967 created the Texas Water Quality Board (TWQB) as the principal authority regulating State waters. In late 1977, the TWQB was merged into a new agency, called the Texas Department of Water Resources (TDWR). The Texas Water Quality Act seeks to encourage the development and use of regional and areawide waste-collection, treatment, and disposal systems. A waste-treatment facility is described as: "Any plant, disposal field, lagoon, incinerator, area devoted to sanitary landfills, or other facility installed for the purpose of treating, neutralizing, or stabilizing waste." The definition is further expanded by TDWR's "Rules of Practice and Procedure"[63)] to mean all wastes including sewage, industrial waste, municipal waste, recreational waste, agricultural waste, or other waste, except for salt water associated with the extraction of oil and gas, which is controlled by the Texas Railroad Commission. However, the Railroad Commission generally defers to the TDWR in matters of protection of potable water supplies, including ground water.

Administration of the State Solid Waste Disposal Act is also the responsibility of TDWR, which maintains direct regulatory control over industrial liquid and solid wastes. The Department of Health regulates disposal of municipal and agricultural solid wastes. Agency interaction with the Health Department and the Railroad Commission is facilitated by TDWR rules.[64)]

Rules and regulations developed by TDWR are reinforced with guidelines presented as "suggested requirements" covering significant aspects of pond and lagoon construction and operation.[65-67] The principal requirements are outlined below.

Highlights

- Wastes should be classified according to standards developed by TDWR, including testing of the effect of the wastes on the soils and lining materials used in pond construction to determine if the waste will breach the integrity of the seepage barrier.

- Impoundments should be designed with sufficient freeboard to minimize the risk of accidental spills or overtopping of liquid wastes due to wave action.

- The guidelines advise that each pond site location will be subject to individual evaluation. Ponds should be in thick relatively impermeable formations, with a thickness dictated by the classification of impounded wastes.

- TDWR provides a description of the construction techniques used for the two most common types of ponds: the "above-ground" pond and the "below-ground" pond. Operators must impound only those wastes designated by the waste-control order, and for which the impoundment was designed.

- Provisions for monitoring facilities are based on sampling ground water and surface water in the vicinity of the disposal site to provide background "yardsticks" against which subsequent operational measurements will be compared. Permit requirements may include monitor wells, stream sampling, and drain systems for leachate collection, with selection of chemical parameters based on site characteristics, types of waste, and method of disposal. Typically, every impoundment receiving hazardous (Class 1A) wastes should include a leachate collection and monitoring system, usually consisting of a gravity drainfield installed under the waste-disposal facility liner. Another option consists of a gravity flow drainfield installed immediately under the waste-disposal facility liner and above a secondary lower liner. Installation of "suction manometers," connected by hoses to a vacuum pump, may be required. The manometers are installed along the sides and under the bottom of the impoundment liner, in order to detect leaks.[66)]

- TDWR requires periodic reports from waste-disposal operators, with frequency specified in the waste-control order. Record-keeping includes a description of wastes, their classification and form (liquid, solid, sludge) and, if ponds are used as interim treatment, data concerning ultimate disposal of the wastes. All monitoring data must be available for inspection and TDWR must be notified within 48 hr of any significant increase from background concentrations.[67)]

- Public hearings may be required in any of 14 different situations, including a decision involving a change of regulations, application for impoundment construction permit, and protests by affected parties. Specific regulations exist to cover violations involving accidental spills as well as breaches of waste-control orders. Failure to comply with a cleanup order leads to court proceedings and a possible fine of up to $1,000 for each day the violation persists. For industrial impoundments covered by the Solid Waste Disposal Act, the State Health Department and TDWR may be partners in court action instituted by local jurisdictions. The money collected through civil penalties is divided equally between the State and local governments. Similar provisions exist to cover situations involving violations of a State-Federal NPDES permit. The TDWR retains the right to revoke a permit.

Wisconsin

The Wisconsin Department of Natural Resources (DNR) has a fully operational ground-water discharge permit system to complement State administration of the NPDES program for protection of surface-water quality. There is a clear-cut division of responsibility within DNR for the development of regulations, implementation, and surveillance. Policy making is the function of the Natural Resources Board, a seven-member unit appointed by the Governor plus a Secretary who is appointed by the Board to manage DNR and its various bureaus.

The Bureau of Water Supply and Pollution Control within DNR's Division of Environmental Protection is responsible for the review of planning, design, construction, and operation of municipal water-supply, sewage-treatment, and industrial waste-treatment systems including surface impoundments. The agency has 16 staff members engaged in regulation of industrial wastewater disposal and 21 staff members whose duties include responsibility for regulation of municipal wastewater activities, with five persons involved in surveillance requirements. The Wisconsin Administrative Code[68)] defines land-disposal systems to include but not be limited to "septic tank soil adsorption systems, ridge and furrow systems, seepage ponds, spray irrigation systems, and other systems where effluent is disposed of by percolation into the ground." Another part of the Code[69)] supplements the definition with discharge limitations, monitoring provisions, and a case-by-case permitting system relative to protection of ground-water quality.

Highlights

- For the purposes of design, construction, and operation, land-disposal systems are divided into four categories based on the source of the wastewater discharge. Class I covers municipal and domestic wastes; Class II, canned, preserved, and frozen fruits and vegetable discharges; Class III, dairy product processing; and Class IV, meat products. In addition, controls exist for discharges from construction, sand and gravel, and stone and concrete products operations.[70)]

- Detailed ground-water data are required prior to the granting of a discharge permit. This information includes direction of ground-water flow, baseline quality data, proposed monitoring facilities during operation of the system, and location of all drinking-water wells within half a mile (0.8 km) of the proposed land-disposal system.

- DNR has prepared explanatory documents to guide permit applicants through the permitting process. The actual permit may stipulate both surface-water and ground-water protection requirements and makes provision for departmental decisions on determination of monitoring needs.[71)]

- Monitoring wells are required in order to provide data such as ground-water levels and concentrations of organic nitrogen, ammonia, nitrogen, nitrate plus nitrite nitrogen, chloride, sulfate, TDS, alkalinity, hardness, and pH.

- Discharge limitations for land disposal allow discharge of wastes only after secondary treatment. However, provision exists for imposition of additional treatment in situations where the wastewater is the result of mixed industrial and municipal wastes.

- BOD in discharges to the land-disposal system must not exceed 50 mg/l in more than 20 percent of the monitoring samples required during a calendar quarter.

- Lagoons used to settle backwash municipal wastewater from iron and manganese removal filters must be designed to hold 10 times the total quantity of wash water discharged during any 24-hr period, be 4 times as long as they are wide, and be 3 times as wide as they are deep. Inlet and outlet controls must minimize velocity currents.

- Public notice regulations include development of "fact sheets" for every discharge over 500,000 gal (1,900 cu m) on any day of the year. The "fact sheets" require physical and geological descriptions of the facility, description of proposed discharges, and a statement of the tentative determination to issue or deny the permit. Discharge limitations, imposition of special conditions, and a proposed schedule of compliance, including interim dates and requirements for meeting the proposed effluent limitations, also must be disclosed.

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SECTION X

OTHER RELATED INVESTIGATIONS

Aside from the investigation described in this report, EPA is conducting or has completed in recent years about 25 investigations dealing to some extent with the effects of surface impoundments on ground-water quality or with techniques and data from other studies of ground-water contamination that may be adapted to surface-impoundment studies. The results of most of these investigations have been described in reports published by EPA or have been summarized in journal articles (see selected references arranged alphabetically by author at the end of this section).

The present study of impoundments, as well as many of the related investigations, stem from authority given in relatively recently enacted legislation, namely: the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500); the SDWA (Safe Drinking Water Act, P.L. 93-523); the RCRA (Resource Conservation and Recovery Act, P.L. 94-580); and the Clean Water Act of 1977 (P.L. 95-217).

Among the significant reports issued by EPA are several that describe methods for designing and constructing monitoring well networks and that give examples of case histories of ground-water contamination. One such report describes the results of the collection and analysis of water samples from test wells drilled at some 50 landfills and lagoons to determine the possibility of subsurface migration of hazardous wastes.[1) A comprehensive report on the effects of waste-disposal practices on ground water identifies impoundments along with a number of other land-disposal methods as potential sources of ground-water contamination.[31) Information on sampling techniques, costs of monitoring programs, and how and where to drill monitoring wells, is given in a manual on monitoring solid-waste disposal facilities.[32) A series of regional studies[9, 19, 21, 26, 43) gives information on representative case histories of ground-water contamination from various sources including waste impoundments; and still another series of reports emphasizes monitoring techniques, data management, and economic considerations.[7, 11, 13, 28, 29, 34)

All of these studies, along with the results of the present study, contribute to overall knowledge and understanding of ground-water contamination and methods of protection. However, a number of data gaps and unanswered questions remain that require further investigation with respect to potential problems resulting from surface impoundments. These include the need for more detailed information on the numbers, locations, and the overall pollution potential of waste impoundments and the economic impact of reclaiming or restoring ground-water resources that have been contaminated by leaky impoundments.

In furthering these objectives, EPA is currently pursuing three courses of action which address surface impoundments. Two of these are under RCRA and the third one is under SDWA. First, under Subtitle C of RCRA, EPA will regulate facilities receiving hazardous wastes, including surface impoundments and landfills. Second, under Subtitle D of RCRA, EPA is required to promulgate criteria for determining which waste-disposal facilities should be classified as sanitary landfills and which should be classified as open dumps. The definitions of "solid waste" and "disposal" in RCRA clearly indicate that surface impoundments will be covered by these criteria. Within one year after publication of the criteria, EPA must publish an inventory of open dumps. This requirement is virtually impossible to meet owing to the large number of disposal sites and the magnitude of the technical, economic, legal, and administrative tasks involved; consequently, the RCRA inventory would be phased in over the next few years. During the first year of the inventory, the emphasis would be on municipal solid-waste landfills and sludge sites. In the second year, the inventory would include those industrial impoundments that have a high potential for ground-water contamination; the inventory would also cover industrial landfills. In later years, the inventory would cover agricultural and mining sites with priority on those impoundments identified as potential problems.

The third action involving surface impoundments is based on authority given in Section 1442(b)(3)(C) of SDWA and is referred to as the SIA (Surface Impoundment Assessment). In connection with that study, EPA's Office of Drinking Water will provide a total of up to $5,000,000 in grants to the States to make individual State-wide studies of surface impoundments.

The objectives of the SIA program are to obtain firm national data on the number of impoundments in existence, to review current construction practices, and to evaluate the ground-water pollution potential of a representative sample of those impoundments. It is hoped that the funding made available will allow the States to: (a) collect, update, and improve data relating to ground-water contamination from impoundments; (b) identify existing State institutional problems should they exist; and (c) provide information to be used in developing or refining legislative programs. The assessment will contribute to the formation of a valuable data base for making future decisions in the fields of ground-water resource management and land-use planning. EPA will compile the data generated by the States and use the recommendations of the States in the formulation of a national approach to dealing with the problem of ground-water contamination resulting from the use of waste impoundments.

The programs under RCRA and SDWA will be integrated and coordinated so that they will be mutually supportive and will minimize duplication of effort. For example, the results of the surface impoundment assessment planned under SDWA will be used as a screening device to establish priorities for the RCRA inventory of landfills and surface impoundments.

While the three actions described above will begin to bring impoundment sites under State control under RCRA, EPA will continue to explore and re-evaluate its authority under RCRA, SDWA, the Federal Water Pollution Control Act, and the Toxic Substances Act, as well as the responsibilities and authorities of other agencies, in order to determine the best regulatory approach under any one or a combination of these authorities. If these authorities are not sufficient to assure adequate control of surface impoundments, EPA will seek additional legislation to help solve the problem.

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SECTION XI

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SECTION XII

APPENDIX A - METRIC CONVERSIONS USED IN REPORT

To convert	Into	Multiply by
acre	hectare	0.4047
acre-feet	cubic feet	43,560
acre-feet	cubic metres	1,234
barrels (oil)	cubic metres	0.159
barrels (oil)	gallons (oil)	42.0
btu	kilogram-calories	0.2520
centimetres	metres	0.01
cubic feet	cubic metres	0.0283
cubic yards	cubic metres	0.7646
feet	centimetres	30.48
feet	metres	0.3048
gallons	cubic metres	0.0038
gallons	litres	3.785
hundredweights (short)	pounds	100
hundredweights (short)	tonnes	0.0454
inches	centimetres	2.540
horse power	horse power (metric)	1.014
micrograms	grams	1.0×10^{-6}
miles (statute)	kilometres	1.609
milligrams/litre	parts per million	1.0
million gallons	acre-feet	3.06
million gallons/day	cubic metres/day	3,785
million gallons/day	cubic feet/second	1.5472
million gallons/day	cubic metres/second	0.0438
mils	centimetres	0.0025
mils	inches	0.001
parts per million	milligrams/litre	1.0
pounds	kilograms	0.4536
pounds/acre	kilograms/hectare	1.121

METRIC CONVERSIONS - (Continued)

To convert	Into	Multiply by
square feet	square metres	0.0929
square inches	square centimetres	6.452
square miles	square kilometres	2.590
tonnes	kilograms	1,000
tons (short)	tonnes	0.9078

Table 12. ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES (Flow, in 1,000 cubic metres/day; total flow not shown owing to incomplete data.)

SIC No.	01 Agriculture (Crops)		02 Agriculture (Livestock)		10 Metal Mining		11 Coal Mining (Anthracite)		12 Coal Mining (Bituminous)		13 Oil and Gas		14 Mining (Non-Metal)	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	1	-	668	-	15	-	-	-	300	-	2	-	41	-
Alaska	-	-	15	-	100	-	-	-	-	-	9	-	-	-
Arizona	-	-	112	-	20	-	-	-	-	-	6	-	-	-
Arkansas	-	-	107	-	-	-	10	-	-	-	540	-	1	-
California	20	-	1,086	-	55	15.18	-	-	-	-	910	-	109	37.89
Colorado	-	-	245	-	23	135.23	-	-	19	78.33	4,617	-	1	0.19
Connecticut	-	-	37	-	-	-	-	-	-	-	-	-	3	6.78
Delaware	-	-	13	-	-	-	-	-	-	-	-	-	-	-
Florida	-	-	350	-	-	-	-	-	-	-	-	-	22	0.11
Georgia	4	-	730	-	7	33.50	-	-	-	-	-	-	48	175.67
Hawaii	-	-	34	-	-	-	-	-	-	-	-	-	-	-
Idaho	-	-	454	-	8	29.33	-	-	-	-	-	-	-	-
Illinois	1	-	658	-	-	-	-	-	100	-	2,000	-	60	-
Indiana	-	-	1,067	-	-	-	-	-	40	47.31	752	-	61	119.91
Iowa	-	-	700	-	-	-	-	-	-	-	-	-	124	356.05
Kansas	-	-	1,063	-	-	-	-	-	5	-	4,525	-	100	-
Kentucky	-	-	136	-	-	-	-	-	800	-	1,000	-	100	1.51
Louisiana	2	-	321	-	3	-	-	-	-	-	8,841	-	11	-
Maine	-	-	175	-	-	-	-	-	-	-	-	-	1	0.95
Maryland	-	-	111	-	-	-	-	-	154	-	-	-	-	-
Massachusetts	-	-	8	-	-	-	-	-	-	-	-	-	-	-
Michigan	-	-	692	-	2	-	-	-	-	-	2,020	-	10	-
Minnesota	-	-	1,185	-	7	75.22	-	-	-	-	-	-	-	-
Mississippi	-	-	586	-	-	-	-	-	-	-	363	-	-	-
Missouri	-	-	1,064	-	10	-	-	-	5	-	6	-	100	3.41
Montana	-	-	316	-	4	26.84	3	0.53	10	-	825	-	-	-
Nebraska	-	-	703	-	-	-	-	-	-	-	200	-	1	-
Nevada	-	-	53	-	-	-	-	-	50	-	15	-	50	-
New Hampshire	-	-	44	-	-	-	-	-	-	-	-	-	-	-
New Jersey	-	-	13	-	20	-	-	-	-	-	-	-	10	0.79
New Mexico	-	-	45	-	20	24.07	-	-	6	-	16,000	-	4	-
New York	25	-	179	-	6	61.70	-	-	-	-	265	-	15	8.78
North Carolina	1	-	502	-	-	-	-	-	-	-	-	-	40	135.65
North Dakota	-	-	543	-	-	-	-	-	12	0.65	1,900	-	-	-
Ohio	-	-	498	-	10	-	-	-	800	-	11,000	-	-	-
Oklahoma	2	-	336	-	3	0.53	-	-	9	-	989	-	6	-
Oregon	-	-	527	-	3	-	-	-	-	-	-	-	3	-
Pennsylvania	13	-	346	-	60	122.63	400	14.00	9,300	4.16	2,500	-	40	-
Rhode Island	-	-	1	-	-	-	-	-	-	-	-	-	-	-
South Carolina	-	-	326	-	-	-	-	-	-	-	-	-	3	8.40
South Dakota	-	-	379	-	1	18.93	-	-	-	-	30	-	-	-
Tennessee	-	-	339	-	1	-	-	-	150	-	100	-	14	-
Texas	-	-	515	-	4	-	-	-	1	-	6,000	-	28	204.32
Utah	-	-	234	-	-	-	-	-	3	2.23	317	-	-	-
Vermont	-	-	62	-	-	-	-	-	-	-	-	-	30	0.98
Virginia	-	-	389	-	10	-	-	-	981	-	100	-	200	-
Washington	2	-	670	-	8	7.95	-	-	3	757.00	-	-	8	0.72
West Virginia	-	-	35	-	-	-	-	-	1,400	-	1,000	-	-	-
Wisconsin	-	-	598	-	11	30.54	-	-	-	-	-	-	7	2.57
Wyoming	-	-	22	-	19	8.36	-	-	22	1.29	5,000	-	-	-
	71		19,292		430		413		14,170		71,832		1,251	

Table 12 (Continued). ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES

SIC No.	144 Sand and Gravel		15 Construction (General)		16 Construction (Heavy)		20 Food Products		201 Meat Products		202 Dairy Products		203 Fruit and Vegetables	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	81	-	-	-	-	-	2	1.74	35	22.18	1	0.15	-	-
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	-	-	-	-	7	-	-	-	-	-
Arkansas	4	0.19	-	-	-	-	3	4.35	4	2.84	-	-	2	0.14
California	46	16.05	1	-	4	5.75	9	1.36	22	2.50	10	0.38	28	31.04
Colorado	27	106.70	-	-	1	0.19	3	0.45	5	0.23	-	-	-	-
Connecticut	4	0.64	-	-	-	-	-	-	-	-	-	-	-	-
Delaware	-	-	-	-	-	-	-	-	1	0.11	-	-	-	-
Florida	-	-	-	-	-	-	1	-	11	3.90	7	-	19	-
Georgia	-	-	6	0.49	-	-	47	41.39	-	-	-	-	-	-
Hawaii	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Idaho	-	-	-	-	-	-	11	39.70	-	-	-	-	-	-
Illinois	-	-	-	-	1	-	5	-	48	-	4	-	3	-
Indiana	12	22.07	1	0.23	-	-	7	5.68	30	3.29	2	-	17	193.26
Iowa	-	-	-	-	-	-	2	-	16	37.83	7	1.64	2	0.37
Kansas	-	-	-	-	-	-	-	-	31	1.44	-	-	-	-
Kentucky	-	-	1	-	-	-	16	8.35	-	-	-	-	-	-
Louisiana	9	-	1	-	3	-	13	-	7	-	6	-	12	-
Maine	-	-	-	-	-	-	-	-	1	4.54	-	-	1	0.62
Maryland	100	-	-	-	-	-	1	-	6	-	-	-	1	-
Massachusetts	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Michigan	16	65.81	-	-	5	-	10	1.92	15	0.38	5	0.29	19	4.84
Minnesota	2	3.79	-	-	-	-	-	-	4	-	3	1.31	16	31.00
Mississippi	34	109.54	2	1.06	1	-	-	-	50	14.31	2	0.15	6	0.95
Missouri	20	3.18	-	-	-	-	-	-	23	3.41	2	-	2	0.11
Montana	2	2.27	-	-	-	-	-	-	8	1.14	2	-	-	-
Nebraska	957	0.19	-	-	-	-	4	4.24	12	18.09	3	-	-	-
Nevada	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Hampshire	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Jersey	-	6.81	-	-	-	-	2	-	-	-	1	-	2	0.25
New Mexico	-	-	-	-	-	-	2	0.11	-	-	-	-	-	-
New York	35	1.02	-	-	1	0.62	2	0.21	3	1.21	13	0.92	25	28.69
North Carolina	15	74.30	1	-	3	-	6	1.14	28	15.90	3	0.11	4	1.48
North Dakota	50	-	-	-	-	-	2	21.23	-	-	-	-	-	-
Ohio	50	-	-	-	-	-	-	-	-	-	-	-	-	-
Oklahoma	7	9.84	-	-	-	-	3	0.45	16	2.46	2	0.19	1	-
Oregon	10	-	-	-	-	-	-	-	-	-	-	-	-	-
Pennsylvania	36	-	1	2.27	3	-	5	-	15	-	11	-	17	0.15
Rhode Island	2	-	-	-	-	-	-	-	-	-	-	-	-	-
South Carolina	3	7.76	-	-	-	-	-	-	6	0.71	-	-	1	0.23
South Dakota	1	1.82	-	-	-	-	-	-	-	-	-	-	-	-
Tennessee	2	-	-	-	-	-	-	-	2	-	2	-	-	-
Texas	29	69.75	-	-	-	-	8	-	24	5.96	2	0.42	11	36.77
Utah	4	-	-	-	-	-	-	-	11	6.06	6	0.23	-	-
Vermont	22	-	-	-	-	-	-	-	1	0.57	11	-	-	-
Virginia	-	-	-	-	-	-	-	-	7	18.93	-	-	1	-
Washington	40	33.01	-	-	-	-	9	5.11	16	0.72	2	0.08	31	58.06
West Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wisconsin	1	0.19	-	-	-	-	-	-	1	-	17	0.87	17	13.02
Wyoming	21	0.68	-	-	-	-	-	-	-	-	-	-	-	-
	1,642		14		22		173		466		124		239	

