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Agency

Office of
Water

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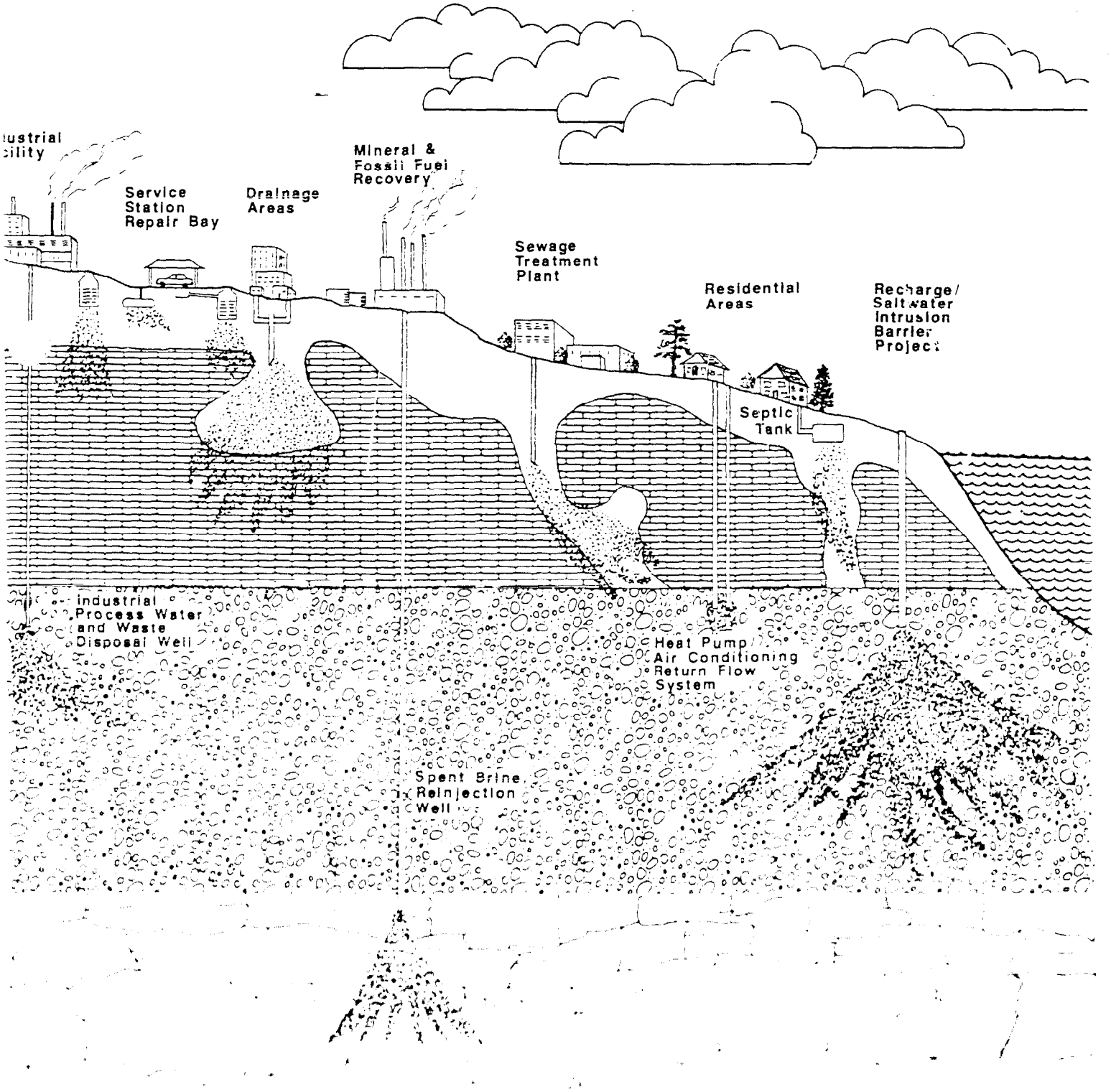
Water

Report To Congress

Class V Injection Wells

- Current Inventory
- Effects on Ground Water
- Technical Recommendations



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REPORT TO CONGRESS

Foreword

This report was prepared by the Office of Water, Environmental Protection Agency, from data gathered by the States, Territories, and Possessions of the United States in fulfilling the regulatory requirement of 40 CFR 146.52(b) and with the support of the EPA Regional offices and the contractor, Engineering Enterprises, Inc. (EEI) under EPA Contract Number 68-03-3416. The EPA project manager was L. Lawrence Graham, and the EEI project officer was Lorraine C. Council. In addition, an EPA Work Group, comprised of representatives from the Office of Water, the Office of Solid Waste and Emergency Response, the Office of General Counsel, the Office of Policy, Planning and Evaluation, the Office of Research and Development, and the EPA Regions provided technical input and review.