Table 12 (Continued). ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES

SIC No.	204 Grain Mills		206 Sugar		208 Beverages		209 Seafood		22 Textiles		221 Cotton Mills		222 Man-Made Fibers		223 Wool	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	3	4.12	-	-	-	-	2	-	7	10.45	6	11.28	-	-	-	-
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Arkansas	-	-	-	-	-	-	-	-	2	2.65	-	-	-	-	-	-
California	5	6.81	15	4.92	31	8.48	5	-	-	-	-	-	-	-	-	-
Colorado	-	-	10	126.04	-	-	-	-	-	-	-	-	-	-	-	-
Connecticut	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-
Delaware	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Florida	2	0.64	10	1.21	2	-	2	-	1	-	-	-	-	-	-	-
Georgia	-	-	-	-	-	-	-	-	29	83.63	-	-	-	-	-	-
Hawaii	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Idaho	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Illinois	2	-	-	-	1	-	2	-	-	-	-	-	-	-	-	-
Indiana	2	1.36	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Iowa	-	-	-	-	-	-	3	0.87	-	-	-	-	-	-	-	-
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kentucky	-	-	-	-	-	-	-	-	1	0.38	-	-	-	-	-	-
Louisiana	4	-	39	-	2	-	35	-	-	-	-	-	-	-	-	-
Maine	2	8.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maryland	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Massachusetts	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	0.98
Michigan	-	-	1	-	2	-	1	-	-	-	-	-	-	-	-	-
Minnesota	2	-	3	34.21	-	-	1	-	-	-	-	-	-	-	-	-
Mississippi	1	-	-	-	5	0.91	5	5.03	3	2.35	-	-	-	-	-	-
Missouri	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-
Montana	-	-	2	2.27	-	-	-	-	-	-	-	-	-	-	-	-
Nebraska	65	1.21	4	53.03	2	-	2	-	-	-	-	-	-	-	-	-
Nevada	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Hampshire	-	-	-	-	-	-	-	-	1	1.06	1	6.81	-	-	1	3.03
New Jersey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Mexico	-	-	-	-	-	-	-	0.10	1	-	-	-	-	-	-	-
New York	-	-	-	-	2	0.64	2	-	1	0.76	1	-	-	-	-	-
North Carolina	-	-	-	-	1	0.19	2	7.49	10	4.84	4	1.36	1	-	1	12.30
North Dakota	-	-	3	7.57	-	-	-	-	-	-	-	-	-	-	-	-
Ohio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oklahoma	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oregon	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Pennsylvania	2	-	-	-	2	0.79	2	-	6	-	-	-	-	-	-	-
Rhode Island	-	-	-	-	-	-	-	-	-	-	-	-	1	0.66	-	-
South Carolina	-	-	-	-	1	1.36	-	-	9	22.33	6	12.77	2	1.00	-	-
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tennessee	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-
Texas	5	27.82	5	85.88	3	5.87	9	0.24	1	0.54	3	20.82	-	-	-	-
Utah	-	-	5	34.33	-	-	1	-	-	-	-	-	-	-	-	-
Vermont	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Washington	-	-	10	30.05	3	2.42	6	0.26	-	-	-	-	-	-	-	-
West Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wisconsin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	98		112		59		82		76		22		5		3	

Table 12 (Continued). ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES

SIC No.	226 Dyeing		24 Lumber		243 Millwork and Others		26 Paper Products		261 Pulp Mills		266 Asbestos Paper		28 Chemical Products		281 Inorganics	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	-	-	11	51.85	6	0.75	11	769.22	2	235.28	-	-	-	-	10	10.37
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	1	-	1	-	-	-	-	-	1	-	-	-
Arkansas	-	-	8	3.60	-	-	3	153.37	2	93.57	-	-	5	5,784.77	2	-
California	-	-	49	965.02	-	-	2	0.87	-	-	-	-	2	1.93	6	93.11
Colorado	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Connecticut	-	-	-	-	-	-	1	-	-	-	-	-	-	-	2	2.23
Delaware	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4.35
Florida	-	-	3	-	-	-	6	312.27	-	-	1	-	-	-	9	-
Georgia	-	-	5	1.21	-	-	11	1,206.60	-	-	-	-	25	149.90	-	-
Hawaii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Idaho	-	-	3	469.34	-	-	-	-	-	-	-	-	-	-	-	-
Illinois	-	-	1	-	-	-	4	-	-	-	1	-	3	-	10	-
Indiana	-	-	1	-	-	-	1	-	-	-	-	-	-	-	5	2.91
Iowa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	7.00
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Kentucky	-	-	2	-	-	-	-	-	-	-	-	-	11	88.42	-	-
Louisiana	-	-	17	-	10	-	7	-	4	-	2	-	-	-	46	-
Maine	-	-	1	56.78	-	-	1	11.73	1	87.06	-	-	-	-	-	-
Maryland	-	-	2	-	-	-	1	-	-	-	-	-	-	-	7	-
Massachusetts	-	-	-	-	-	-	4	15.90	1	-	-	-	1	-	2	0.30
Michigan	-	-	4	0.44	-	-	5	0.45	1	1.14	-	-	1	-	15	-
Minnesota	-	-	-	-	1	1.38	1	-	-	-	1	18.93	-	-	-	-
Mississippi	-	-	18	2.27	9	5.49	5	347.35	1	163.13	2	19.38	2	3.44	3	133.19
Missouri	-	-	1	0.19	-	-	-	-	-	-	-	-	2	-	1	0.26
Montana	-	-	3	54.28	-	-	-	-	1	15.52	-	-	-	-	-	-
Nebraska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	78.77
Nevada	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Hampshire	-	-	-	-	-	-	12	250.98	2	3.60	1	1.02	-	-	-	-
New Jersey	1	3.13	-	-	-	-	-	-	-	-	1	-	-	-	13	1.59
New Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-
New York	1	1.51	-	-	-	-	12	93.72	-	-	1	-	1	-	24	36.37
North Carolina	10	44.13	6	2.23	7	0.30	11	256.47	1	60.56	1	0.57	10	1.10	5	15.78
North Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ohio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oklahoma	-	-	8	0.45	-	-	1	0.13	-	-	6	-	-	-	10	2.80
Oregon	-	-	20	-	20	-	-	-	10	-	-	-	-	-	-	-
Pennsylvania	3	-	3	-	1	-	16	1.36	-	-	3	-	2	-	23	-
Rhode Island	1	1.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
South Carolina	5	66.67	1	0.42	2	-	4	57.57	-	-	1	-	-	-	4	5.84
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tennessee	-	-	-	-	-	-	1	4.73	-	-	-	-	1	3.79	6	0.79
Texas	-	-	19	6.44	5	5.49	10	149.68	6	131.72	-	-	6	4,174.86	63	6,523.42
Utah	-	-	-	-	-	-	-	-	-	-	-	-	1	-	5	2.20
Vermont	-	-	-	-	-	-	10	15.90	-	-	-	-	-	-	1	-
Virginia	-	-	-	-	-	-	1	2.31	4	19.72	-	-	-	-	1	0.45
Washington	-	-	16	29.49	8	1.89	14	17.79	2	135.81	1	-	2	-	4	1.40
West Virginia	-	-	-	-	-	-	-	-	-	-	-	-	4	-	6	222.44
Wisconsin	-	-	2	0.36	2	0.22	-	-	3	46.93	-	-	-	-	-	-
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
	21		205		72		156		41		22		80		293	

Table 12 (Continued). ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES

SIC No.	282 Plastics		283 Drugs		284 Soaps		285 Paints		286 Organics		287 Agricultural (Chemicals)		289 Miscellaneous (Chemicals)	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	2	17.37	-	-	-	-	-	-	1	7.12	2	-	-	-
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	-	-	1	-	1	-	2	-	-	-
Arkansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-
California	1	1.14	-	-	-	-	-	-	4	-	2	6.43	4	-
Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Connecticut	1	1.64	-	-	1	52.99	1	-	-	-	-	-	-	-
Delaware	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Florida	2	-	-	-	-	-	-	-	7	0.11	16	-	1	-
Georgia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hawaii	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Idaho	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Illinois	7	-	-	-	2	-	1	-	-	-	4	-	-	-
Indiana	2	5.68	2	-	1	-	1	-	-	-	-	-	3	2.46
Iowa	3	19.34	-	-	1	0.38	-	-	-	-	3	228.13	1	1.63
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kentucky	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Louisiana	13	-	1	-	1	-	-	-	15	-	16	-	9	-
Maine	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maryland	1	-	-	-	-	-	-	-	-	-	1	-	-	-
Massachusetts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Michigan	2	-	1	-	-	-	1	-	11	2.54	-	-	6	0.55
Minnesota	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Mississippi	5	24.45	1	1.70	-	-	-	-	1	4.35	3	239.74	-	-
Missouri	-	-	1	-	-	-	-	-	-	-	2	4.16	-	-
Montana	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Nebraska	-	-	1	-	-	-	1	-	-	-	2	5.64	-	-
Nevada	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Hampshire	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Jersey	2	18.93	4	6.47	-	-	-	-	10	0.26	-	-	-	-
New Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New York	2	2.65	1	1.32	-	-	-	-	-	-	1	20.44	2	-
North Carolina	7	12.49	3	2.42	1	-	-	-	-	-	2	-	2	1.32
North Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ohio	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oklahoma	1	0.19	1	1.89	1	-	-	-	2	-	2	2.35	1	-
Oregon	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pennsylvania	10	-	3	0.19	1	-	-	-	-	-	5	37.85	16	-
Rhode Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-
South Carolina	5	3.79	1	3.41	-	-	-	-	1	-	1	-	1	-
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tennessee	3	-	-	-	-	-	-	-	-	-	-	-	1	-
Texas	46	1,153.90	-	-	5	-	3	0.95	98	2,993.89	23	88.60	12	0.90
Utah	-	-	-	-	-	-	-	-	3	5.56	-	-	-	-
Vermont	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Virginia	2	2.65	1	-	-	-	-	-	-	-	-	-	-	-
Washington	-	-	-	-	-	-	-	-	1	-	3	0.45	2	1.97
West Virginia	1	424.64	-	-	-	-	-	-	-	-	1	-	-	-
Wisconsin	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120		21		14		9		155		92		62	

Table 12 (Continued). ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES

SIC No.	29 Petroleum Refining		30 Rubber Products		31 Leather Products		311 Leather Tanning		32 Stone Products		33 Metal Products		34 Fabricated Metal Products		35 Machinery	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	3	1.93	3	0.26	-	-	-	-	-	-	9	46.25	13	1.93	2	1.66
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	-	-	-	-	3	-	-	-	1	-	-	-
Arkansas	-	-	-	-	-	-	-	-	5	11.73	4	-	2	0.26	-	-
California	29	713.43	3	2.65	-	-	-	-	44	16.58	8	3.94	10	-	12	0.53
Colorado	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1	0.19
Connecticut	-	-	-	-	-	-	-	-	1	7.57	1	-	15	10.11	1	0.58
Delaware	1	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Florida	2	-	-	-	-	-	-	-	41	2.08	2	-	19	0.15	5	5.30
Georgia	5	0.59	2	0.68	1	1.63	-	-	3	1.42	-	-	3	5.05	-	-
Hawaii	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Idaho	-	-	-	-	-	-	-	-	-	-	2	40.88	-	-	-	-
Illinois	14	-	5	-	-	-	-	-	7	-	13	-	3	-	5	-
Indiana	50	33.50	1	-	1	-	-	-	15	7.83	8	2,616.15	9	9.05	-	-
Iowa	5	-	4	8.42	-	-	-	-	2	4.35	-	-	3	0.32	2	-
Kansas	16	70.82	-	-	-	-	-	-	-	-	-	-	6	24.94	-	-
Kentucky	2	-	2	8.86	-	-	-	-	-	-	-	-	2	-	-	-
Louisiana	35	-	3	-	-	-	-	-	16	-	5	-	7	-	3	-
Maine	-	-	-	-	-	-	2	7.12	1	-	-	-	1	3.48	-	-
Maryland	2	-	2	-	-	-	1	-	8	-	3	-	1	-	1	-
Massachusetts	1	-	-	-	-	-	1	3.75	1	-	1	1.06	13	0.72	-	-
Michigan	11	1.88	12	2.64	-	-	-	-	19	0.11	25	5.52	37	6.53	7	0.79
Minnesota	3	13.09	-	-	-	-	-	-	1	2.73	-	-	1	-	2	-
Mississippi	6	11.77	2	3.86	-	-	-	-	25	56.59	5	0.38	4	1.32	2	0.61
Missouri	2	-	-	-	-	-	-	-	16	11.36	4	31.79	-	-	3	0.53
Montana	16	23.58	-	-	-	-	-	-	3	6.92	4	235.81	-	-	-	-
Nebraska	1	11.85	-	-	-	-	-	-	105	-	-	-	6	-	2	2.31
Nevada	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Hampshire	-	-	1	-	-	-	4	2.91	2	-	3	1.93	1	0.27	1	-
New Jersey	35	-	-	-	-	-	-	-	15	3.86	-	-	1	-	1	-
New Mexico	19	1,422.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New York	2	151.97	-	-	1	-	-	-	32	7.31	5	5.19	2	0.65	-	-
North Carolina	3	0.95	-	-	-	-	-	-	29	5.07	5	0.64	7	1.89	2	-
North Dakota	1	1.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ohio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oklahoma	4	-	3	1.02	-	-	-	-	17	21.20	9	3.22	7	-	4	-
Oregon	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Pennsylvania	42	17.41	6	-	1	-	-	-	59	6.06	63	81.00	20	-	12	-
Rhode Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
South Carolina	1	2.31	2	9.34	-	-	-	-	4	1.97	1	0.49	4	4.03	3	1.94
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tennessee	8	-	2	-	-	-	-	-	4	4.73	1	1.14	5	53.71	2	-
Texas	116	1,465.08	5	4,345.18	-	-	1	-	50	29.72	67	682.00	19	2.57	15	16.91
Utah	5	14.65	-	-	-	-	1	-	3	1.29	16	307.49	3	0.57	-	-
Vermont	-	-	-	-	-	-	5	1.14	60	0.38	-	-	-	-	-	-
Virginia	-	-	-	-	1	2.31	-	-	-	-	-	-	-	-	-	-
Washington	26	3.10	-	-	-	-	-	-	26	7.76	7	162.64	2	-	-	-
West Virginia	1	0.23	-	-	2	0.35	-	-	1	-	5	0.93	2	2,559.80	-	-
Wisconsin	-	-	-	-	-	-	-	-	3	1.25	4	-	4	1.70	-	-
Wyoming	4	11.61	-	-	-	-	-	-	1	-	-	-	-	-	-	-
	471		58		7		15		626		280		234		88	

Table 12 (Continued). ESTIMATE OF NUMBERS OF INDUSTRIAL IMPOUNDMENT SITES AND FLOW DATA, BY SIC CODES

SIC No.	36 Electrical Machinery		37 Transportation		38 Instruments		39 Miscellaneous Manufacturing		49 Utility Services		Undifferentiated	
State	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow	No.	Flow
Alabama	1	-	1	0.91	1	0.23	6	136.67	6	202.46	-	-
Alaska	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	1	-	-	-	4	-	-	-
Arkansas	-	-	-	-	1	-	2	-	2	-	4	0.87
California	2	0.19	4	608.63	3	-	4	-	106	1.04	147	43.53
Colorado	-	-	-	-	-	-	-	-	10	1,889.83	-	-
Connecticut	2	1.06	2	2.54	-	-	1	0.25	9	2.91	1	-
Delaware	-	-	-	-	-	-	-	-	-	-	28	-
Florida	4	-	4	-	1	-	2	0.59	15	-	-	-
Georgia	-	-	2	-	-	-	1	13.63	10	208.55	-	-
Hawaii	-	-	-	-	-	-	-	-	4	-	19	-
Idaho	-	-	-	-	-	-	-	-	-	-	-	-
Illinois	3	-	5	-	-	-	-	-	84	-	47	-
Indiana	1	0.26	7	2.04	-	-	2	-	71	2,518.31	3	-
Iowa	-	-	-	-	-	-	-	-	2	1.34	29	23.81
Kansas	-	-	4	14.91	-	-	1	-	-	-	-	-
Kentucky	1	2.31	2	1.45	-	-	-	-	4	-	-	-
Louisiana	2	-	3	-	1	-	-	-	74	-	117	-
Maine	1	-	-	-	-	-	-	-	10	4.81	21	101.59
Maryland	-	-	1	-	1	-	-	-	9	-	16	-
Massachusetts	1	-	-	-	-	-	1	0.15	9	10.83	1	0.11
Michigan	6	0.88	15	0.20	2	-	-	-	6	1.71	6	0.16
Minnesota	-	-	-	-	-	-	-	-	2	171.10	1	-
Mississippi	7	4.35	2	7.12	-	-	1	8.74	18	3,240.57	35	25.59
Missouri	1	0.29	4	10.90	-	-	-	-	6	3,062.44	6	-
Montana	-	-	3	0.11	-	-	-	-	2	3.07	-	-
Nebraska	-	-	-	-	-	-	-	-	3	12.45	6	5.11
Nevada	-	-	-	-	-	-	-	-	-	-	10	-
New Hampshire	1	1.94	-	-	-	-	-	-	1	-	9	39.10
New Jersey	1	0.45	1	-	1	7.57	-	-	9	5.53	100	-
New Mexico	-	-	-	[illegible]	-	-	-	-	8	0.37	-	-
New York	4	0.17	4	84.18	2	16.39	-	-	5	20.29	100	0.26
North Carolina	4	2.12	3	1.21	1	6.74	1	-	31	647.88	11	0.91
North Dakota	-	-	-	-	-	-	-	-	7	545.57	1	4.92
Ohio	-	-	-	-	-	-	-	-	-	-	600	-
Oklahoma	3	-	2	-	-	-	-	-	219	5.00	4	0.38
Oregon	-	-	-	-	-	-	-	-	20	-	-	-
Pennsylvania	16	-	1	-	5	-	1	-	151	105.98	1,937	-
Rhode Island	1	0.38	-	-	-	-	-	-	-	-	7	14.19
South Carolina	3	0.45	1	-	2	1.02	1	0.15	2	-	-	-
South Dakota	-	-	-	-	-	-	-	-	2	1.34	30	-
Tennessee	2	-	1	-	-	-	-	-	3	-	2	2.27
Texas	4	8.44	14	185.80	-	-	-	-	226	37,304.96	96	19.07
Utah	-	-	-	-	-	-	-	-	1	0.55	-	-
Vermont	2	6.81	-	-	1	1.82	-	-	1	0.38	100	-
Virginia	-	-	-	-	-	-	-	-	-	-	200	-
Washington	-	-	1	8.14	-	-	-	-	4	3.44	-	-
West Virginia	-	-	-	-	-	-	-	-	8	916.69	200	2.65
Wisconsin	-	-	-	-	-	-	-	-	25	4.39	6	49.20
Wyoming	-	-	-	-	-	-	-	-	5	3.94	-	-
	73		87		23		24		1,194		3,900	

SECTION XII

APPENDIX C - SPECIFIC INDUSTRIAL WASTE CHARACTERIZATIONS

SIC 01 - AGRICULTURAL PRODUCTION - CROPS

This group includes establishments (farms, orchards, greenhouses, nurseries, etc.) primarily engaged in the production of crops or plants, vines, and trees (excluding forestry operations). There are relatively few waste impoundments associated with the crop farming segment of the food industry. Many farms, particularly in western States, maintain irrigation reservoirs but these generally contain fresh water rather than wastewater. The only significant volume of waste material produced by crop farms are the unusable parts of plants such as leaves, hulls, chaff, etc., which are usually recycled back into the soil. Fertilizers and pesticides may cause contamination where these substances seep into ground water.

SIC 02 - AGRICULTURAL PRODUCTION - LIVESTOCK

The contaminants of primary concern in wastes from feedlot operations are high BOD, high COD, nitrogen, phosphate, and certain trace constituents such as inorganic salts. In addition, pharmaceuticals and pesticides occasionally may be found in runoff water. Traces of copper are reported in waste from swine-raising operations, but are usually minimal. Color and turbidity from manure runoff are also contaminants of concern. Occasionally, pathogenic organisms exist in manure, although there are no data to indicate that this is a chronic problem. Impoundments for holding runoff are less of a threat than those for raw waste, owing to the difference in concentrations of contaminants.

SIC 10 - METAL MINING

In addition to the extraction of ore from the ground, many metal-mining facilities also include ore beneficiation and dressing operations, which are designed to separate the metal-bearing minerals from unwanted material and to prepare the ore for shipment or further processing. The unwanted material is often disposed of in large impoundments referred to as tailings ponds.

A variety of wastewater is generated by mining operations, and the mines make extensive use of large impoundments, both for wastewater treatment and for waste disposal. In general, the sizes of the impoundments employed by the larger mining facilities can be many times greater than those used in many other major industries.

Although mines differ greatly in size, configuration, type of minerals mined, and type of beneficiation process, the major wastewater streams from mines are generally from the following sources:

1. Mine water refers to ground water that drains through underground ore seams, contacts the exposed material in open pit mining, or seeps or overflows from tailings ponds and other impoundments. Its volume and composition depend on the type of mining operation and the local ground-water environment.

2. Process water is that water used in the hydraulic transport of ore slurries, in the various washing and beneficiation processes, and in the operation of air-pollution control equipment. It may be contaminated with the naturally occurring minerals contained within the ore and with chemical agents used in the various extraction and beneficiation processes.

The following sections describe the types of impounded wastes for the major categories of metal-mining operations.

<u>SIC 101 - Mining of Iron Ores</u>

There are three main sources of wastewater in the mining and processing of iron ore:

1. Mine drainage.

2. Process water from thickeners and flotation units.
3. Water used in the hydraulic transport of ore slurries and tailings; this is usually the largest source of wastewater.

Mine drainage can contain dissolved salts such as chloride, sulfate, calcium, magnesium, etc. It is relatively neutral and may contain traces of nitrate and ammonia owing to the use of blasting agents.

Processing wastewater from ore beneficiation operations can contain organic flotation agents, acid, clay, oil and grease, and a variety of minerals dissolved from the ore itself. Concentrations of dissolved metals are generally less than 10 mg/l.

The material in tailings ponds is a dense wet sludge having a solids concentration of 10 to 50 percent by weight. The water fraction of the tailings, which can leak out of the sides or the bottom of the pond, contains dissolved minerals from the ore itself. The water is relatively neutral and contains low concentrations of dissolved salts and heavy metals.

SIC 102 - Mining of Copper Ores

Many of the same general types of wastes generated by the mining of iron ore are generated in copper mining. However, many copper mines, in addition to extracting high grade ore from the ground, employ hydrometallurgical leaching techniques using sulfuric acid to dissolve copper from low grade ores.

Most copper mine drainage water is relatively neutral. However, where copper and iron sulfide minerals are present, some mines may produce acidic wastewater not unlike the acid mine drainage from coal mines (see SIC 12, Coal Mining). Many mines utilize mine water for ore processing, thus reducing the amount of water discharged.

In the hydrometallurgical extraction of copper from dumps of low grade ores and waste materials, generally from open-pit mining operations, leaching solutions, composed of tailings, pond water, makeup water, and, in some cases, sulfuric acid, are distributed over the dumps and are allowed to percolate through them. The copper-bearing fluid is collected and subjected to further processing. Very large tailings ponds are used in processing copper ore, and a large fraction of the tailings pond overflow is recycled to the leaching dumps and other uses. The water fraction of the solids deposited in the tailings ponds is slightly alkaline, containing moderate amounts of solids (primarily magnesium, calcium, sulfate, and chloride) along with trace amounts of heavy metals.

SIC 103 - Mining of Lead and Zinc Ores

Lead and zinc-bearing ores are commonly mined and processed together. The mine water can range from slightly acidic to slightly alkaline and can contain traces of heavy metals. Generally, the more acidic the water, the greater will be the metals concentration. As in most other kinds of mining operations, tailings ponds are employed, both to dispose of waste material and to settle out suspended particles in process water prior to recycling. The water fraction of the material deposited in tailings ponds can contain dissolved salts, trace concentrations of heavy metals, and small concentrations of surfactants used as flotation reagents. The water also contains a rather high COD, which may be caused by organic reagents used in the process or by reduced metallic species.

SIC 104 - Mining of Gold and Silver Ores

Water from primary gold and silver mining can contain dissolved salts and trace quantities of heavy metals. The primary source of wastewater is in the beneficiation process, which in addition to the common processes of classification, flotation, and thickening, also includes cyanidation, amalgamation, and carbon adsorption. Tailings ponds are used in both types of mining, and the composition of the water fraction of the tailings is not unlike that of lead and zinc mining.

SIC 105 - Mining of Bauxite and Other Aluminum Ores

Depending on the nature of associated minerals and the local groundwater situation, mine water from bauxite mining can be either moderately acidic or moderately alkaline. Acidic mine water can have a pH in the range of 2.8 to 3.5, dissolved solids (primarily sulfates) in the range of 500 to 1200 mg/l, and a variety of dissolved heavy metals in the 1 to 10 mg/l range. Trace amounts of fluoride also are present.

SIC 106 - Mining of Ferroalloy Ores

Ferroalloy ores include cobalt, chromium, columbium, tantalum, manganese, molybdenum, nickel, and tungsten. Mining and beneficiation processes are largely similar to those employed in iron and copper ores. Tailings ponds are used, and the water fraction of the tailings can contain dissolved salts and trace quantities of heavy metals.

SIC 109 - Mining of Miscellaneous Metal Ores

This group includes the mining of the ores of mercury, uranium, radium, vanadium, antimony, beryllium, platinum, titanium, and rare-earth ores. With the exception of the mining of uranium and radium, where low levels of radiation present unique safety and environmental problems, wastewater from tailings ponds and other operations are generally similar to those of other mining operations. Many of the beneficiation processes include ammonia leaching and solvent extraction, which provide opportunity for ammonia and organic solvents to enter wastewater streams.

SIC 11 - ANTHRACITE COAL MINING AND SIC 12 - BITUMINOUS COAL MINING

The mining and preparation of anthracite and bituminous coal are very similar with respect to the use of waste impoundments and the composition of waste materials generated; therefore, these two groups are considered together.

Water is not an inherent part of coal-mining operations. However, large quantities of wastewater are generated by water entering the coal seams and coming in contact with the coal and other minerals. Water passing through coal mines may become somewhat acidic due to complex chemical reactions involving sulfur and iron compounds (pyrite); this water is referred to as "acid mine drainage." The drainage from underground and surface mines tends to be similar in composition where the geology is similar. The most troublesome characteristics of acid mine drainage are its low pH and relatively high acidity and concentrations of dissolved iron. In places, manganese may also be present in high concentrations.

The treatment of acid mine drainage is mainly designed to neutralize the acidity and to precipitate the dissolved iron and other metallic ions. Large earthen holding ponds are used at some installations to collect the mine drainage and to equalize the flow of wastewater prior to treatment. After equalization, lime is added and the acid mine drainage is sent to aeration ponds where the iron is first oxidized to the ferric state and then precipitated as ferric hydroxide. The precipitated ferric hydroxide and other metallic hydroxides, carbonates, and sulfates are then settled out and sent to a sludge-holding pond. Although the metallic hydroxides in the sludge are mostly in the solid phase, small amounts still remain in the liquid phase, and should the sludge be exposed to acidic conditions, further dissolution of the hydroxides can occur.

Because of geologic conditions, many mines produce water that is slightly alkaline and contains low concentrations of metals. This drainage water is usually only subjected to suspended solids removal in large earthen ponds.

Coal preparation, in which coal is sized and graded and where undesirable minerals are removed from the coal, can produce large volumes of slurry-like waste material which is disposed of in impoundments. Leachate from these impoundments can be similar in composition to acid mine drainage.

It should be noted that waste impoundments associated with coal mining and preparation operations often occupy hundreds of acres (hundreds of hectares). Therefore, they have a potential for causing extensive ground-water contamination where significant amounts of water seep into ground water from the impoundments.

SIC 13 - OIL AND GAS EXTRACTION

The oil and gas extraction industry generates both intermittent wastes and continuous wastewater streams. Intermittent wastes are produced during drilling operations and include drilling muds and drill cuttings. Drilling mud consists of either clay/water mixtures or clay/oil mixtures.

Once the well has been drilled and oil or gas is pumped from the ground, a continuous wastewater stream commonly referred to as "produced water" is generated. Produced water consists of water residing with the oil in the underground geological formations. It is usually quite saline, and by the time it leaves the well, it contains a significant amount of the crude oil.

The total dissolved solids concentration of product water can often exceed 100,000 mg/l. Produced water is usually treated for the removal of oil and suspended solids. In many places, treatment takes place in steel tanks and concrete basins. Elsewhere, earthen lagoons are used. In parts of the western United States, produced water is disposed of by discharge into large earthen evaporation ponds.

SIC 14 - MINING OF NONMETALLIC MINERALS

Most of the operations included in this category produce wastewater streams of widely varying contamination potential. Impoundments are commonly utilized by this industry as settling ponds for wastewater treatment, as waste-disposal or "tailings ponds," and as material storage areas. The characteristics of selected wastes from this category are described in the following paragraphs.

Kaolin clay, in terms of production, is the major clay produced in the U.S. Most kaolin mining and processing operations produce a wastewater contaminated with zinc (from the addition of zinc hydrosulfite) and dissolved solids, mostly in the form of sulfates and sulfites. Many facilities use lime precipitation for removing zinc from wastewater streams prior to discharge. The waste treatment is generally carried out in earthen ponds, so the potential for ground-water contamination does exist. Tailings generated from the production of kaolin clay leave the process prior to the introduction of zinc hydrosulfite and, therefore, are not contaminated with zinc.

The mining and processing of feldspar can produce wastewater contaminated with fluorides, sulfates, amines, oils, and organic frothing agents. Fluoride concentrations can be in the 10 to 100 mg/l range. The mining and processing of other minerals used for refractories can also produce wastewater streams contaminated with low concentrations of organic flotation agents.

The mining and processing of talc, soapstone, and pyrophyllite produce wastewater streams that are largely contaminated with suspended solids. Tailings ponds are employed for the disposal of the waste fractions of the ore. Where flotation is used, small quantities of organic flotation agents may be present.

Barite mining uses water in various processing operations, and the water is extensively recycled prior to discharge. Large earthen settling basins are used for wastewater treatment. Tailings ponds are also used for disposal of unwanted mineral fractions. The wastewater can contain moderate amounts of dissolved solids (500 to 1,000 mg/l) as well as traces of heavy metals (less than 1 mg/l). Acidic mine water is also produced by certain facilities.

Fluorspar mining produces a wastewater contaminated with fluoride, lead, and zinc, as well as organic flotation agents. The fluoride concentrations are generally less than 1.0 mg/l. Large tailing ponds are used for the disposal of waste materials. Some mines produce a relatively neutral mine-water discharge stream containing low concentrations of heavy metals.

Potash, soda, and borate minerals are commonly recovered by solution mining by either evaporative concentration and separation of naturally occurring brines, by dissolving soluble deposits, or by in-situ leaching wells. Typical of this segment of the industry are very large earthen evaporation ponds filled with water containing very high concentrations of dissolved inorganic salts. The salts in evaporation ponds used in the potash industry commonly consist of potassium, sodium, magnesium, chloride, and sulfate. A large percentage of soda ash is produced from trona ore deposits in Wyoming, and the water in the tailings and evaporation ponds contains sodium, chloride, carbonate, and other dissolved salts.

Borate mining is carried out in the desert areas of California. The borate ore is dissolved in water and then subjected to several evaporation, crystallization, and separation steps. Large evaporation ponds are used. The water is very high in alkalinity (10,000 mg/l as $CaCO_3$).

Most phosphate ore is processed through flotation. The major wastes are slimes and flotation tailings which consist primarily of clay and sand. Large tailings ponds are used. The water fraction of the tailings contains low concentrations of phosphate and fluoride (less than 20 mg/l). The tailings also exhibit low levels of radioactivity due to the presence of trace amounts of radium-226 and uranium.

Rock salt is mined from underground salt domes or horizontal beds of salt. The salt is relatively pure. Some wastewater is produced from equipment washing and surface runoff. The primary contaminant is the salt itself, which is usually present in the 5,000 to 20,000 mg/l concentration range.

Most sulfur in the U.S. is hydraulically mined by forcing superheated water under pressure into underground sulfur-bearing formations which also contain salt deposits. The melted liquified sulfur is brought to the surface through the main sulfur mining well. The cooled down injected water which contains a small percentage of salt, small amounts of sulfides, and other inorganic sulfur compounds is then brought to the surface by means of "bleed" wells. Treatment of bleedwater usually consists of oxidizing the sulfides to sulfates in large earthen ponds. Most sulfur mining facilities are located on the Gulf Coast in Texas and Louisiana and discharge their treated effluent into brackish water or seawater.

SIC 16 - HEAVY CONSTRUCTION

This group encompasses nearly all large public and industrial construction activities, most of which involve extensive earth moving and excavation. Soil erosion and runoff water heavily laden with suspended solids are common sources of contamination problems associated with construction sites. The pumping of drainage water from foundations and open trenches also produces large quantities of muddy water. Water around construction sites is often contaminated with oil and gasoline from equipment, cement truck washout water, and general trash.

Efforts to control these sources of contamination have resulted in the use of temporary impoundments to collect construction site drainage and to settle out suspended solids. Water in these impoundments either slowly seeps back into the ground, or if the flow to the impoundment is sufficiently continuous, overflows from the impoundment.

Dredging of swamps, rivers, or other bodies of water, in one way or another, removes solid material accumulated on the floor of a body of water and deposits it elsewhere, usually on land near the dredging location. The material thus transferred is referred to as "dredging spoils," and is rather fluid, containing solid material mixed with large volumes of water. Dredging spoils are often deposited in large diked areas. Because these impoundments are seldom, if ever, lined, it is possible for the liquid fraction of the dredging spoils to seep into ground water.

The composition of dredging spoils is as varied as the composition of the material deposited in bodies of water. If the dredging spoils are taken from a swampy area, the material will generally contain large amounts of organic matter from decaying vegetation, as well as phosphates and nitrogenous compounds. Although much of this is present in the solid phase, it is quite possible for a large amount to be leached into a liquid fraction. Dredging spoils taken from highly polluted rivers can contain oily substances, heavy metals, pesticides, and synthetic organic compounds. Again, while most of these are usually in the solid phase, they do have finite solubilities and, therefore, can be a source of ground-water contamination. If dredging spoils, taken from an estuary containing saline water, are deposited in an area having low salinity ground water, contamination of ground water due to salinity could become a problem.

Although there is no typical composition of dredging spoils, the extent to which this material can be contaminated can be seen in the following partial analysis of sediment from Baltimore Harbor:

Heavy Metals	Concentration (ppm) (Dry-weight basis)
Zinc	2,600
Lead	1,503
Cadmium	193
Copper	320
Chromium	3,035

SIC 20 - FOOD AND KINDRED PRODUCTS

Impoundments are significant parts of waste-treatment systems in the food and kindred products industry. The parameters of concern are primarily BOD and suspended solids but may also include COD, oil, grease, salts, and others, depending on the specific segment of the industry. The major wastewater in the industry comes from washing and peeling fruits and vegetables, preparing other incoming materials, cleaning and washing down equipment, and cooking. Most of these operations produce high BOD and suspended solids.

Wastewater handling in the industry ranges from raw discharge to receiving waters or sewers to use of in-plant treatment systems. Biological treatment is the preferred method and usually includes either aerated or non-aerated oxidation ponds. Some plants utilize impoundments to hold water or slurries from washing or other operations; where these ponds are unlined, a potential for contamination of ground water may exist.

SIC 22 - TEXTILE MILL PRODUCTS

Less than one-third of all textile mills have substantial wet operations that result in wastewater discharge. This wastewater is associated with processing and rinsing steps in the dyeing and finishing operations.

The wastewater can contain animal residues (wool-scouring operations), acids, alkalies, and soap and detergents used in yarn and fabric cleaning. A large variety of organic dyes are used, in combination with various dyeing assistants such as inorganic salts, halogenated hydrocarbons, and phenols. Specialized finishes, which impart permanent press, water repellency, and fire retardant characteristics also utilize a complex mixture of organic chemicals. Gross parameters such as BOD, COD, and suspended solids are typically used to characterize textile wastewater rather than the identification of specific compounds. In addition, the presence of dye material causes wastewater from many textile mills to be highly colored, but dyes are only of moderate concern in terms of contamination potential.

Biological treatment is extensively used to treat wastewater in the textile industry. Plants located in urban areas generally discharge to municipal sewage-treatment systems, however, about 500 plants, mostly in the Southeast, have their own secondary wastewater-treatment facilities that consist chiefly of large aerated lagoons.

Dye carriers such as halogenated hydrocarbons and phenols are known to be resistant to biological degradation and may contaminate ground water. Certain heavy metals such as chromium, zinc, and copper may also be present.

SIC 24 - LUMBER AND WOOD PRODUCTS

In logging operations and in sawmill operations, manmade impoundments are used to store logs on their way to further processing (log ponds) and to store, sort, and feed logs into a sawmill (mill ponds). Pond water contains suspended solids from wood fibres and organic matter leached out of the bark and wood.

Although not a concentrated waste, log pond water can have a measurable BOD, in addition to being somewhat colored and containing small amounts of phosphate and nitrogenous compounds. Log ponds and mill ponds typically overflow into a receiving stream. There is presently little treatment of the wastewater, but one of the suggested methods is biological treatment using either aerated or non-aerated oxidation ponds.

A more concentrated wastewater is produced in the processing of logs into either board, plywood, particleboard, or other wood products. Wastewater is generated by log washing, log steaming, veneer processing, glue washing, cooling, and other operations. The wastewater contains organic matter from the wood itself and substances present in the glues that are organic in nature and commonly contain phenolic compounds. The wastewater is largely biodegradable. However, in wood-preserving operations, traces of heavy metals and fluorides can be present in the wastewater, as well as higher concentrations of phenolic and tar-like materials.

SIC 26 - PAPER AND ALLIED PRODUCTS

Pulp and paper mills produce large quantities of process wastewater resulting from wood preparation, pulping, papermaking, bleaching, and other water-using operations. The combined wastewater contains suspended solids resulting largely from the presence of wood fibres and also contains dissolved and colloidal organic material composed largely of chemicals extracted from the wood itself. The organic fraction of the wastewater is typically characterized only in terms of gross parameters such as BOD and COD. Certain segments of the industry produce wastewater containing considerable amounts of color.

Because pulp and paper mill wastewater exhibits a high degree of biodegradability, large, mostly unlined, aerated lagoons are commonly used throughout the industry. Sludge from the wastewater-treatment process is largely biodegradable, although wood fibres generally degrade at a relatively slow rate.

SIC 28 - CHEMICALS AND ALLIED PRODUCTS

Chemicals and allied products form a very complex category that includes literally thousands of products and thousands of different waste streams. A primary waste classification can be made in terms of the inorganic or organic character of the waste. Inorganic components can be changed in form but cannot be destroyed. However, the toxic properties and potential environmental impacts vary sharply with the form of the inorganic components. In theory, waste streams containing organic materials can be treated to destroy the organic material. However, this may not be practical or economic. In addition, many organic waste streams contain inorganic components introduced as a result of the chemical processing.

SIC 287 - Agricultural Chemicals

The two principal categories of agricultural chemicals are fertilizers and pesticides. Fertilizers can be classified as phosphatic and nitrogenous types.

Potential contaminants in the effluents from phosphate fertilizer operations are fluorine, phosphorus, and nitrogen, where ammonia is used as a basic raw material. Potential contaminants from nitrogen fertilizer operations include ammonia, nitrate, nitric acid, and possibly nitrogen dioxide. Most fertilizer complexes combine the effluents from the various process units into a large recycle water system. This contaminated recycle water system is self-contained for a large portion of the year. It is only when local precipitation exceeds the evaporation in a given period that effluent treatment is necessary.

Also associated with the manufacturing of phosphate fertilizers are trace elements such as cadmium, arsenic, vanadium, uranium, and radium, which are present in the phosphate ores in Florida and in western phosphate rocks in small concentrations. In general, these elements are dissolved by the phosphate rock acidulation process and tend to be retained in the acid rather than be discarded with the gypsum waste. Only cadmium is likely to be found in measurable quantities in the gypsum waste which is usually stored in large ponds.

Pesticides include a large group of diverse compounds and mixtures; however, they can be broadly grouped in the following subcategories:

1. Halogenated organic pesticides
2. Organo-phosphorus pesticides
3. Organo-nitrogen pesticides
4. Metallo-organic pesticides
5. Formulators and packages of mixtures of the above materials.

Contaminants from the manufacture of pesticides include BOD, COD, suspended solids, phenol, and various pesticides. Chloride concentrations may be very high. Specific contaminant parameters for organo-nitrogen pesticides are ammonia, ammonia nitrogen, and pesticides. Metallo-organic pesticide operations have little or no wastewater effluent. Toxic metals used in these processes, which may accidentally find their way into ground water, include arsenic, mercury, copper, zinc, tin, and manganese. Wastewater associated with formulation and packaging plants comes from clean up of spills and leaks and from stormwater runoff. Other pollutant parameters considered of secondary importance are settleable solids, dissolved solids, acidity, alkalinity, oil and grease, chloride, and sulfide.

Because of the highly toxic nature of many of these products, a considerable amount of concentrated waste is treated by in-plant control technology; for example, halogenated organic compounds are destroyed by incineration or by adsorption on carbon. Organo-phosphorus and organo-nitrogen compounds can be detoxified by acid or alkaline hydrolysis. Phenols can be removed by adsorption on carbon or resins. Cyanide can be destroyed by oxidation with chlorine.

After removal of the more toxic components, the effluent is generally further treated by secondary biological treatment using trickling filters, activated sludge, or aerated lagoons. Because of the presence of high salt concentrations and toxic residues in the waste, biological treatment is only successful after an acclimatization of the organisms to the particular waste stream.

SIC 29 - PETROLEUM REFINING

U.S. refineries vary in complexity from very small refineries with simple atmospheric fractionation or topping to large integrated refineries manufacturing a multitude of petroleum and petrochemical products from a variety of feedstocks. The raw wastewater load is dependent upon the type of processes employed by the refinery, and treatment technology is a combination of in-plant and end-of-pipe treatment alternatives. The significant wastewater constituents are: BOD, COD, TOC, total suspended solids, oil and grease, phenolic compounds, ammonia, sulfide, and chromium.

The most commonly used wastewater-treatment systems consist of equalization, followed by initial oil and solids removal (API separators, etc.). Further oil and solids are removed by dissolved air flotation or filtration and clarification. The next step is biological treatment mainly by the activated sludge process and aerated lagoons. Final treatment may include a trickling filter, activated carbon, or multi-media filtration.

Suspended solids include both organic and inorganic materials such as sand, silt, and clay. The organic fraction includes grease, oil, tar, and animal and vegetable matter. Ammonia is commonly combined as ammonium sulfide, but can also exist in several other chemical combinations including ammonium chloride. Phenolic compounds are produced by the decomposition of multicyclic aromatics such as anthracene and phenanthrene. Phenol losses also occur from solvent refining operations which use phenol as a solvent. Organic and inorganic sulfur compounds present in wastewaters have their origin in the variety of organic sulfur compounds present in the crude oil. Various types of processing convert these organic sulfur compounds to hydrogen sulfide and hence, to alkali sulfides. Chromium salts occur mainly from the use of chromium compounds added to cooling water for corrosion control. Zinc compounds may be introduced similarly into wastewater.

Most refinery wastewater is alkaline due to the presence of ammonia and the use of caustic soda for sulfur removal. Cracking and crude distillation are the principal sources of alkaline discharges. Alkylation and polymerization utilize acids as catalysts and produce severe acidity problems.

A variety of other metallic ions are found in wastewater discharges. The major sources are the crude oil itself and associated corrosion products. In addition to chromium and zinc, the metal ions most commonly found are aluminum, arsenic, cadmium, cobalt, copper, iron, lead, mercury, nickel, and vanadium.

Chloride is one of the major anions in refinery effluents and is present because large amounts of sodium chloride are often associated with the crude oil in its natural surroundings. Additional chloride may be introduced in the processing, for example, copper chloride, which is used in sweetening processes, and aluminum chloride, which is used in a catalytic isomerization.

SIC 30 - RUBBER AND MISCELLANEOUS PLASTIC PRODUCTS

This category includes only the manufacture of rubber products after the rubber itself has been produced. Process wastewater in the manufacture of tires and inner tubes includes the discharge of solutions used in the manufacturing process, washdown of process areas, runoff from raw material storage areas, and spills and leaks of solvents and lubricating oils. Wet air-pollution control systems also contribute to the waste load. The primary pollutants in the wastewater are oil and grease, suspended solids, acidity or alkalinity (depending on the process), and organic solvents. Most wastewater treatment in the tire industry consists of removal of suspended solids and oil and grease. A number of plants employ settling lagoons.

The wastes from the manufacture of other rubber products are similar to that of tire manufacture in that they contain oil and grease, suspended solids, acidity, or alkalinity. One notable difference is the fabrication of certain types of hose in which small amounts of lead are present in the effluent. Also, certain latex product manufacturing operations produce wastewater containing zinc and chromium.

SIC 31 - LEATHER AND LEATHER PRODUCTS

Leather tanning and finishing generate significant quantities of contaminated wastewater. The combined wastewater streams from these operations contain relatively high concentrations of biodegradable organic matter and moderate amounts of oil and grease, suspended solids, nitrogenous material (ammonia and nitrate), chromium, sulfide, and fecal coliforms.

Sludge from the treatment systems contains large amounts of biodegradable organic matter and much of the same material found in the wastewater. It is usually disposed of in landfills. The most objectionable constituents are chromium, sulfide, and nitrogenous compounds.

SIC 32 - STONE, CLAY, GLASS, AND CONCRETE PRODUCTS

Common constituents in wastewater for the glass, cement, and asbestos industries, include BOD, phosphate, fluoride, copper, lead, and common cations and anions. The glass and asbestos manufacturing industries discharge treated water to receiving bodies. Sludge from the treatment plant goes to a landfill. In the flat glass industry, lagoons are used to reduce suspended solids. Settling ponds serve a similar function for the asbestos industry.

The cement industry utilizes ponds for disposal of waste kiln dust. Some of the water from the ponds may be reused or, if possible, discharged to receiving waters.

SIC 33 - PRIMARY METAL INDUSTRIES

The primary metal industries produce large volumes of wastewater, much of which is treated in earthen impoundments. The industry also produces very large volumes of sludges, slags, dusts, and other solid or semi-solid wastes that are disposed of either in impoundments or in large dumps. Because the primary metal industries incorporate literally hundreds of different operations, many of which generate their own waste streams, only the characteristics of the major waste streams from the more significant operations are examined in the following sections.