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Executive Summary

This report to Congress, prepared by the United States Environmental Protection Agency (USEPA), summarizes the results of State surveys concerning Class V injection wells as defined by the 1986 Amendments to the Safe Drinking Water Act. In accordance with the Act, the report (1) identifies the categories and corresponding inventories of Class V wells in the United States and its Territories and Possessions, (2) describes primary contamination problems associated with different categories of these wells, and (3) summarizes recommendations for minimum design, construction, installation, and siting requirements that could be applied to protect underground sources of drinking water (USDW) from such contamination wherever necessary including corrective action and remedial action recommendations.

Reports addressing Class V well construction features, injectate chemical characteristics and volumes, contamination potentials, corrective alternatives, and recommendations for remedial actions and regulatory approaches were submitted by State Directors of 56 of the 57 States, Territories, and Possessions of the United States. The reports were reviewed, summarized, and collated in preparing this report to Congress on Class V injection wells.

There are seven general categories identified and over 170,000 Class V injection wells inventoried by the States. The general categories include drainage wells, geothermal wells, domestic (sewage) waste disposal wells, wells related to mineral and fossil fuel recovery, industrial/commercial/utility wells, recharge wells, and miscellaneous wells. Ninety-four percent of all Class V wells belong to only four of the general categories: drainage wells (58%), domestic waste disposal wells (25%), geothermal wells - mostly heat pump/air conditioning return flow wells - (6%), and wells related to mineral and fossil fuel recovery (5%).

Distribution of the inventoried wells among the ten USEPA Regions is varied. Thirty-seven percent of the wells reported are located in Region IX, seventeen percent in Region X, sixteen percent in Region IV, and ten percent in Region V. Regions VIII and II each reported five percent of the wells. Regions VII, III, and VI each reported between two and four percent of the total number of wells, and Region I reported less than one percent.

Ground-water contamination potentials for each of the thirty well types (subcategories of the seven general well types) were assessed based on information provided by the States and based on a rating system which incorporated the following criteria: potential useability and identification of USDW; typical construction, operation, and maintenance procedures; chemical and physical characteristics of the injectate; and contamination potential based, in part, on injectate volumes. Some well types exhibited a range of contamination potentials. Class V wells

assessed to have high ground-water contamination potentials include agricultural drainage wells; improved sinkholes (high to moderate); raw sewage waste disposal wells and cesspools; septic systems; domestic wastewater treatment plant disposal wells (high to low); industrial process water and waste disposal wells; automobile service station waste disposal wells; and aquifer recharge wells (high to low).

Class V wells assessed to have moderate ground-water contamination potentials include storm water drainage and industrial drainage wells; improved sinkholes (high to moderate); special drainage wells (moderate to low); electric power and direct heat reinjection wells; aquaculture return flow wells; domestic wastewater treatment plant disposal wells; domestic wastewater treatment plant disposal wells; in-situ fossil fuel recovery wells; cooling water return flow wells (moderate to low); aquifer recharge wells (high to low); experimental technology wells (moderate to low); and abandoned drinking water/waste disposal wells.

Class V wells assessed to have low ground-water contamination potentials include special drainage wells (moderate to low); heat pump/air conditioning return flow wells; domestic wastewater treatment plant disposal wells (high to low); solution mining wells; spent brine return flow wells; cooling water return flow wells (moderate to low); aquifer recharge wells (high to low); saline water intrusion barrier wells; subsidence control wells; and experimental technology wells (moderate to low). Class V wells with unknown ground-water contamination potential include radioactive waste disposal wells and aquifer remediation wells.

The States recommended additional study in several areas. A primary concern of many States is that the existing inventory database is incomplete. Therefore, they recommend continuing efforts to locate uninventoried Class V facilities and upgrading the existing database of technical data for inventoried facilities. Regional and local hydrogeologic investigations may be necessary in order to more precisely define the potential impact of various Class V injection practices in areas containing sensitive aquifers.