SIC 331 - Blast Furnaces, Steel Works, and Rolling and Finishing Mills

This group encompasses most of those facilities constituting the iron and steel industry. Steel mills produce a variety of wastewater streams that are largely the result of the use of wet air-pollution control devices. In terms of volume and pollution potential, some of the more significant wastewater streams are those generated by blast furnaces and rolling operations. Practically all iron and steelmaking operations produce wastewater containing high suspended solids.

Contaminants of concern in blast furnace scrubber water are suspended solids, fluoride, phenol, cyanide, ammonia, and sulfide. Small amounts of heavy metals can also be present. Coke oven wastewater, although relatively small in volume, has very high contents of ammonia and phenols. It is usually treated separately from the other wastewater streams.

Steel mills generate very large volumes of slag, wastewater-treatment sludge, and dusts from air-pollution control systems. A portion of these materials is recycled within the plant to reclaim iron values; but a large volume is destined for land disposal. Large unlined settling ponds are often a part of steel mill wastewater-treatment operations.

Slag can be contaminated with heavy metals such as chromium, copper, manganese, nickel, lead, and zinc, as well as fluoride. Most of these constituents are in the solid phase, but a certain amount of leaching can take place under even slightly acidic conditions.

Wastewater-treatment sludge contains high concentrations of iron oxide, silica, and other inorganics. The water fraction of the sludge can contain fluoride, cyanide, sulfide, phenol, oil and grease, and a variety of trace heavy metals.

SIC 332 - Iron and Steel Foundries

As in the case of steel mills, the major source of wastewater from iron and steel foundries is from the operation of wet air-pollution control systems. The wastewater also contains large amounts of suspended solids. In addition, it can contain fluoride, oil and grease, phenol, sulfide, and trace heavy metals. The organic binders used in molding operations also can result in the wastewater having low to moderate BOD. Many foundry wastewater-treatment facilities employ earthen settling ponds for the removal of suspended solids.

Foundries produce slag, which has a composition not unlike that from steel mill blast furnaces. A large portion of the slag is sold to slag processors who incorporate it into construction materials; but a large fraction is disposed of on land.

Although an increasing number of foundries are practicing sand reclamation, spent molding sand is still a major source of solid waste within the industry. Spent sand is often impounded on or near the foundry site. The sand can contain organic binding materials as well as metallic species that adhere to the particles.

SIC 333 - Primary Smelting and Refining of Nonferrous Metals

Most copper produced in this country is from sulfide ores. In the process, large quantities of sulfur dioxide are generated, which are removed and converted into sulfuric acid. Most of the sulfuric acid is sold commercially, but a portion is utilized internally in various plant operations, such as in the leaching of low-grade ores and in the recovery of byproduct metals. The overall smelting and refining of copper produces a variety of wastewater streams, as well as large quantities of slag and other solid wastes; much of the wastewater is recycled.

Slag, sludge, and other solid wastes are partly recycled to recover metal values, and some are granulated and deposited in tailings ponds, which, in places, also serve as reservoirs for recycle water. The waste material may contain various heavy metals such as cadmium, chromium, copper, mercury, manganese, nickel, lead, tin, selenium, and zinc. Most of the metals are in the solid phase, although low concentrations of some metals are dissolved in the water.

Primary lead in the U.S. is recovered entirely from sulfide ores. As in the case of the copper industry, large amounts of sulfur dioxide are produced which are typically collected and converted into sulfuric acid for in-plant use and byproduct metal recovery.

Sources of wastewater include air-pollution control systems, slag granulation, and plant blowdown and cooling water. Impoundments are used as settling ponds and for solid waste disposal. The sludge and slag contain heavy metals principally in the solid phase, while the wastewater contains low concentrations of soluble heavy metals, chiefly cadmium, lead, copper, nickel, and zinc. Total dissolved solids usually range from 100 to 1,000 mg/l.

Zinc ore is first roasted and the collected sulfur dioxide converted into sulfuric acid, which is then used to leach the zinc oxide into zinc sulfate in preparation for conversion into zinc metal. The water and solid waste streams are not unlike those generated by primary lead smelting.

Water from wet scrubbers used for air-pollution control is the major source of wastewater from the primary aluminum industry. The volume and nature of the wastewater can vary greatly with the type of process employed. Scrubber water can contain suspended solids, fluoride, oil and grease, chloride, sulfate, COD, and trace metals. Trace amounts of cyanide have also been detected at some plants. Fluoride is usually the contaminant of primary concern, and lime treatment is frequently used to precipitate fluoride as calcium fluoride. Mechanical water pollution-control equipment such as clarifiers and thickeners are mostly used, rather than earthen impoundments. The sludge is landfilled, and leaching of fluoride and trace heavy metals is a potential problem.

Other nonferrous metals produced in the nation include antimony, beryllium, bismuth, chromium, cobalt, magnesium, nickel, platinum, and others. Many of the related process operations produce wastes not unlike those discussed above, such as scrubber water from air-pollution control devices, slag and dust from the actual processing, and wastewater treatment sludges.

SIC 34 - FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND TRANSPORTATION EQUIPMENT

The products of this category are highly diverse, and production facilities range in size from relatively small shops to large manufacturing complexes; therefore, wastewater from the production facilities differ considerably in both volume and composition.

Metal-machining operations often produce wastewater contaminated with suspended solids, oils, and solvents. Metal-finishing operations can contribute chromium, zinc, and other heavy metals, as well as cyanide. Forging and heat-treating operations can contribute suspended solids and oil and grease to the wastewater streams. Painting and coating operations can contribute quantities of both solid and liquid organic material. In addition, the type of air-pollution control system plays a major role in determining the size and composition of certain wastewater streams.

Most wastewater treatment in this group is designed to remove suspended solids and oil and grease, as well as specific heavy metals if plating operations are involved in the manufacturing process. Although most wastewater treatment is performed in steel or concrete basins, some of the older and larger facilities employ earthen settling ponds.

Sludge from wastewater treatment is usually disposed of on land or near the plant site. The water fraction of the sludge contains much of the same material found in the wastewater itself. The sludge also contains considerable quantities of oil and grease. Waste cutting oils (composed of an oil-water emulsion) are often a disposal problem. They are either partially reclaimed, sent to a contract disposer, or landfilled on site.

SIC 35 - MACHINERY, EXCEPT ELECTRICAL

The products of this group are highly diverse. Most production facilities are large and can be described as heavy manufacturing. Wastewater streams come from many different sources and are ususally combined and treated in a central facility. As in many other manufacturing operations, the wastewater varies considerably in composition yet tends to contain the same types of constituents.

Foundry operations, which are included in many of the manufacturing complexes, produce wastewater containing suspended solids, biodegradable organic matter, and small amounts of fluoride, sulfide, cyanide, phenol, as well as trace heavy metals.

Metal-machining and forming operations produce wastewater contaminated with suspended solids, oil, and solvents. Metal finishing and painting operations contribute chromium, other heavy metals, cyanide, paint, and solvents to the wastewater stream.

Concrete or steel basins are commonly used for the treatment of wastewater, although a number of facilities still employ settling ponds for the removal of suspended solids. Wastewater-treatment sludge is usually disposed of on land on or near the plant site, as is spent sand from foundry operations. Both materials can be contaminated with many of the constituents found in the wastewater.

SIC 36 - ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT, AND SUPPLIES

This industry group contains diversified manufacturing operations. Some facilities do not produce wastewater; others have wastewater streams resulting from plating, painting, and general manufacturing operations. Both the aqueous and nonaqueous wastes produced by this industry are quite diverse. For example, the manufacture of large transformers can produce small amounts of wastes contaminated with polychlorinated biphenyl, and the manufacture of batteries can produce wastewater and sludge containing heavy metals.

Except in the case of battery manufacturing, there is little published information that characterizes the wastes specific to this group. By the nature of the manufacturing operations, however, the wastewater can contain heavy metals and cyanide if plating is performed, organic solvents if cleaning and painting are done, and oil and grease if metal machinery is part of the operation. Wastewater flow rates are typically small and, therefore, earthen lagoons are probably seldom used. Most likely the greatest potential for ground-water contamination within this industry would be associated with the disposal of heavy-metal sludge from wastewater-treatment facilities and solvent-contaminated solid waste.

SIC 37 - TRANSPORTATION EQUIPMENT

A large number of different and highly complex wastewater-generating operations are involved in the manufacture of transportation equipment. Manufacturing plants have a relatively large number of individual waste streams, which usually are combined and treated in a central wastewater treatment facility. Although there is a great deal of complexity and variability within this industry, many of the combined wastewater streams have, at least qualitatively, a similarity in composition.

Foundry operations, which are employed by many of the plants, produce wastewater streams that have high contents of suspended solids, contain moderate amounts of biodegradable organic matter (from binder and molding compounds), and small amounts of fluoride, sulfide, cyanide, and phenol, as well as trace heavy metals. Metal-machining and forming operations produce wastewater contaminated with suspended solids, oils, and solvents.

Metal-finishing operations can contribute chromium, other heavy metals, and cyanide to the wastewater. Although the wastewater from specific plants can vary considerably in composition, most of the constituents will be present in at least detectable quantities.

Most facilities use concrete basins for the treatment of wastewater. However, there is a significant number of facilities, particularly those having foundry operations, that employ large unlined settling ponds for wastewater treatment.

Because wastewater from these operations contains very high concentrations of suspended solids, large quantities of sludge are generated. This sludge is usually disposed of on land on or near the plant site. The water fraction of the sludge contains the same material as the wastewater.

Spent sand from foundry operations is contaminated with many of the constituents in the wastewater. When not washed and reprocessed for reuse, it too is disposed of on land, often in very large quantities.

SIC 49 - ELECTRIC, GAS, AND SANITARY SERVICES

This group is divided into several major subdivisions, each of which produces substantially different types of wastes.

SIC 491 - Electric Services

Included under electrical services are power generation plants and power transmission systems. Power generation plants produce large quantities of wastes, which are commonly conveyed to large impoundments on or near the plant site. A variety of wastes both liquid and solid are generated by fossil fuel (coal, oil, and gas) power plants. Depending upon the local availability of water, condenser cooling water can either be once-through or recirculated. Increased concern over thermal pollution effects on streams has required a number of power plants in certain locations to reduce the temperature of their cooling water prior to discharge. Large cooling ponds, with or without mechanical aeration, are sometimes used to provide the required temperature reduction. If the cooling water is once-through, the only likely contaminant is small amounts of free chlorine which is periodically used to control biological growth in the cooling system. If the cooling water discharged is the blowdown from a recirculation cooling water system, it will contain the same dissolved minerals present in the intake water but at a higher concentration (concentration increases greater than 10-fold are common). In certain cases, particularly where the chloride concentration of the intake water is high, small amounts of chromate are added to inhibit corrosion.

Boiler feedwater requires very high standards of purity and, therefore, minerals and suspended solids must be removed. The water-treatment wastes include calcium carbonate, lime-softening sludges, and ion-exchange brines. These waste streams are relatively small and contain mostly the minerals that were present in the intake water, plus water-treatment chemicals such as alum, polyelectrolytes, and powdered disposable ion-exchange resin. Brine is usually discharged to ponds or streams, and sludge is placed in landfills or is ponded.

Coal-fired fossil fuel plants produce large quantities of ash; the ash content of coal ranges from 6 to 20 percent. The ash, removed from the plant via the ash-handling system and the air-pollution control system, is generally mixed with water and sluiced to very large ash-handling ponds where it settles as a wet sludge. The composition of the water fraction, which may seep through the bottom and sides of the ash ponds, depends greatly on the composition of the ash. The water can be either moderately acidic or moderately alkaline (500 to 5,000 mg/l as $CaCO_3$). Inorganic salts are present, as well as relatively low concentrations of heavy metals, ammonia, phosphate, and nitrate.

Many power plants that burn high sulfur content coal are installing sulfur dioxide removal systems, which commonly use an alkaline substance to react with the stack gas to form a complex calcium sulfate/sulfite solid that is eventually disposed of as wet sludge. The sludge also contains a certain fraction of fly ash that contains small quantities of heavy metals. The primary constituents of the leachate are calcium, sodium, sulfate, sulfite, and trace quantities of heavy metals.

SIC 492 - Gas Production and Distribution

This group includes the transmission and distribution of natural gas, the production and distribution of manufactured or liquified petroleum gas, and production of coke oven gas. Gas transmission itself does not make use of impoundments. However, before gas can be transferred from a gas field to a pipeline system it must be processed to remove sulfur and some of the heavier hydrocarbon fractions. Gas-processing plants process a variety of wastewater streams, such as cooling tower blowdown, hydrocarbon-contaminated streams, and others. The waste streams are generally small and are usually not treated in impoundments.

SIC 494 - Water Supply

This group primarily includes municipal water-treatment plants and water-distribution systems. The required treatment for a municipal water supply depends on the quality of the raw water. It can consist of removal of suspended solids by coagulation, sedimentation, and filtration; removal of hardness by lime softening; and removal of dissolved solids by means of ion exchange.

If coagulation, sedimentation, and filtration are employed, a waste sludge is generated that contains both the suspended solids originally present in the raw water and the water-treatment chemicals such as alum, lime, and organic coagulants. If lime softening is employed, a sludge principally composed of calcium and magnesium carbonate is generated. Formerly, these materials were discharged back into the receiving stream constituting the water supply, but pollution-control regulations forbid this practice in many areas. Consequently, these sludges are now mostly disposed of in impoundments or on land. Although lime-treatment sludge is somewhat alkaline in general, water-treatment plant sludges are relatively innocuous, although the presence of sludge containing decaying organic matter can produce a leachate having a biochemical oxygen demand.

SIC 495 - Sanitary Services

In terms of liquid waste generation, the principal category included under sanitary services pertains to sewerage systems. Sewerage systems include municipal sewage-treatment plants and the sewer lines connecting the sources of domestic wastewater to the sewage-treatment plant. In many places, sewage-treatment plants employ physical and biological treatment processes that take place in above-ground concrete or steel basins that are not classified as impoundments in this study. However, ponds and lagoons are also commonly used. Constituents in sewage effluent include, ammonia, nitrate, detergents, dissolved solids, BOD, COD, phosphate, chloride, miscellaneous organics, and others.

In the process of treating sewage, a liquid/solid residue commonly referred to as sewage sludge is produced. Sewage sludge contains much of the biodegradable organic matter removed from the sewage itself, as well as a variety of inorganic components including heavy metals. There are a variety of processes currently in use for reducing the volume and further degrading sewage sludge prior to its ultimate disposal. In addition to being dewatered by mechanical means, it can be degraded by anaerobic digestion, by wet air oxidation, by incineration, or can be applied to land where it can become part of the soil.

The composition of sewage sludge differs considerably, depending in part on the amount and type of industrial discharges into sanitary sewage-treatment plants. High concentrations of chloride, heavy metals, nitrogen compounds, and phosphate are characteristic of digested sludge. Digested sludge prior to dewatering has a moisture content of 90 to 95 percent. The bulk of the metals are in the solid phase, but they can be leached to varying degrees depending on local conditions.

Urban stormwater runoff is either discharged directly to a receiving stream, combined with domestic sewage and treated in a sewage-treatment plant, or impounded prior to eventual discharge or seepage into ground water. The composition of urban runoff has a wide range. At any given location, the concentration of contaminants in urban runoff will be high during the initial phase of a storm and will then attenuate as the runoff period proceeds. The composition is also highly site-dependent. Runoff from industrialized areas contains a much more varied content of contaminants than that from strictly residential areas. BOD, oil and grease, suspended solids, chloride (from road salting), pathogenic organisms, pesticides, fertilizers, and heavy metals are common in urban and suburban stormwater.

SECTION XII

APPENDIX D - COSTS OF TECHNOLOGICAL CONTROLS

COST RELATIONSHIPS

- The capital investment is given in terms of February 1977 dollars, corresponding to an engineering New Record Construction Cost Index of 2504.
- The total annual operating cost includes capital recovery (repayment of the principal and interest of a loan) at 10 percent for 10 yr, which corresponds to an average annual rate of 16.3 percent of the initial capital investment.
- The total annual operating cost includes taxes plus insurance at 2 percent of the initial capital investment.
- Annual maintenance expenses are estimated to be 2 to 4 percent of the initial capital investment, depending on the specific construction and equipment comprising the various systems.
- Operating labor rates, including all associated overhead, are $16 per hr.
- Electrical energy is @ $0.02/kwhr.
- Fuel energy is @ $2/million Btu ($0.50/million kg-cal).

SPECIFIC COST MODULES

The cost modules described in the following paragraphs may be used individually or in combinations to prevent, retard, or ameliorate contamination of ground water that is used as a drinking water source.

Alternative 1 - Installation of an Impermeable Membrane

The total cost of installing an impermeable membrane during the construction phase of an impoundment is dependent on the type of material used for the membrane, its thickness, and the type of preparation and finishing operations required by the specific physical features of the site. The following are generalized total installed costs for several of the more common types of liners:

a) Butyl Rubber

Thickness		$/sq ft	($/sq m)
30 mil	(0.75 mm)	0.55	(5.92)
60 mil	(1.5 mm)	5.85	(62.97)

b) Hypalon^R

Thickness		$/sq ft	($/sq m)
20 mil	(0.5 mm)	0.46	(4.95)
30 mil	(0.75 mm)	0.54	(5.81)
45 mil	(1.12 mm)	0.72	(7.75)

c) Polyvinyl Chloride (PVC) - PVC is one of the cheapest materials for liners; however, the cost of installation is increased because PVC must be covered owing to its poor weathering qualities. Cover should be a minimum of 6 in (15.24 cm) of earth or earth and gravel.[1)]

Thickness		$/sq ft	($/sq m)
10 mil	(0.25 mm)	0.34	(3.66)
20 mil	(0.50 mm)	0.44	(4.74)
30 mil	(0.75 mm)	0.50	(5.38)

Numerous other types of lining materials are available. Taking into account the variability of material, installation procedures, and site-specific cost factors, a very general range of total installed costs for impermeable membranes would be \$0.35 to \$1.00/sq ft (\$3.77 to \$10.76/sq m), and a reasonable average would be \$0.60/sq ft (\$6.46/sq m).

Alternative 2 - Installation of a Layer of Impermeable Material

The most common substance used for creating a layer of impermeable material is bentonite clay. Typical application rates are 2 to 5 lbs/sq ft (10 to 24 kg/sq m). With a typical delivered price of bentonite @ \$150/ton (\$168/tonne), and an estimated cost of application @ \$0.10/sq ft (\$1.08/sq m), the total installed cost for bentonite layers is as follows:

Application Rate			
lbs/sq ft	(kg/sq m)	\$/sq ft	\$/sq m
2	(9.76)	\$0.25	(2.69)
3.5	(17.09)	\$0.36	(3.88)
5	(24.41)	\$0.48	(5.17)

The installation component of the total cost can vary considerably from site to site.

Alternative 3 - Collection of Contaminated Water Seeping From Impoundment

Infiltration Gallery

The unit cost for an infiltration gallery is given in terms of dollars per square foot of vertical cross section, that is, the cross-sectional area perpendicular to the ground-water flow. In estimating unit costs for an infiltration gallery, the following assumptions have been made:

Trench width - 4 ft (1.2 m)
Trench depth - 40 ft (12.2 m)
Trench length - 500 ft (152 m)

The estimated unit cost for an installed infiltration gallery includes materials, equipment, labor, and general contractor overhead and profit. The itemized capital cost breakdown is as follows:

Capital Cost Item	$/sq ft	($/sq m)
	Vertical Cross Section	
Mobilization and Demobilization (includes heavy equipment for earth movement)	0.60	(6.46)
Excavation 10 cu yd (7.6 cu m) scraper, 50 cu yd/hr (38 cu m/hr) @ $1.15/cu yd ($1.50/cu m)[2)]	0.35	(3.77)
1 1/2 cu yd (1 cu m) hydraulic back-hoe, 105 linear ft/day (32 linear m/day) @ $1.00/cu yd ($1.31/cu m) dry, @ $2.00/cu yd ($2.62/cu m) wet[2)]		
Gravel Backfill 3/4 in (1.9 cm) crushed stone gravel, 2 mi (3.2 km) haul in 180 hp dozer @ $6.40/cu yd ($8.36/cu m)	0.95	(10.23)
Drilling Fluid 1 bag additive per 500 gal (1.9 cu m) water @ $52/25 lb ($52/11.3 kg) bag	3.70	(39.83)
Perforated Pipe 6 in (15 cm) stainless steel well screen @ $55/linear ft ($180/linear m)	1.40	(15.07)
Pumps and Casing 5 operating pumps, 5 standby 100 gpm (6.3 l/s) submersible pumps with casing, @ $1,200 each	0.60	(6.46)
Total Capital Unit Cost: (Infiltration Gallery)	$7.60	($81.82)

Direct operating costs for an infiltration gallery are mainly pumping and discharge costs, which are usually a small percentage of the yearly capital related costs such as capital recovery @ 16.3 percent of initial investment and taxes and insurance @ 2 percent.

Wellpoint System

Unit cost estimates for a standard wellpoint system have been calculated on the basis of the assumed specifications summarized below. Actual costs are highly site specific:

- Wellpoints equally spaced on 5 ft (1.5 m) centers.
- Dewatering to a depth of 15 ft (4.6 m) with 25-ft (7.6 m) long wellpoints.
- Installation equipment.
- Mobilization and demobilization of 40-ton (36 tonne) crane @ $200[2)].
- Crane rental @ $1,500/wk and oil, fuel, and grease @ $260/wk.
- Hole puncher-sanding casing rental @ $560/wk.
- High pressure jet pump rental @ $350/wk.
- Jetting hose @ $1/linear ft ($3.28/linear m).
- Shipping for rental equipment @ $400 round trip.
- Permanent wellpoint system.
- 100 25-ft (7.6 m) long, 2 1/2-in (6.4 cm) diameter PVC wellpoints and risers @ $80 each.
- 500 ft (152 m) of 8-in (20 cm) diameter PVC header pipe, including rubber gaskets every 20 ft (6.1 m), @ $12/linear ft ($39.37/linear m).

- Two 8-in (20 cm) diameter wellpoint centrifugal pumps, powered by 60 hp electric motors, @ $1,300 each.
- Sand for wellpoint casing, assuming 1 cu yd (0.76 cu m) per wellpoint @ $5.40/cu yd ($7.06/cu m)[2].
- Labor for 5-man crew, installing 6 wellpoints per 6-hr shift, @ $17/man-hour[2].
- 300 man-hours to install and remove equipment[2].

Total Capital Unit Cost: $2.85/sq ft ($30.68/sq m)
(Wellpoint System)

Eductor System

The standard wellpoint system discussed above uses vacuum pumping from the ground surface. For that reason, it is limited by its potential suction lift to shallow dewatering situations. For deeper dewatering situations, eductor systems are able to lower the water table as much as 100 ft (30 m). An eductor system uses a vacuum at the base of the well. Water is pressure pumped into the ground and a return line is provided. Twice as much equipment is needed; and as a result, the system is at least twice as costly as a standard wellpoint system. Costs are presented for a 500-ft (152 m) line of wells, 40 ft (12 m) deep, and equally spaced on 20-ft (6 m) centers.

Capital Cost Item	$/sq ft Vertical Cross Section	($/sq m)
Wells		
12-in (30 cm) diameter hole with 6-in (15 cm) diameter well, drilled and cased, 5 ft (1.5 m) of well screen @ $90/linear ft ($295/linear m)	2.50	(26.91)

Pumps

6-in (15 cm) diameter submersible pumps, 100 gpm (6 l/s) @ $1,200 each	1.50	(16.14)
Total Capital Unit Cost: (Eductor System)	$4.00	($43.06)

This cost is largely influenced by the well spacing. For example, if the wells are spaced on 40 ft (12 m) centers, the costs would be reduced 50 percent. Spacing is determined by field testing of soil transmissivity, where one well is installed for pumping and 3 to 4 wells are installed for observing the rate and depth of water-level decline.

Alternative 4 - Return of the Collected Water Back to Impoundment

The cost module for returning collected water back to an impoundment is based on a complete pumping station plus a piping system connecting the pumping station with the impoundment. The capital cost curve for returning collected water back to an impoundment is shown in Figure 21; the total annual operating cost curve is shown in Figure 22.

Alternative 5 - Physicochemical Immobilization of Waste Material

Of all the techniques potentially available for the prevention of ground-water contamination, physicochemical immobilization probably exhibits the highest degree of variation in cost. The cost is dependent on the ratio of immobilizing agent required per unit of waste, the ease of handling the material, the physical features of the specific impoundment, and on whether the waste is being immobilized directly as it is generated or whether the situation involves a large reservoir of existing waste. Reported unit costs for physico-chemical immobilization range from $20 to $50 per actual ton ($22 to $55 per tonne) of waste material.

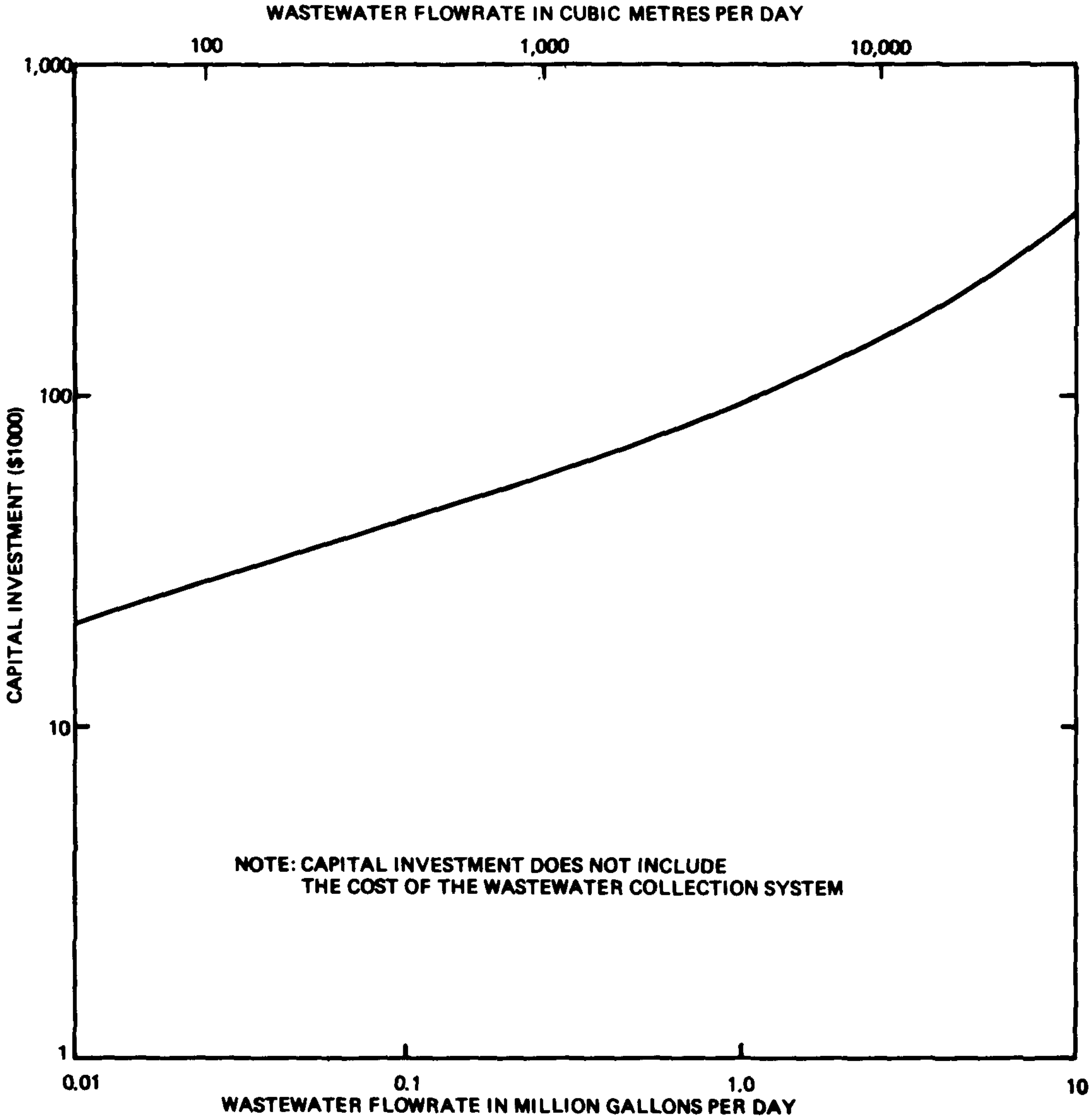

Figure 21. Capital investment costs for return of collected water back to the impoundment; Alternative 4.

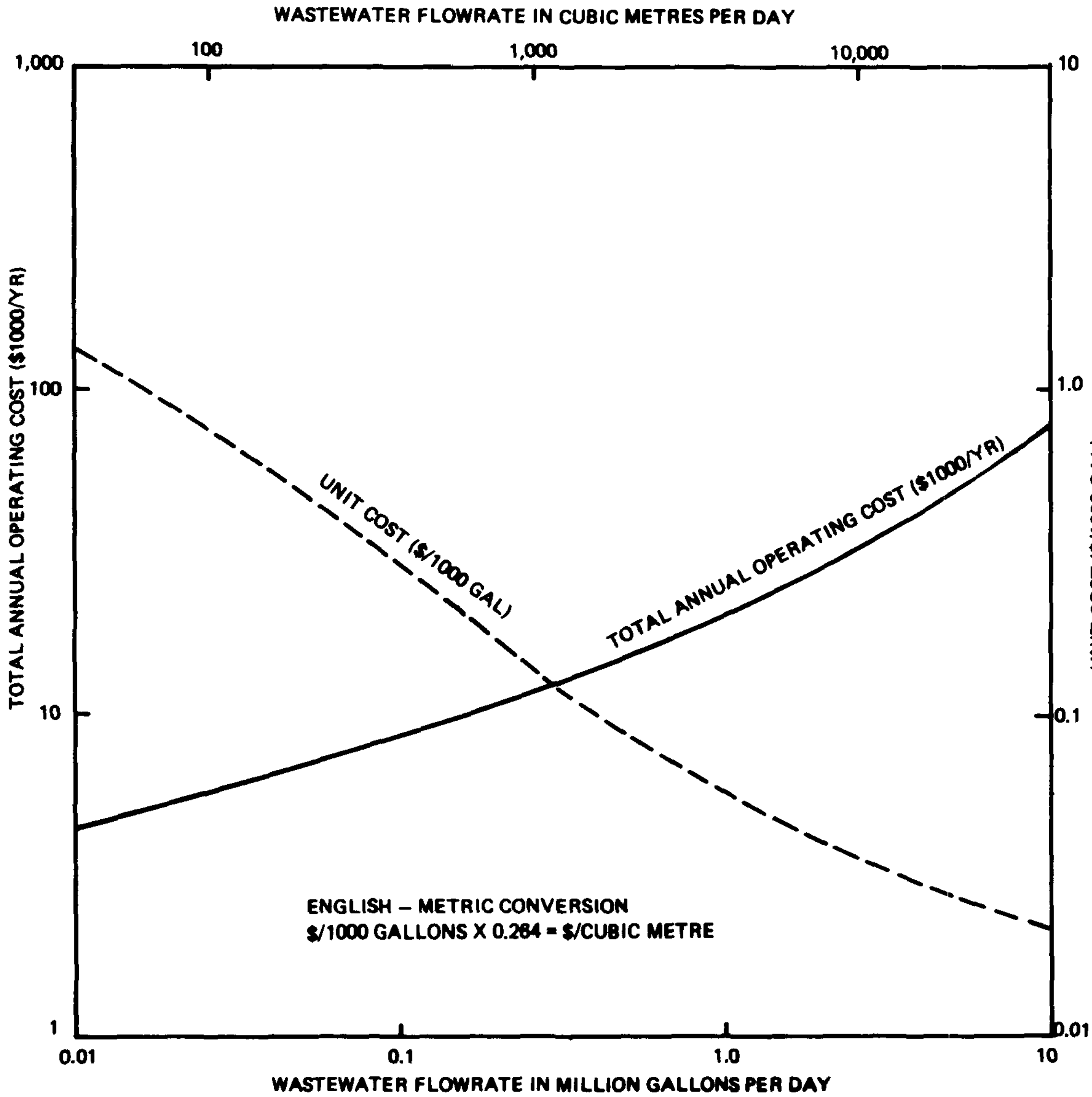

Figure 22. Total annual operating costs for return of collected water back to the impoundment; Alternative 4.

Alternative 6 - Ground-water Cutoff Wall

Slurry Trench Cutoff Wall

To obtain unit capital costs for a slurry trench cutoff wall, the following assumptions have been made:

Trench width - 4 ft (1.2 m)
Trench depth - 40 ft (12.2 m)
Trench length - 50 ft (15.2 m)
1 ton of bentonite per 37 cu yd (1 tonne/31.2 cu m)

The estimated unit cost for a slurry trench cutoff wall includes materials, labor, material, overhead, and profit. Overhead is about 19 percent, profit is about 6 percent. The itemized capital unit cost is estimated as follows:

Capital Cost Item	$/sq ft Vertical Cross Section	($/sq m) Vertical Cross Section
Mobilization and Demobilization		
(includes heavy earthmoving equipment and slurry mixing plant)	1.80	(19.38)
Excavation		
10 cu yd (7.6 cu m) scraper, 50 cu yd/hr (38.2 cu m/hr) @ $2.15/cu yd ($2.81/cu m)	0.30	(3.23)
1 1/2 cu yd (1.1 cu m) dragline, 65 cu yd/hr (49.7 cu m/hr) @ $2.10/cu yd ($2.75/cu m) wet soil[2)]		
Slurry		
Bentonite @ $90/ton ($99/tonne) delivered (60 percent solid)	1.30	(13.99)

Water and slurry centrifugal pumps @ $6/hr[3)]

40 man-hours labor per day @ $13/hr[3)]

Backfill

Two 65 hp (65.9 hp) dozers mixing and blending @ $2/cu yd ($2.62 cu m)[3)]

	0.30	(3.23)
Total Capital Unit Cost: (Slurry Trench)	$3.70	($39.83)

Grout Cutoff Wall

Most of the cost of installation of a grout cutoff wall is attributed to the drilling or driving of grout injection pipes. The pipes are installed on 1 to 5 ft (0.3 to 1.5 m) centers in 3 parallel rows. As the grout is injected (2 to 10 gpm (0.1-0.6 l/s) pumping rates are reported), the pipe is continuously withdrawn. Costs for a grout cutoff are based on the following assumptions:

Cutoff width - 4 ft (1.2 m)
Cutoff depth - 40 ft (12.2 m)
Cutoff length - 500 ft (152 m)

Three rows of drill holes, on 1 ft (0.3 m) centers in soils with 25 percent voids.

Capital Cost Item	$/sq ft Vertical Cross Section	($/sq m)
Drilling		
Drilling, and driving pipe @ $5/linear ft ($17/linear m)[2)]	5.00	(53.82)

Pumping		
Pumping (8-gpm (0.5 l/s) pump @ $0.50/hr) chemical grout @ $1.25/gal ($0.33/l) of solution (including catalyst)	8.00	(86.11)
Labor		
Pumping and chemical mix labor, 8-man crew at an average rate of $15 each accomplishing 10 sq ft/hr (0.9 sq m/hr)	4.50	(48.44)
Total Capital Unit Cost: (Grout Cutoff Wall)	$17.50	(188.37)

The above costs are lower where there are fewer voids in the soil being grouted. Also, the costs are lower where silicate grouts are used. Silicate grouting costs, from reported field experience, are $50 to $100/cu yd ($65 to $131/cu m) compared to $100 to $200/cu yd ($131 to $262/cu m) for chemical grouts.

Alternative 7 - Capping of the Impoundment Surface

If an inactive impoundment contains solid or semi-solid material exhibiting sufficient mechanical strength, capping can be performed using much the same techniques as in installing an impermeable membrane or layer of impermeable material. The costs in such cases would be in the same range as those described for Alternatives 1 and 2. If the waste material in the impoundment cannot support the weight of men and light construction equipment, the technique is not feasible.

Alternative 8 - Treatment of Contaminated Water

The cost relationships for the treatment of contaminated water cover a range of flow rates of from 0.01 to 10 mgd (38 to 37, 850 cu m/d). Capital costs are given in thousands of dollars per year, and also translated into unit treatment costs in terms of dollars per thousand gallons treated. It is assumed that all alternatives involving the treatment of contaminated water will have to include an equalization basin at the inlet of the treatment system and a treated water discharge system at the outlet of the treatment system.

Equalization Basin (8A)

Equalization basins are constructed of concrete and are designed to provide a 12-hr detention time. The basins are equipped with agitators. The amount of agitation power is 15 hp per million gal (3,785 cu m) capacity. The capital cost curve for equalization is shown in Figure 23; the total annual operating cost curve is shown in Figure 24.

Biological Treatment (8B)

The biological treatment system is based on a high detention time activated sludge system with associated sedimentation, sludge thickening, and vacuum filter dewatering. The specific design basis for the biological treatment system is summarized below:

. Influent BOD	500 mg/l
. Percent BOD	80 percent
. Aeration basin detention time	12 hr
. Aeration power requirement	2 lbs/hr, 0_2 per hp (0.9 kg/hr, 0_2 per hp)
. Sludge conversion rate	0.5 lbs/lb (0.5 kg/mg) BOD removed
. Sedimentation basin overflow rate	400 gpd/sq ft (16.3 cu m/day/sq m)
. Sludge thickener rate	4 lbs/day/sq ft (19.5 kg/day/sq m)

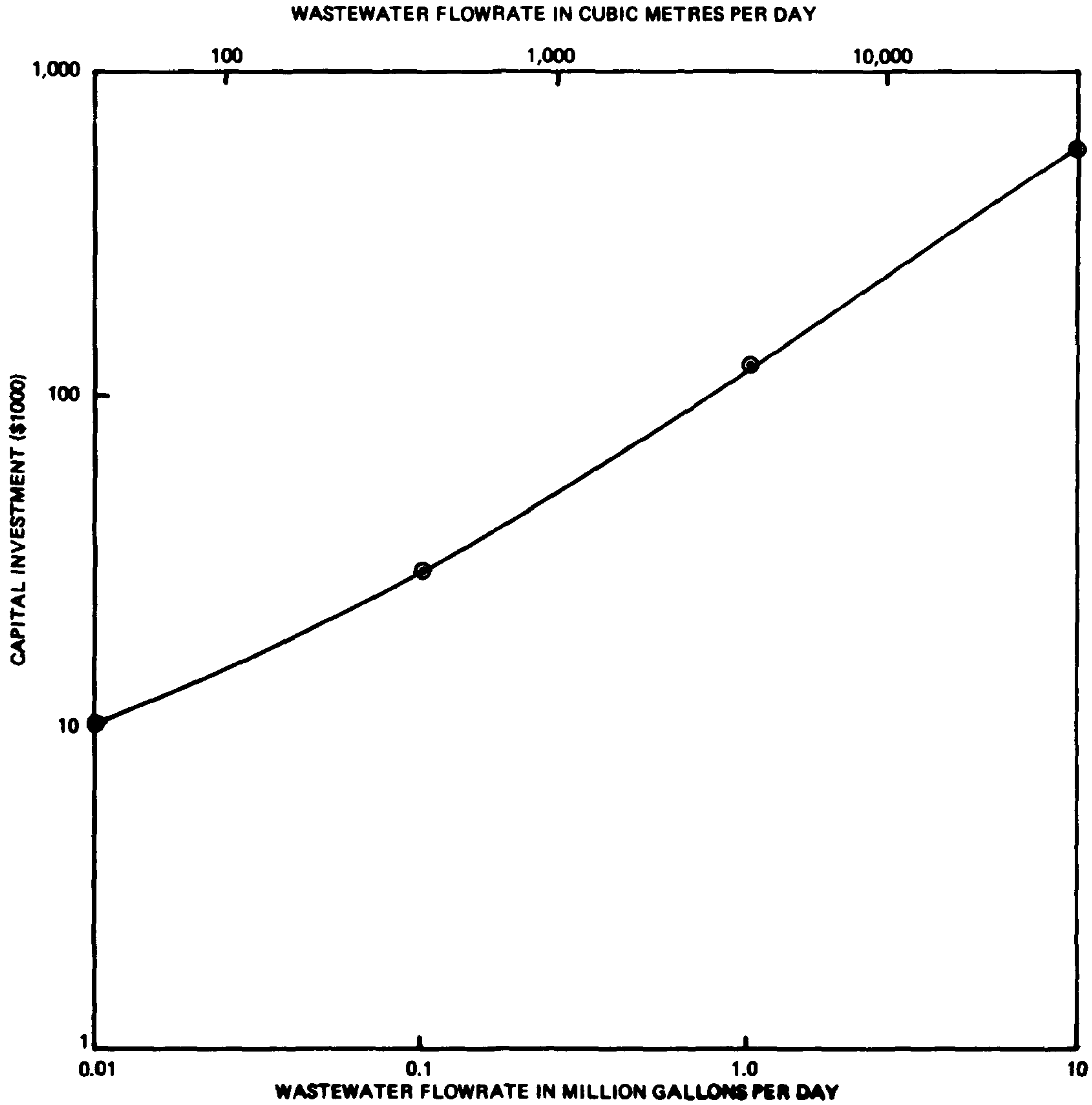

Figure 23. Capital investment costs for wastewater treatment--equalization basin module; Alternative 8A.

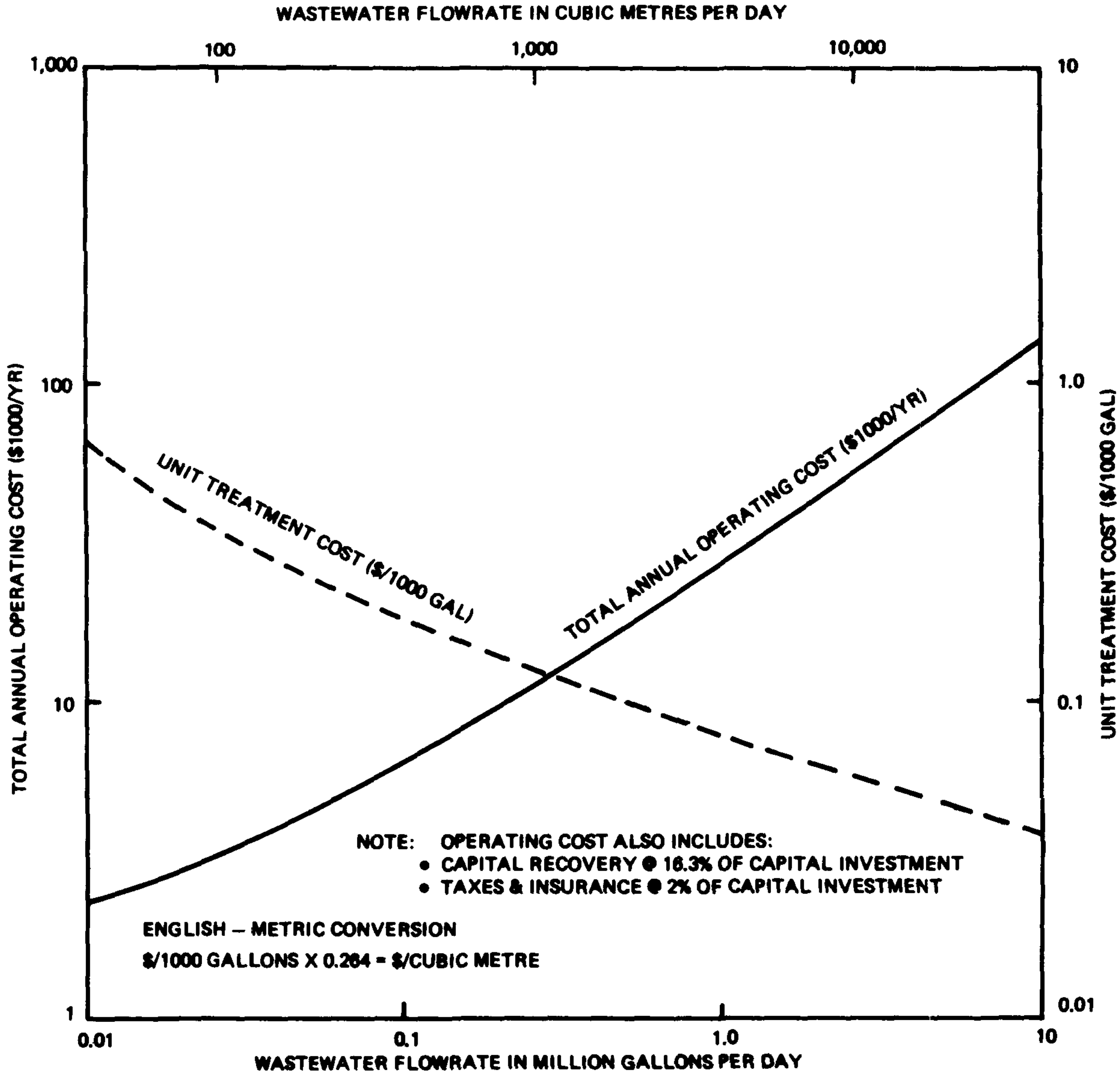

Figure 24. Total annual operating costs for wastewater treatment--equalization basin module; Alternative 8A.

- Vacuum filtration rate — 3 lbs/hr/sq ft (14.6 kg/hr/sq m)

- Solids concentration of dewatered sludge — 25 percent

- Sludge disposal - sludge generated by the biological treatment system is disposed of at a typical cost of $5.00 per actual ton ($5.50 per tonne) of sludge (wet basis)

The capital cost curve for biological treatment is shown in Figure 25; the total annual operating cost is shown in Figure 26.

Activated Carbon Adsorption (8C)

The activated carbon adsorption system includes both the adsorbers and thermal regeneration system for wastewater treatment capacities that exhaust more than 2,000 lbs/day (907 kg/day) of carbon. For systems exhausting less than 2,000 lbs/day (907 kg/day) of carbon, it is assumed that a contract for an adsorption/ regeneration service would be provided in which an outside firm supplies all of the equipment, periodically removes the exhausted carbon for off-site regeneration, and returns regenerated carbon, all for a yearly fee. There is no initial capital investment required for the contract service (exclusive, of course, of wastewater collection and discharge systems).