The States also made several technical recommendations for adequate well siting, construction, operation, and maintenance to protect ground-water quality. The recommendations range from banning the use of cesspools and raw sewage waste disposal wells to developing appropriate mechanical integrity tests for geothermal electric power generation reinjection wells. Recommendations were also made to determine the ground-water contamination potentials of radioactive waste disposal wells and wells associated with aquifer remediation projects.

CLASS V REPORT TO CONGRESS

SECTION 1
INTRODUCTION

1.1 OBJECTIVE AND SCOPE

This report to Congress summarizes information and recommendations provided solely by the UIC programs of the States, Territories, and Possessions of the United States on Class V injection wells. Specifically, the report addresses the current inventory of Class V injection wells and their potential to affect ground water. Technical recommendations of the Directors of State Underground Injection Control Programs are presented. The U.S. Environmental Protection Agency recommendations are in the process of development.

1.2 BACKGROUND

On December 14, 1974, Congress enacted the Safe Drinking Water Act (PL 93-523) to protect the public health and welfare of persons and to protect existing and future underground sources of drinking water (USDW). In Part C of the Act, Congress directed the United States Environmental Protection Agency (USEPA) to develop regulations for the protection of underground source(s) of drinking water from contamination by the subsurface injection or emplacement of fluids through wells. In 1980, USEPA promulgated these regulations under 40 CFR Parts 144 through 146 and Part 124. The regulations specify minimum standards and technical requirements for the proper siting, construction, operation, monitoring, and plugging and abandonment of injection wells.

The Act also mandated the development of a Federally approved Underground Injection Control (UIC) program for each State, Possession, and Territory. Approval of a particular program is based on a finding that the program meets minimum standards and technical requirements of SDWA Section 1422 or Section 1425 and the applicable provisions set forth in 40 CFR Parts 124 and 144 through 146. States whose programs were submitted to and approved by USEPA are known as Primacy States. These states have primary enforcement responsibility for the regulation of injection wells in their States. In those instances where a State has opted not to submit a program for approval or where the submitted program does not meet the minimum standards and technical requirements, the program is promulgated and administered by USEPA. States with Federally administered programs are known as Direct Implementation (DI) States and are subject to the regulations set forth in 40 CFR Parts 124 and 144 through 146. There are 22 DI States, Possessions, and Territories at present. Reports on the Class V programs in the DI states and recommendations were prepared under the direction of the "Director" of that State program, i.e., the Regional Administrator. All underground injection is unlawful and subject to penalties unless authorized by a permit or rule.

The UIC regulations define and establish five classes or categories of injection wells. Class I wells inject hazardous and non-hazardous waste beneath the lowermost formation containing, within one-quarter mile of the well bore, an USDW. Class II wells are used in conjunction with oil and gas production. Class III injection wells are used in conjunction with the solution mining of minerals. Class IV wells inject hazardous or radioactive wastes into or above a formation which is within one-quarter mile of an USDW. (Class IV wells are prohibited by 40 CFR 144.13.) Class V wells include any wells that do not fall under Classes I through IV. Typically, Class V wells are used to inject non-hazardous fluids into or above underground sources of drinking water.

In 1980, USEPA chose to defer establishing technical requirements for Class V wells. Instead, these wells are authorized by rule. That is, injection into Class V wells is authorized until further requirements under future regulations are promulgated by USEPA. However, Class V wells are prohibited from contaminating any USDW or adversely affecting public health. Therefore, wells which are found to be violating this prohibition are subject to enforcement or closure. Some Primacy States require injection well permits while others currently implement authorization by rule or law.

The Agency has not established specific requirements for Class V wells for several reasons. By definition, the category of Class V encompasses a variety of well types ranging in complexity from radioactive waste disposal wells to storm water drainage wells. At the time of the original promulgation, little was known about the operation of these wells. The Agency reasoned that due to the large number and types of Class V wells in existence, the variability of injection fluids and volumes, the lack of knowledge concerning the extent of environmental damage caused by these wells, and the lack of knowledge concerning the consequences of bringing them under regulation, technical requirements could not be established that effectively would assure that operations of all Class V wells would not endanger USDW. Therefore, the Agency concluded that it was necessary to develop an assessment of Class V injection well activities prior to any regulatory development.