Because the capital and operating costs for carbon adsorption are more sensitive to the actual concentrations of contaminants than many other wastewater treatment processes (such as biological treatment), cost curves were developed for both a low strength waste (COD = 50 mg/l) and a high strength waste (COD = 250 mg/l). The specific design basis for the carbon adsorption system is summarized as follows:

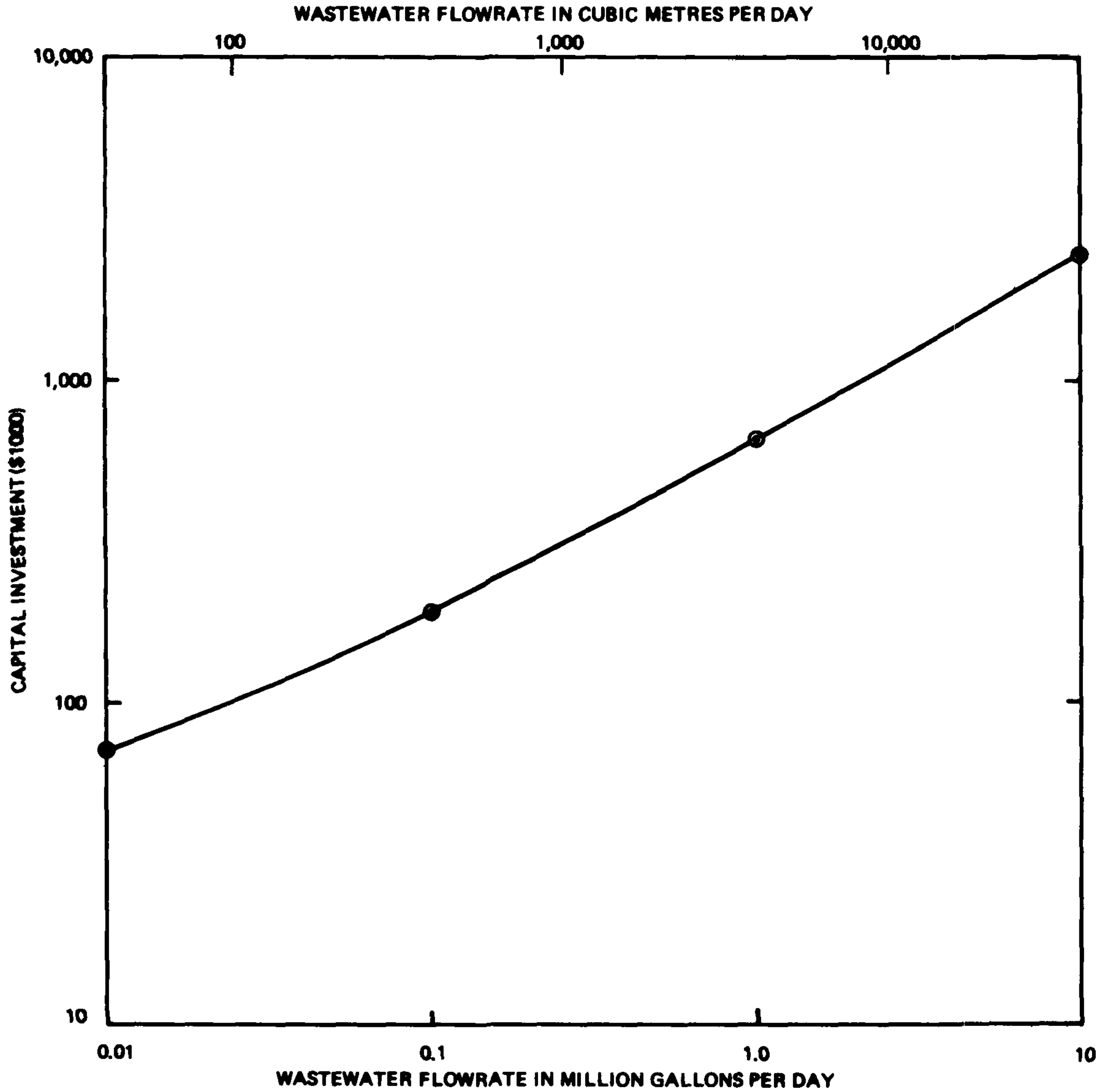

Figure 25. Capital investment costs for wastewater treatment--biological-treatment system module; Alternative 8B.

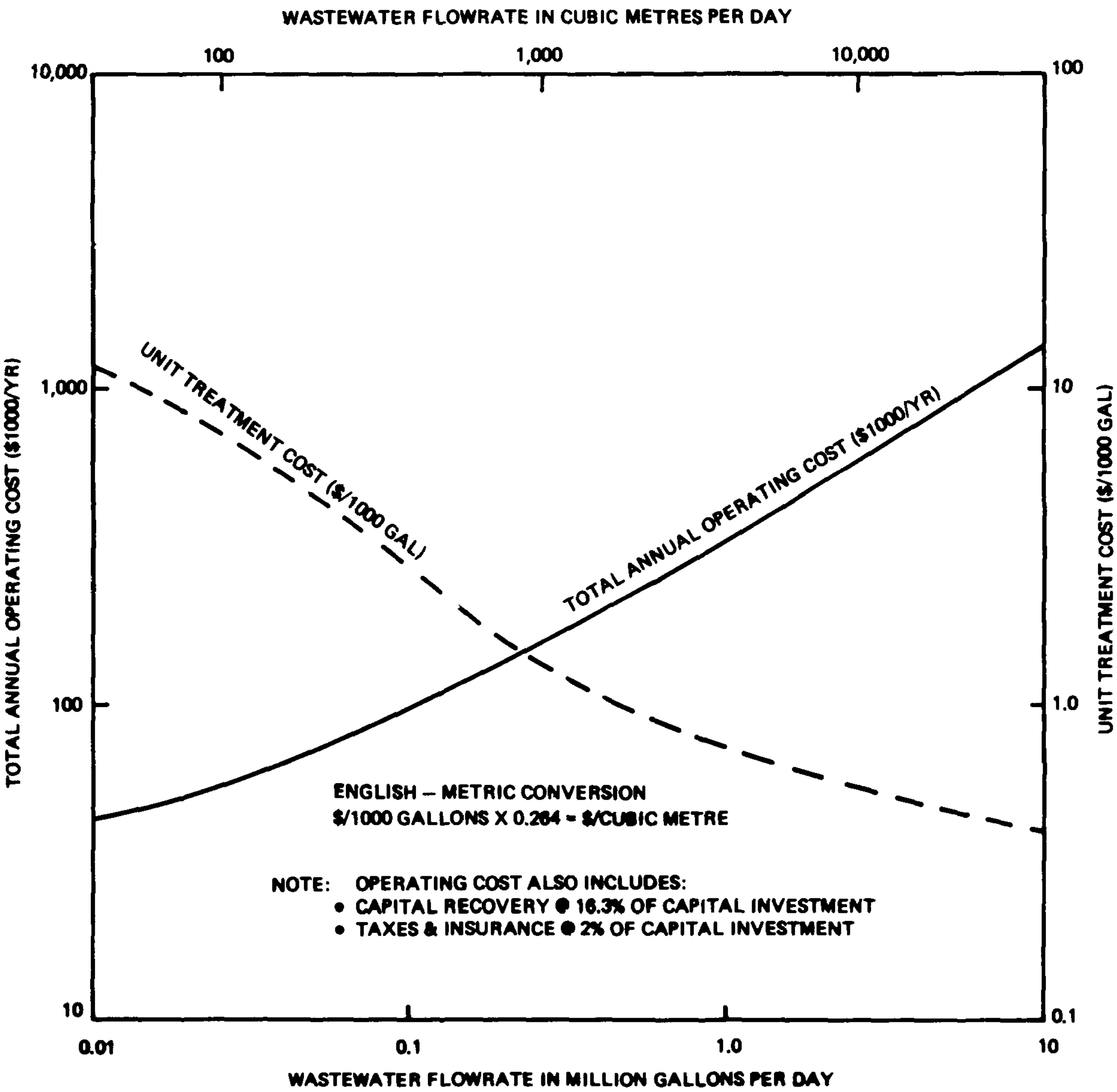

Figure 26. Total annual operating costs for wastewater treatment--biological-treatment system module; Alternative 8B.

. Percent COD removal	90 percent
. Carbon adsorption capacity	0.10 lbs (0.045 kg) COD removed per lb (0.45 kg) of carbon
. Number of adsorption trains	2
. Bed depth	15 ft (4.5 m) for low COD, 20 ft (6.1 m) for high COD
. Configuration	Upflow, packed beds
. Carbon attrition rate	5 percent per regeneration
. Cost of replacement activated carbon	\$0.55/lb (\$1.21/kg)
. Regeneration furnace hearth loading	40 lbs/day/sq ft (195 kg/day/sq m)
. Regeneration energy	6,000 Btu per lb (13,200 Btu per kg) of carbon

The capital cost curve for activated carbon adsorption is shown in Figure 27; the total annual operating cost curves for the low and the high strength wastes are shown in Figures 28 and 29, respectively.

Heavy-Metals Removal (8D)

The heavy-metals removal system is based on chemical precipitation using lime and alum. The equipment consists of a chemical feed system, a solid-recirculation clarifier (where the actual precipitation will take place), a sludge thickener, and a vacuum filter for final sludge de-watering. The specific design basis is summarized as follows:

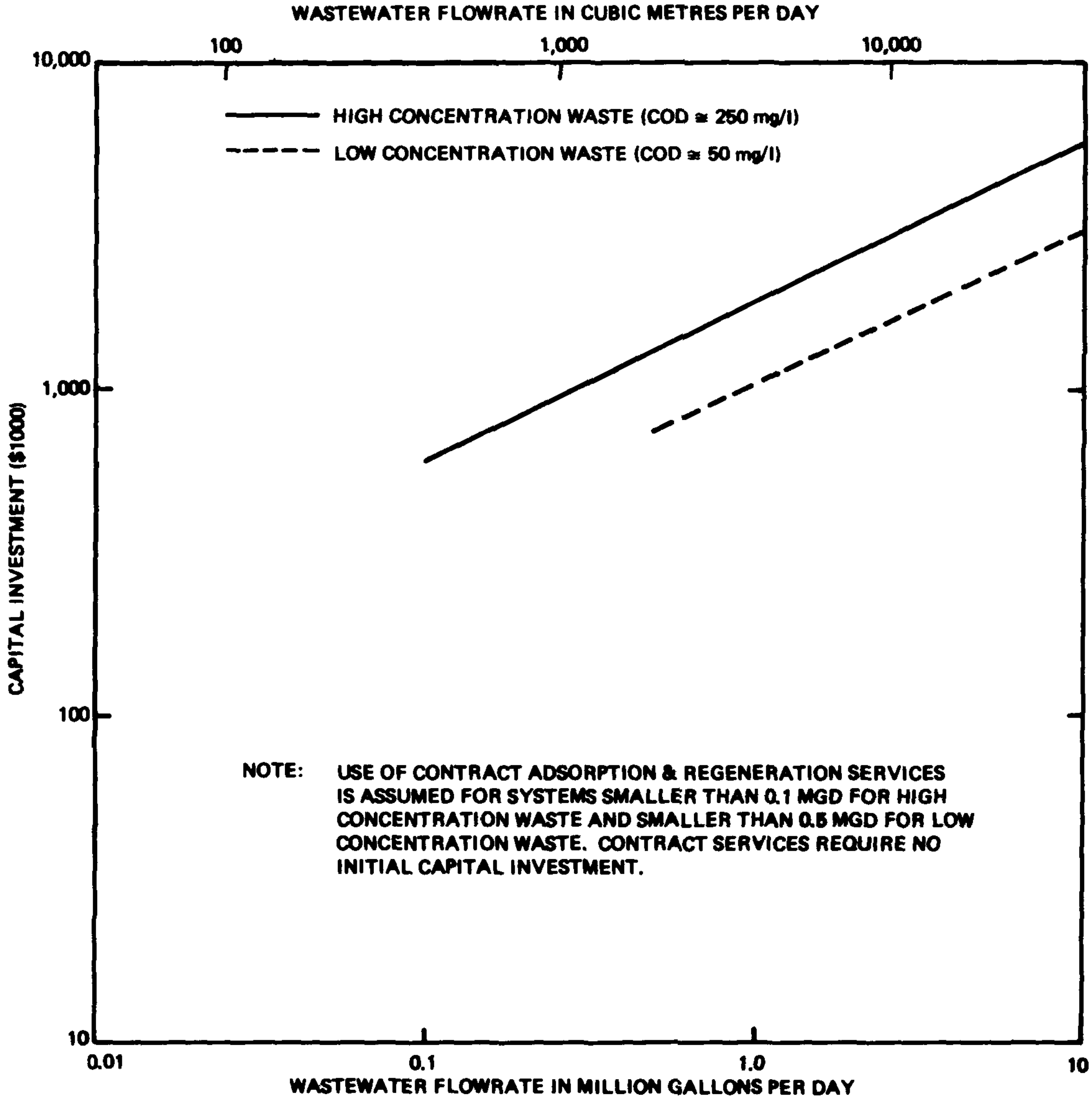

Figure 27. Capital investment costs for wastewater treatment--activated carbon adsorption module; Alternative 8C.

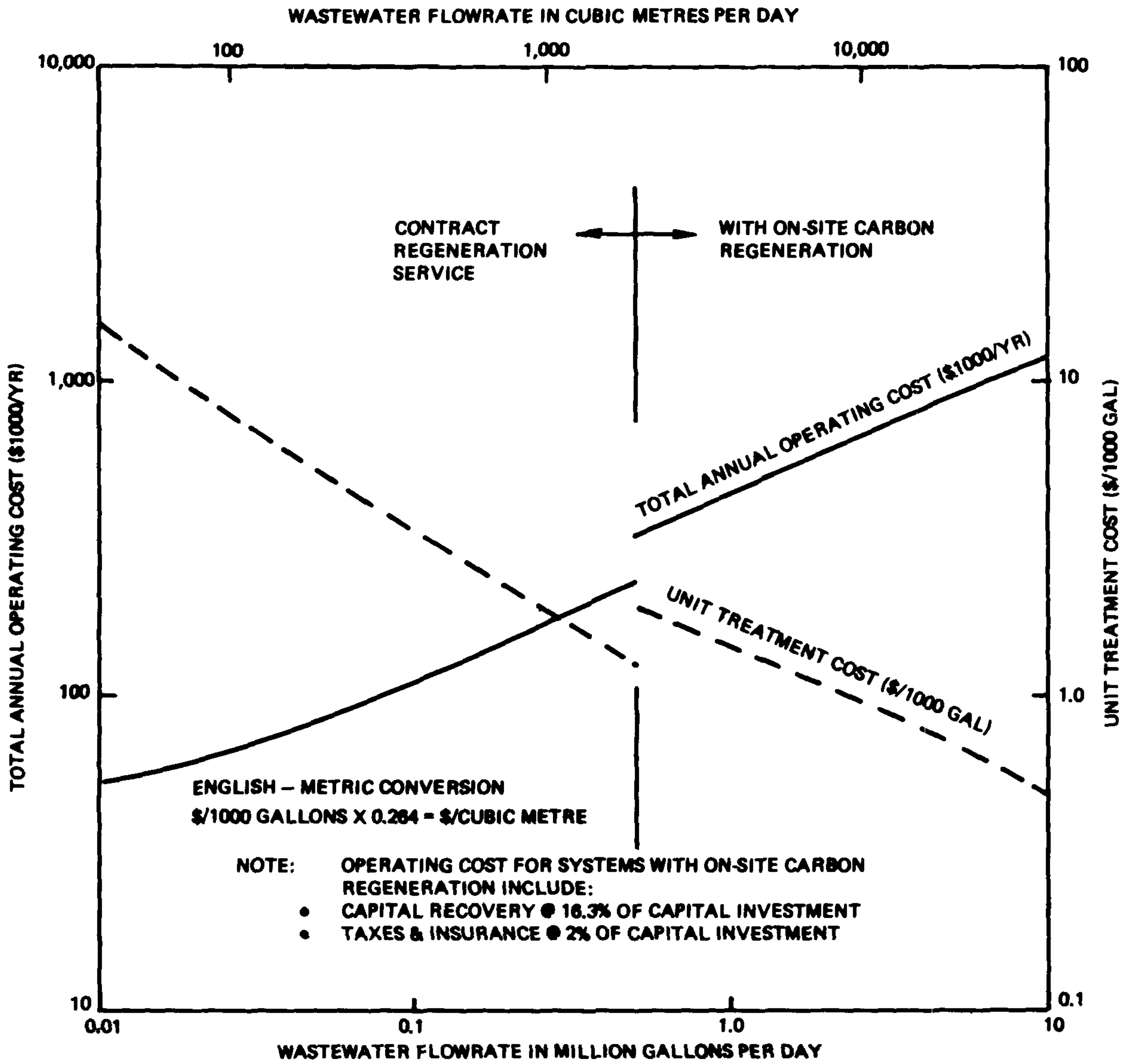

Figure 28. Total annual operating costs for wastewater treatment--activated carbon adsorption module, low strength waste (COD = 50 mg/l); Alternative 8C.

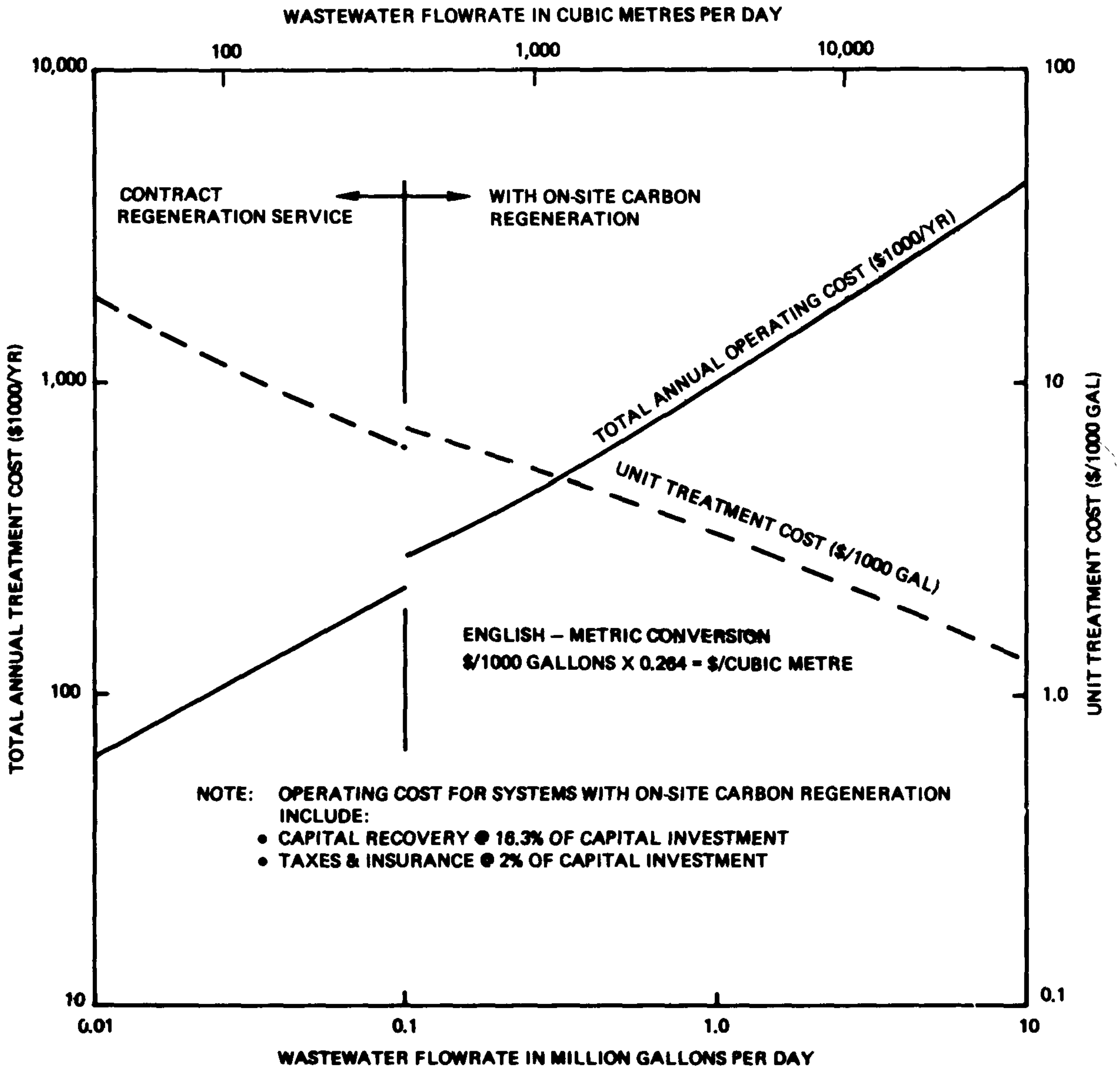

Figure 29. Total annual operating costs for wastewater treatment--activated carbon adsorption module, high strength waste (COD = 250 mg/l); Alternative 8C.

. Wastewater concentration of soluble heavy metals	20 mg/l
. Effluent concentration of heavy metals	0.5 mg/l
. Lime dosage	100 mg/l
. Cost of hydrated lime	$50/ton ($55/tonne)
. Alum dosage	50 mg/l
. Cost of alum	$100/ton ($110/tonne)
. Clarifier overflow rate	500 gpd/sq ft (20.4 cu m/day/sq m)
. Sludge thickener rate	4 lbs/day/sq ft (19.5 kg/day/sq m)
. Vacuum filter rate	3 lbs/hr/sq ft (14.6 kg/hr/sq m)
. Solids concentration of dewatered sludge	25 percent
. Sludge disposal - sludge generated by the heavy metals removal system is disposed of @ $5.00 per actual ton ($6.00 per tonne) of sludge (wet basis)	

The capital cost curve for heavy metals removal is shown in Figure 30; the total annual operating cost curve is shown in Figure 31.

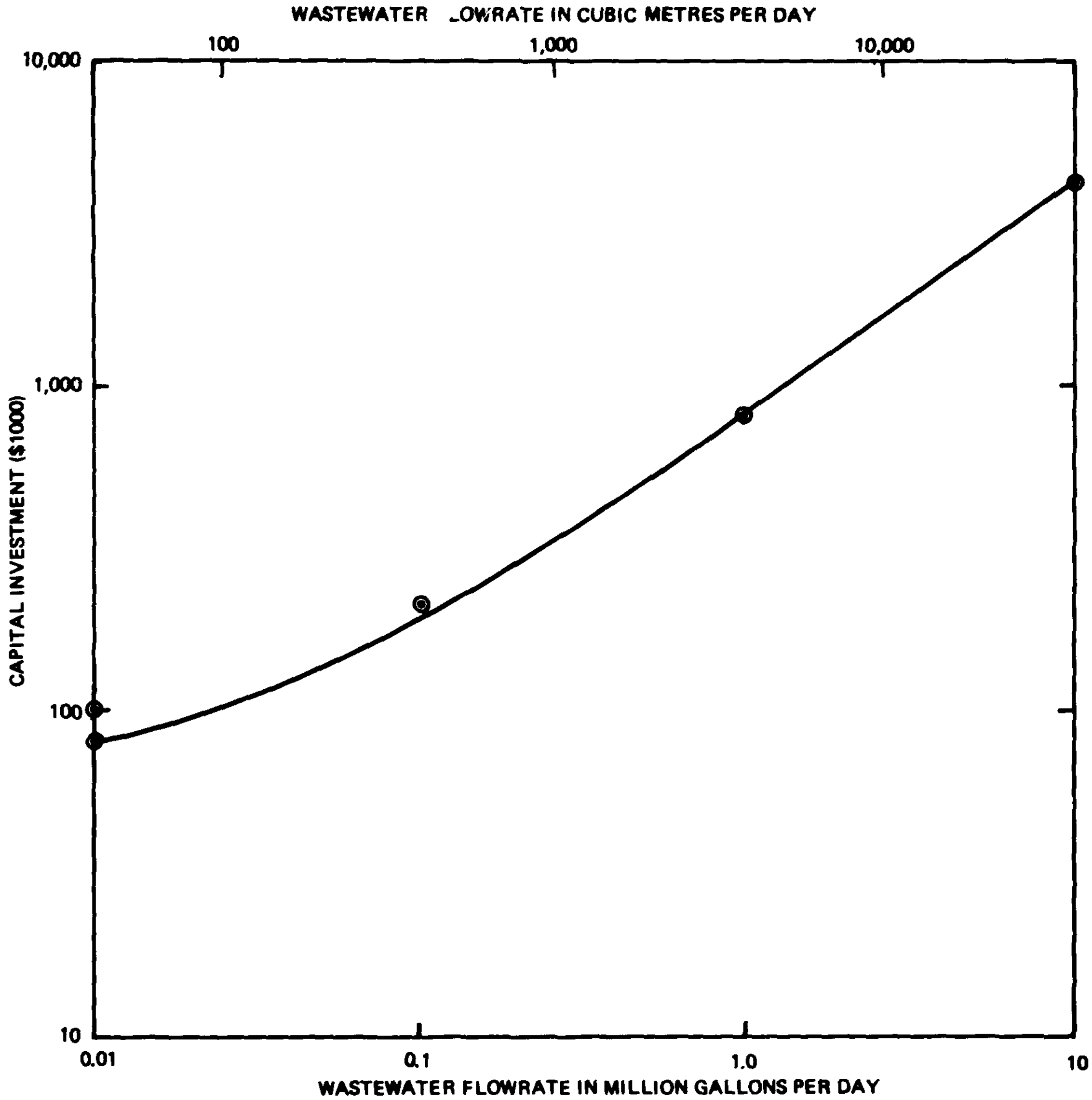

Figure 30. Capital investment costs for wastewater treatment--heavy-metals removal module; Alternative 8D.

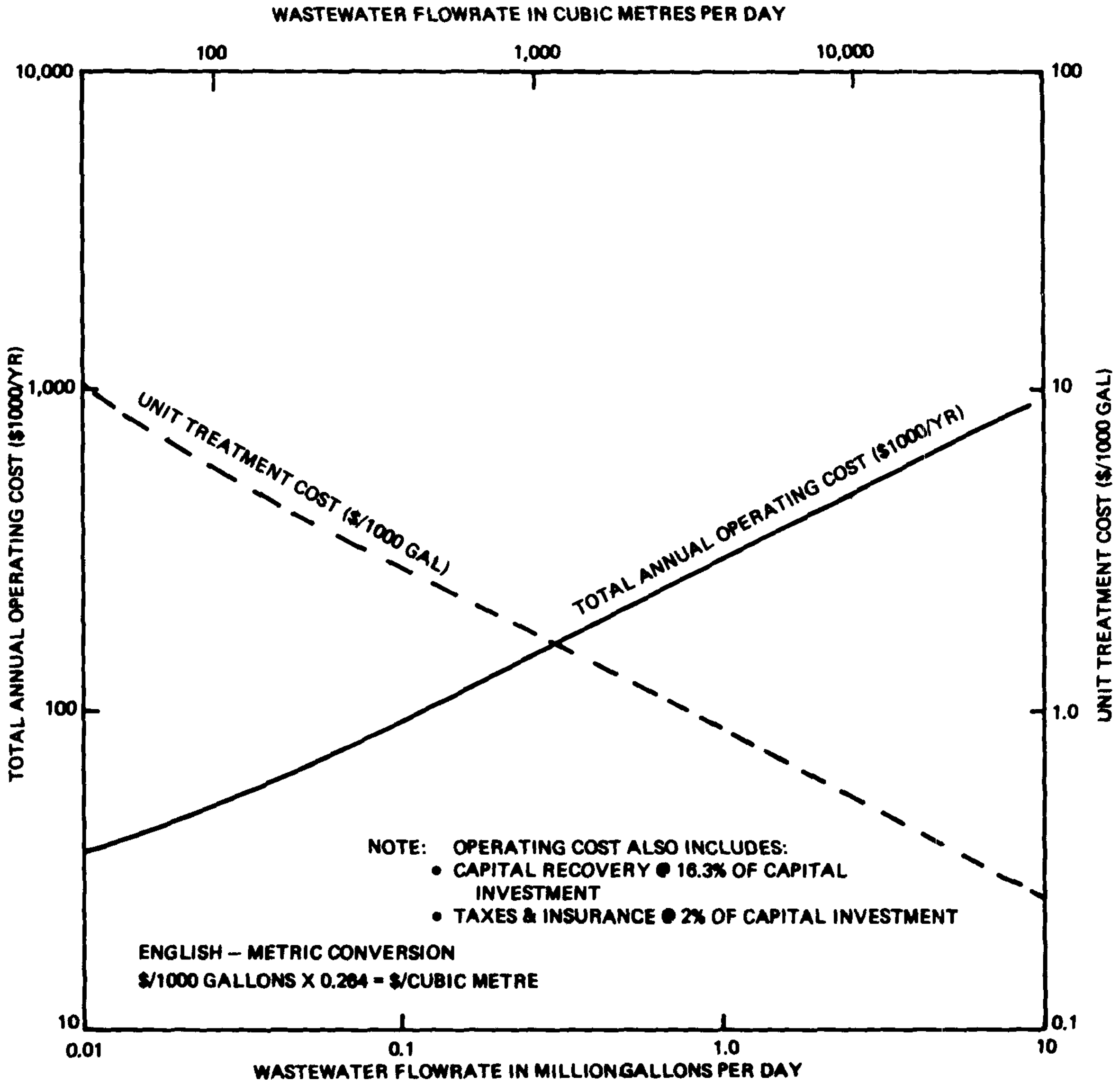

Figure 31. Total annual operating costs for wastewater treatment--heavy-metals removal module; Alternative 8D.

Dissolved-Solids Removal (8E)

This cost module is intended to be used where it is deemed absolutely necessary to remove high concentrations of soluble inorganic salts. It is based on first concentrating the whole stream into a much smaller volume and then finally evaporating the highly concentrated stream to dryness, leaving a residue of salt particles. The evaporator condensate, now free of dissolved solids, is discharged as a treated wastewater stream. The salt particles are then disposed of into a lined storage basin. The specific design basis is as follows:

- For wastewater flow rates below 0.17 mgd (643 cu m/day), the costs are based on using a vapor recompression evaporator; above 0.17 mgd (643 cu m/day), the costs are based on a multi-stage flash evaporator.
- Wastewater dissolved solids concentration. 5,000 mg/l
- Evaporator concentration effect. 30:1
- Power required for vapor recompression evaporator is based on 3.3 hp per 100-gpd (380 l/day) capacity.
- Thermal energy for the multi-stage flash evaporator is based on 150 Btu/lb (380 Btu/kg) water evaporated.
- The final evaporation to dryness takes place in a wiped-film evaporator which requires 1,000 Btu/lb (2,200 Btu/kg) of water evaporated.
- The salt residue disposal basin has a 10-yr storage capacity.

The capital cost curve is shown in Figure 32; the total annual operating cost curve is shown in Figure 33.

Treated Wastewater Discharge System (8F)

The treated wastewater discharge system is based on pumping the treated water to a nearby receiving stream. In the cost module, the discharge system consists of a pump station plus 2,000 ft (610 m) of sewer pipe. The capital cost curve is shown in Figure 34; the total annual operating cost is shown in Figure 35.

Alternative 9 - Development of a New Source of Water Supply in an Uncontaminated Area

The costs for developing raw ground water are dependent upon factors related not only to the local hydrogeology but also to the costs of land and transmission systems. For example, the aquifer to be tapped can be at depths of from 5 ft (1.5 m) to possibly 1,500 ft (458 m) below the land surface and yield water to wells at rates of from a few gallons per minute (1/s) to as much as several thousand gallons per minute (about 10,900 cu m/day). The finished wells may be free flowing or may require pumping with as much as several hundred feet (about 80 m) of lift.

The range of variation in yield and the difficulties encountered in developing that yield directly influence the costs of raw water. In addition, the transmission of the water over long distances and the procurement of sizeable tracts of land for the preferred location of municipal well fields can also overshadow local development costs. Thus, without an extensive amount of data gathering, the cost of a "typical" municipal well field is difficult to define, and a more general approach to estimating the replacement cost for a contaminated well field has to be followed.

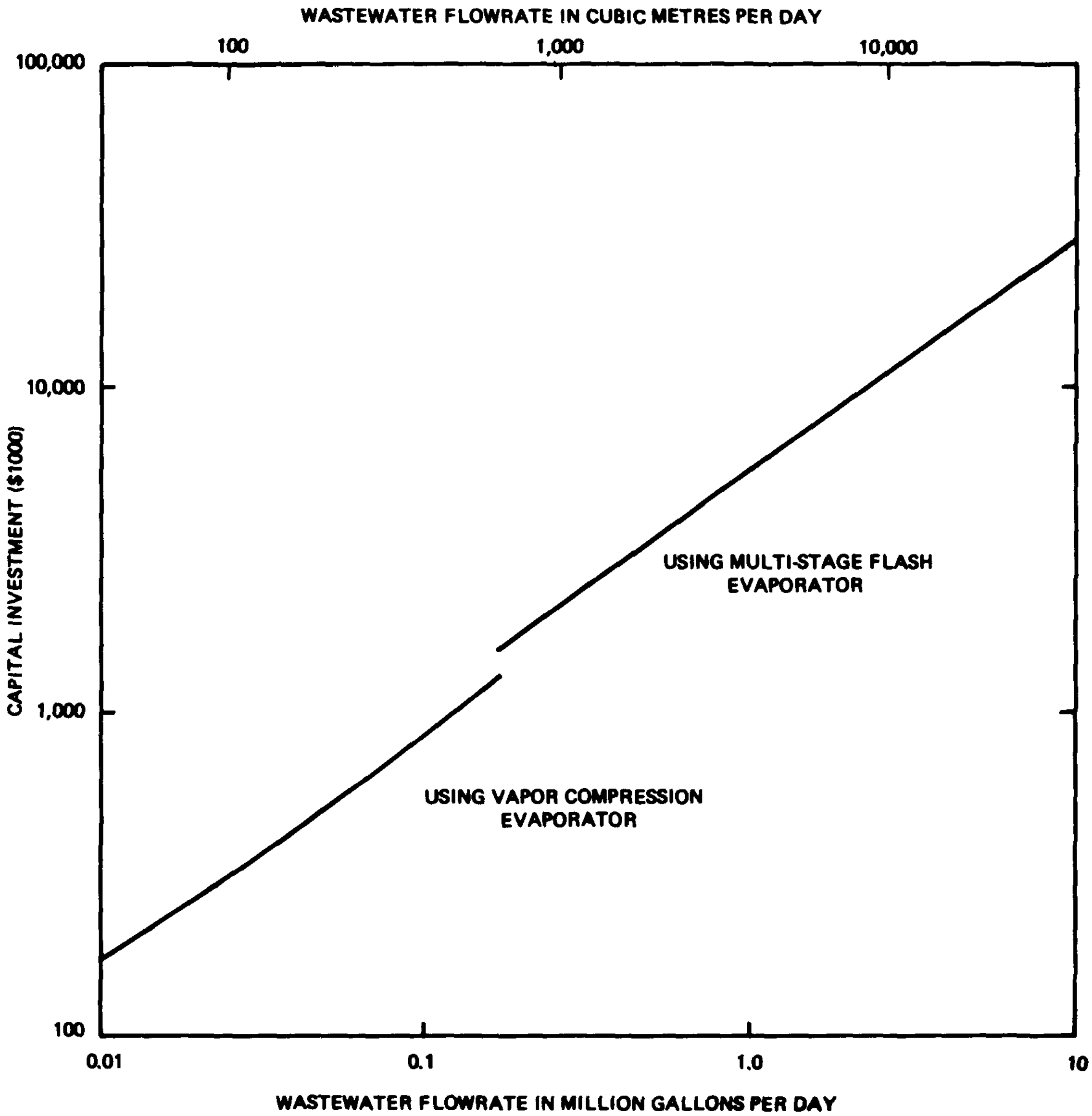

Figure 32. Capital investment costs for wastewater treatment--dissolved-solids removal module; Alternative 8E.

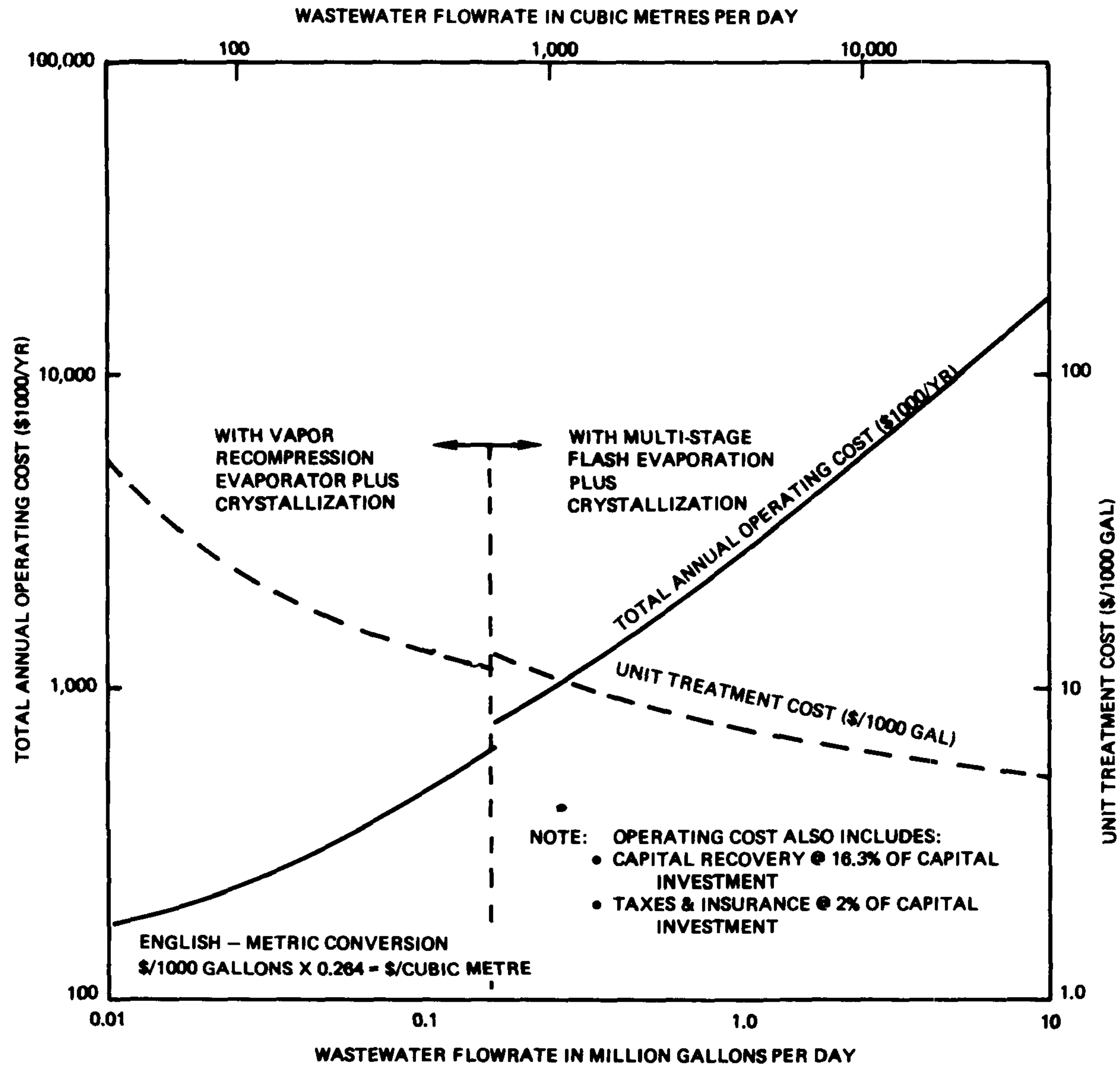

Figure 33. Total annual operating costs for wastewater treatment--dissolved-solids removal module; Alternative 8E.

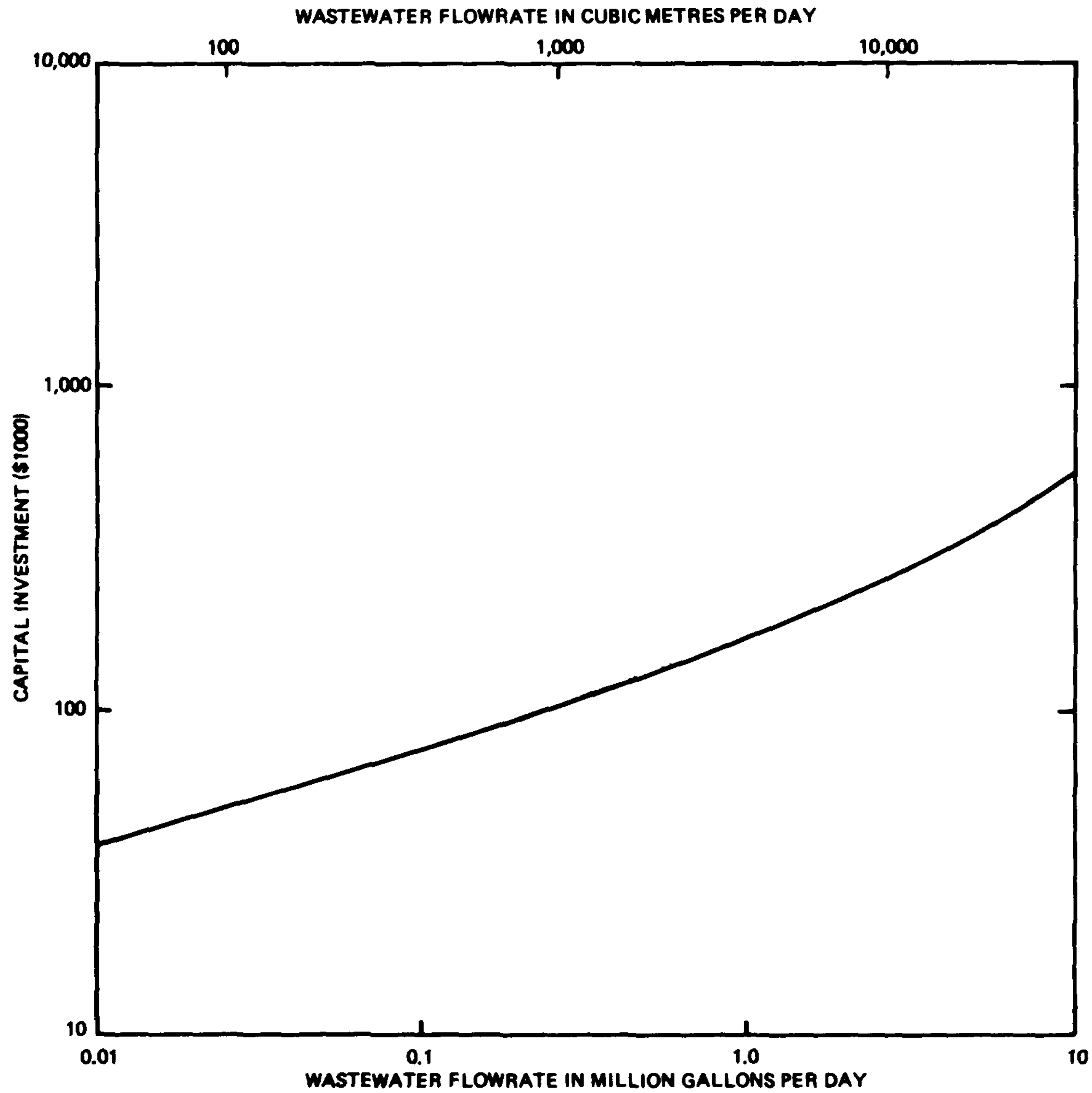

Figure 34. Capital investment costs for wastewater treatment--treated wastewater discharge module; Alternative 8F.

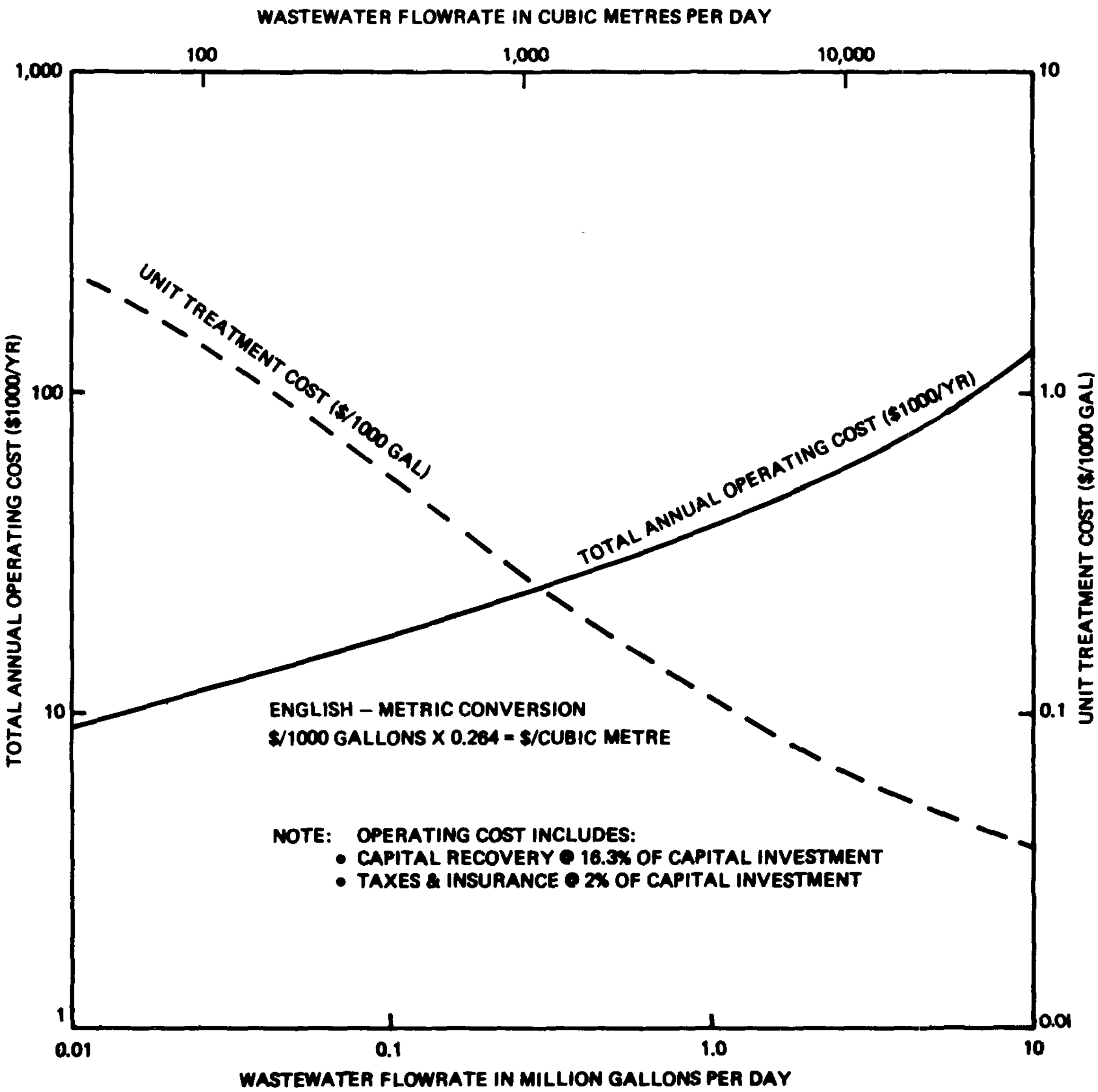

Figure 35. Total annual operating costs for wastewater treatment--treated wastewater discharge module; Alternative 8F.

A curve that relates estimated capital expenditure to well-field pumpage for selected raw water costs is shown in Figure 36. An assumed capital recovery of 6 yr has been used except for pump costs, which are spread out over 10 yr, and for well costs, which are spread out over 20 yr. Because the higher costs of raw water usually reflect expenditures for the additional land and transmission systems, the percentage of raw water costs attributed to pumps and wells are seen to decrease at the higher rates. Energy was considered to be 30 percent of the raw water cost on a yearly basis, and the miscellaneous category includes funds for land, transmission systems, and other construction features.

Alternative 10 - Treatment of Contaminated Ground Water Prior to Use

If widespread contamination of ground water requires that a new ground-water supply be located, it is likely that a new potable water-treatment plant will be necessary for the treatment of that water prior to the public use. Ground water in many areas has high hardness generally due to excess calcium and magnesium contents. Therefore, the treatment of ground water prior to use as a potable water supply commonly involves the lime/soda method for reducing hardness.

New Potable Water Treatment Plant (10A)

The cost module for the new potable water-treatment plant includes the following items:

1. A lime-softening system consisting of a lime, soda ash, and alum feed system and two solids recirculation clarifiers.

2. A dual media sand filtration system.

3. A chlorination system.

The following design basis was used in generating the capital and operating costs:

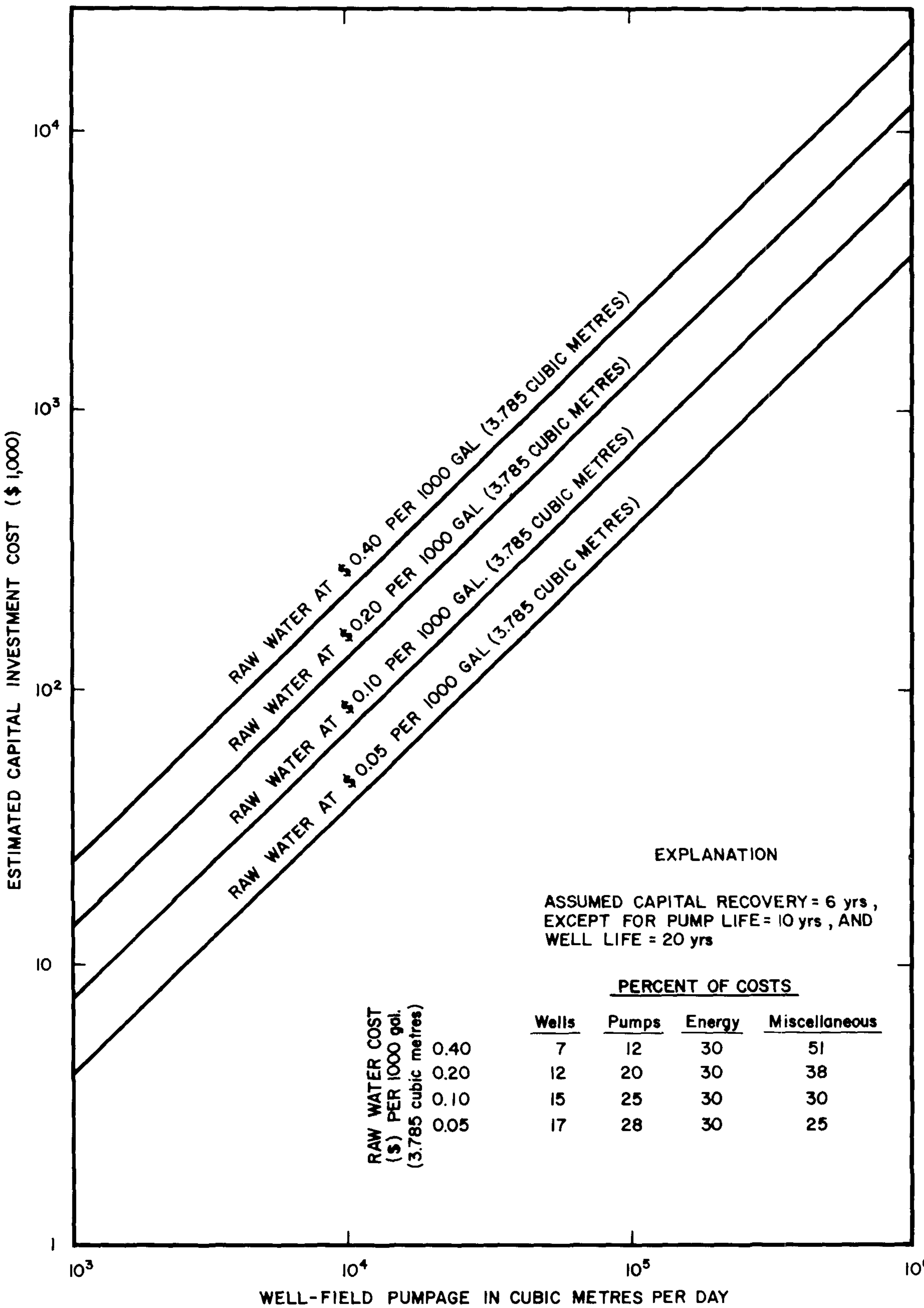

Figure 36. Estimated well-field replacement costs in relation to raw water pumpage; Alternative 9.

. Hardness reduction	500 mg/l (as $CaCO_3$)
. Ratio of total hardness to non-carbonate hardness	2
. Lime dosage	4.2 lbs/1,000 gal (0.5 kg/cu m)
. Price of hydrated lime	\$50/ton (\$55/tonne)
. Soda ash dosage	2.15 lbs/1,000 gal (0.26 kg/cu m)
. Price of soda ash	\$65/ton (\$72/tonne) (as Na_2O)
. Alum dosage	50 mg/l
. Price of alum	\$100/ton (\$110/tonne)
. Chlorine dosage	5 mg/l
. Price of chlorine	\$200/ton (\$220/tonne)
. Lime treatment sludge is disposed of onsite.	Onsite cost is negligible; offsite cost is about \$0.05/ 1,000 gal; most plants do not use lime treatment.
. The cost of the treatment plants does not include pumping stations or any other elements of the water transmission systems, either into or out of the plant.	

The capital cost curve for a new potable water treatment system is shown in Figure 37; the total annual operating cost curve is shown in Figure 38.

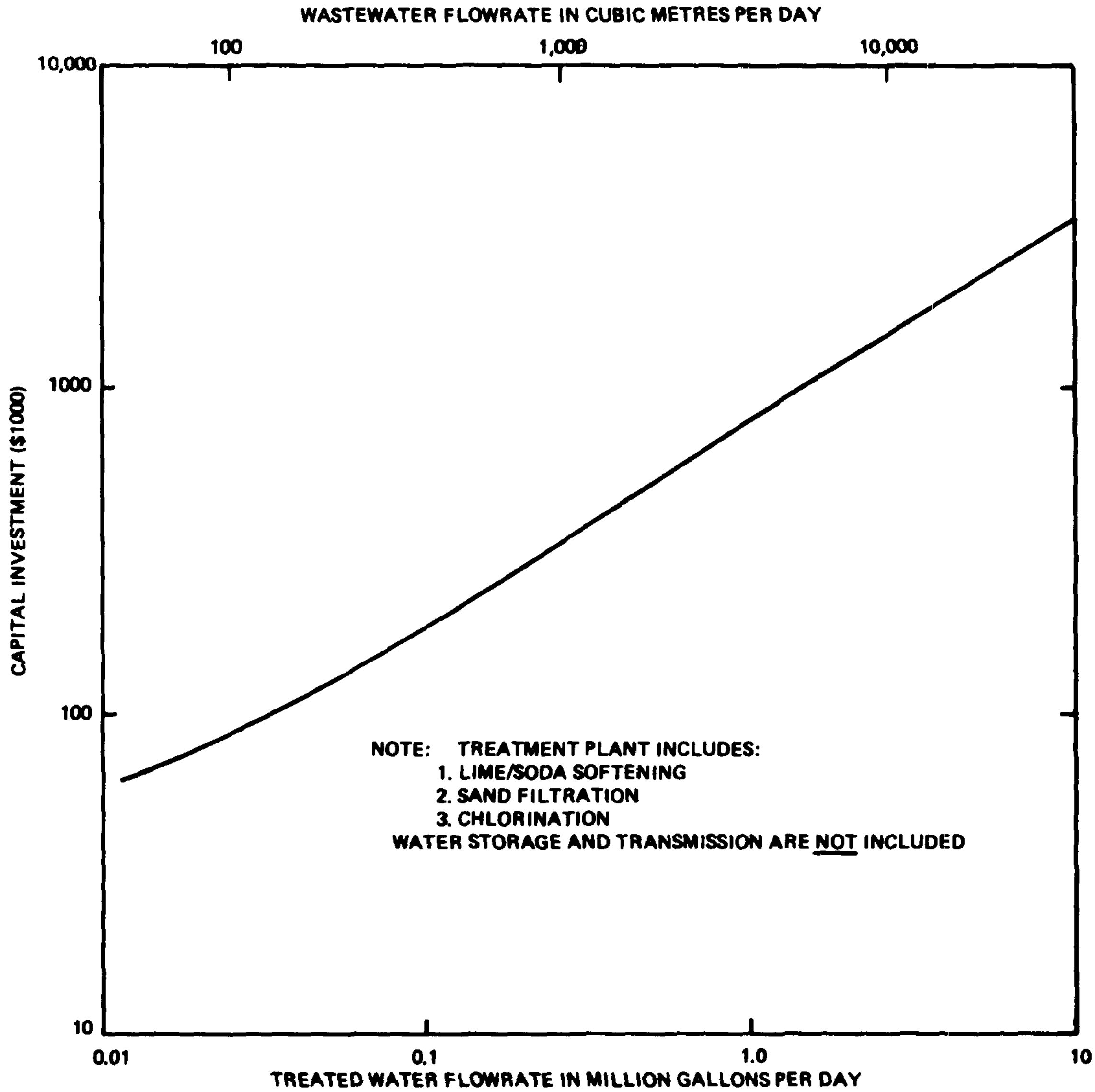

Figure 37. Capital investment costs for water treatment--new potable water-treatment plant module; Alternative 10A

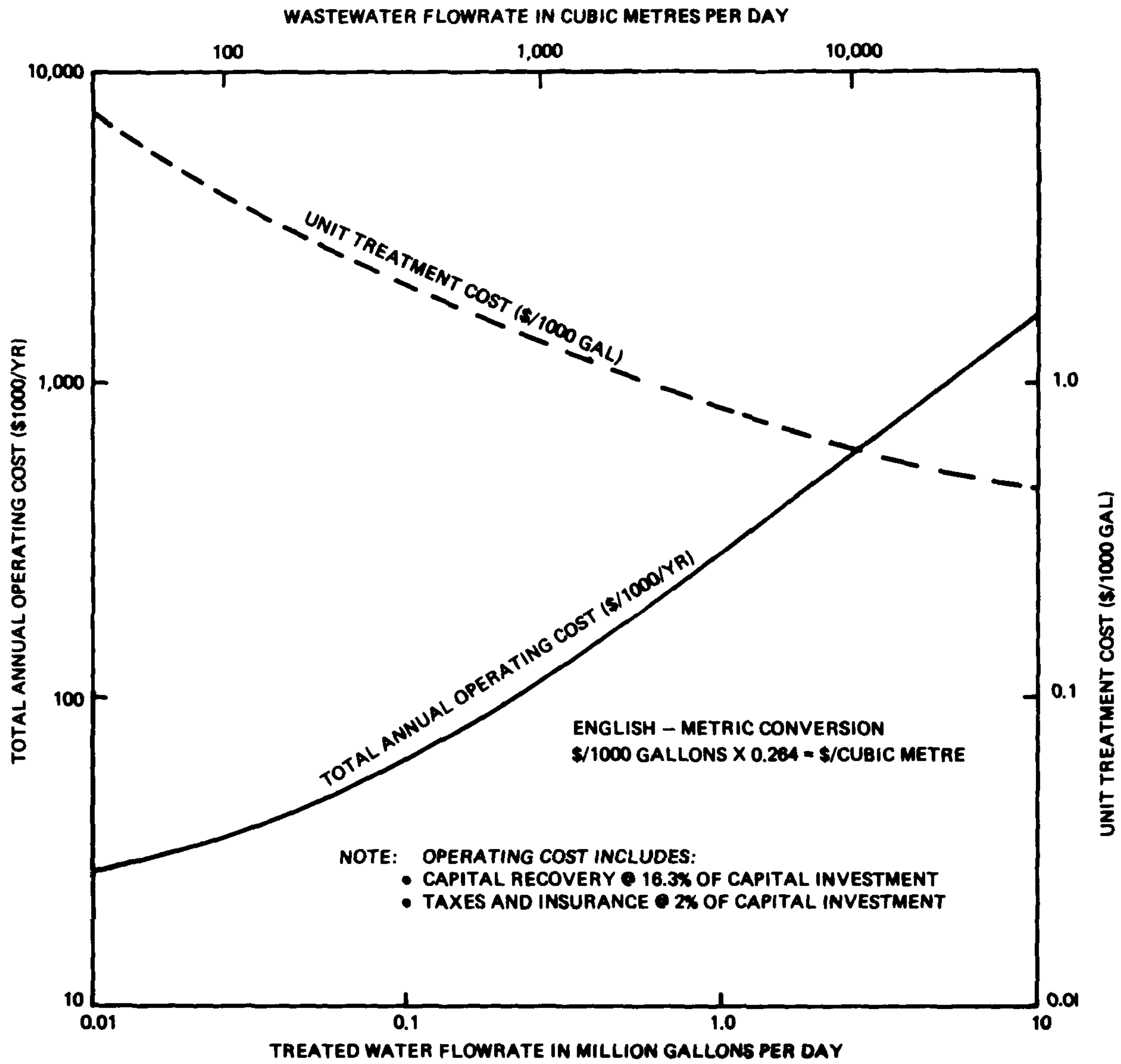

Figure 38. Total annual operating costs for water treatment--new potable water-treatment plant module; Alternative 10A.

Raw Water Storage Impoundment (10B)

The costs for a raw water storage impoundment are based on a facility consisting of an open basin, in two sections, lined to reduce leakage, emergency pumping facilities for transferring raw water from the storage basin into the normally operating system, piping, grading, fencing, and other appurtenances essential to a completed installation. The cost curve for the capital investment as a function of storage capacity is shown in Figure 39. The direct operating cost consists mainly of general maintenance, which is usually a very small percentage of the initial capital investment (probably less than 1 percent for the larger impoundments). The major components of the total annual operating costs are the capital recovery and taxes and insurance, which are set at 16.3 percent and 2 percent of the initial capital investment, respectively.

USE OF THE COST CURVES

To demonstrate the use of the cost curves, an example is given below for the hypothetical situation of an impoundment filled with a waste sludge containing soluble heavy metals in sufficiently high concentration to warrant the implementation of ground-water contamination prevention measures. The impoundment has the following physical features:

Dimensions - 1,000 ft x 1,000 ft (305 m x 305 m)

Distance from ground level to underlying impervious strata - 20 ft (6.1 m)

Flow of contaminated water leaking through the sides and bottom of the impoundment - 200,000 gpd (757 cu m/day).

The prevention techniques include collection of the contaminated water (Alternative 3 in Section VIII) plus treatment of the water prior to discharge into a receiving stream (Alternative 8). The capital investment for the total ground-water contamination prevention system is calculated as follows:

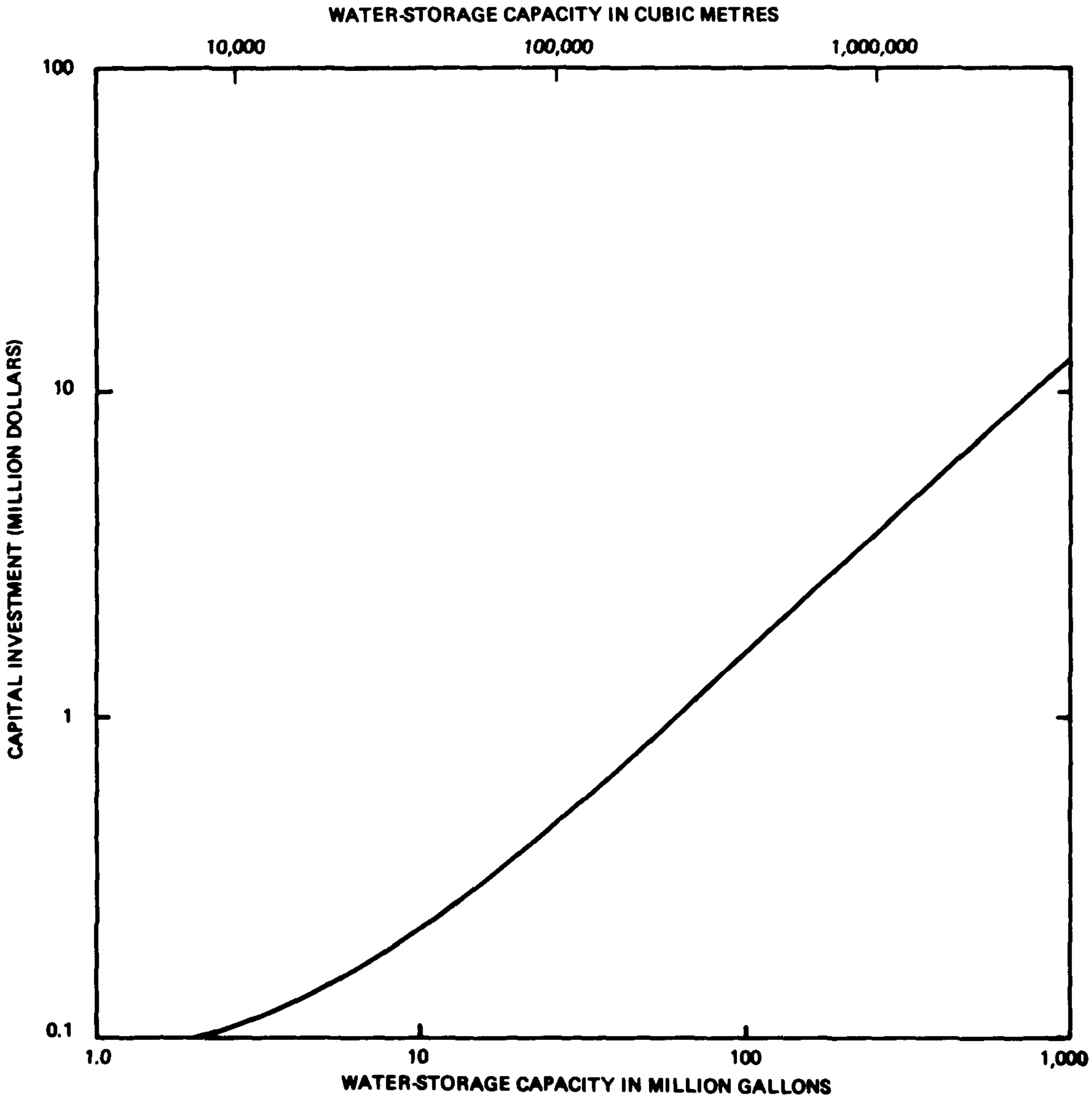

Figure 39. Capital investment costs for water storage--raw water storage impoundment module; Alternative 10B.

(a) Ground-water Collection System

In selecting a wellpoint system as the means of completion, the total area normal to the flow of contaminated water is the perimeter of the impoundment times the depth from the surface to the underlying impervious strata (4 x 1,000 x 20), or 80,000 sq ft (7,432 sq m). At a unit cost of $2.85/sq ft ($30.68/sq m), the total capital investment for the wellpoint system is $228,000.

(b) Treatment of Contaminated Waste

As stated previously, it is assumed that all wastewater-treatment systems will have an equalization basin, a heavy-metals removal system, and a treated water discharge system. The capital investment for the components of the total wastewater-treatment system based on a 200,000 gpd flow rate (760 cu m/day), is as follows:

Equalization (from Figure 23)	$ 45,000
Heavy-metals removal (from Figure 30)	$270,000
Treated water discharge system (from Figure 34)	$ 95,000
TOTAL:	$410,000

Total capital investment for the ground-water contamination prevention system is:

Collection system	$228,000
Wastewater-treatment system	$410,000
TOTAL:	$638,000

The total annual operating costs are calculated in a similar manner.

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3. Harza Engineering Company. 1965. Engineering investigation and design studies for underseepage control for Saylorville Dam, Des Moines, Iowa.

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16. ABSTRACT

The investigation was designed to provide broad background information on the use of municipal, industrial, and agricultural surface impoundments in the United States, with particular reference to the potential threats they may pose to the quality of underground drinking water resources and to methods of controlling or abating such threats. The study was made by EPA as part of that agency's responsibility for controlling subsurface emplacement of wastes, as mandated by Section 1442(a)(8)(c) of the Safe Drinking Water Act (P.L. 93-523). The principal subjects covered in the report are: (1) numbers, types and uses of impoundments, (2) chemical characteristics of the impounded wastes, (3) mechanisms by which wastes that seep from impoundments may contaminate ground water, (4) selected case-history data on ground-water contamination, (5) technical controls and costs for preventing and alleviating contamination, and (6) State regulatory controls over the use of impoundments.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Surface Impoundments, ground water quality protection, pits, ponds and lagoons, seepage		5/G 5/E

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