Under 40 CFR 146.52(a), USEPA requires owners and operators of Class V injection wells to notify the Director of the State or the Direct Implementation UIC program of the existence of all Class V wells under their control and to submit pertinent inventory information (as required under 40 CFR 144.26(a)). The Directors then are required, under 40 CFR 146.52(b), to complete and submit to USEPA a report containing the following:

1. Information on the construction features of Class V wells and the nature and volume of injected fluids;

2. An assessment of the contamination potential of Class V wells using hydrogeological data available to the State;

3. An assessment of the available corrective alternatives where appropriate and their environmental and economic consequences; and

4. Recommendations both for the most appropriate regulatory approaches and for remedial actions where appropriate.

The reports are required to be submitted no later than three years after the effective date of the State's UIC program approval. Several of the reports are not due until November 1987.

The 1986 Amendments to the Safe Drinking Water Act require USEPA to prepare and submit to Congress a report on Class V injection wells. The report is to summarize the results of the State reports and to note State recommendations for the design, siting, construction, operation, and monitoring of each Class V well type that has the potential to contaminate ground water. Specifically, Section 1426(b) of the Act states:

> The Administrator shall submit a report to Congress, no later than September 1987, summarizing the results of State surveys required by the Administrator under this section. The report shall include each of the following items of information:
>
> 1. The number of categories of Class V wells which discharge nonhazardous waste into or above an underground source of drinking water.
>
> 2. The primary contamination problems associated with different categories of these disposal wells.
>
> 3. Recommendations for minimum design, construction, installation, and siting requirements that should be applied to protect underground sources of drinking water from such contamination wherever necessary.

While the intent of Section 1426 is clear, it should be noted that the definition of Class V wells does not limit injection to only "into or above USDW" and does not limit Class V wells to only "disposal wells." Spent brine return flow wells (inventoried to date) and Class V radioactive waste disposal wells are examples of wells which inject below the lowermost USDW. Aquifer recharge wells and mineral and fossil fuel recovery wells are examples of wells which are not disposal wells.

Under 40 CFR Section 144.3, a "well" is defined as a bored, drilled, or driven shaft, or dug hole, whose depth is greater than its largest surface dimension. "Well injection" is defined as the subsurface emplacement of fluids through a bored, drilled, or driven well; or through a dug well where the depth of the dug well is greater than its largest surface dimension. A "fluid" is any material or substance which flows or moves, whether in semisolid, liquid, sludge, gas or any other form or state. The definitions of the five injection well classes are found in 40 CFR 144.6. A list of Class V well types recognized by USEPA for the purpose of this study is presented in Table 1-1.

As can be seen in Table 1-1, the Class V injection well category is large and diverse. This is due to the broad definition of Class V wells. If a well does not fit into one of the first four classes and meets the definition of an injection well, it is considered a Class V well.

Although included in Table 1-1 as Class V injection wells, air scrubber waste and water softener regeneration brine disposal wells, types 5X17 and 5X18, are not included in the inventory and assessment portion of this report. At the time the State Class V injection well reports were written, air scrubber waste and water softener regeneration brine disposal wells were categorized as Class V injection wells. As a result, however, of a July 31, 1987, USEPA policy decision, these well types, in certain situations, may fall under the Class II category rather than Class V. This was determined to be the case with those 5X17 and 5X18 wells inventoried in the State reports.

Class V injection wells can be divided into two general types of wells based on construction. "Low-tech" wells 1) have no casing designs or have simple casing designs and well head equipment and 2) inject into shallow formations by gravity flow or low volume pumps. In contrast, "high-tech" wells typically 1) have multiple casing strings, 2) have sophisticated well equipment to control and measure pressure and volume of injected fluid, and 3) inject high volumes into deep formations.

Low-tech well types include agricultural drainage wells (5F1), storm water and industrial drainage wells (5D2, 5D4), improved sinkholes (5D3), heat pump/air conditioning return flow wells (5A7), some aquaculture return flow wells (5A8), raw sewage disposal wells and cesspools (5W9, 5W10), septic systems (5W11, 5W31, 5W32), some mine backfill wells (5X13), some cooling water return flow wells (5A19), some industrial process water and waste disposal wells (5W20), automobile service station waste disposal wells (5X28), and abandoned water wells (5X29).

High-tech well types include geothermal wells used for electric power or for direct heat (5A5, 5A6), some aquaculture return flow wells (5A8), domestic wastewater treatment disposal wells (5W12), mining, sand, or other backfill wells (5X13), solution mining wells (5X14), in-situ fossil fuel recovery wells (5X15),

spent brine return flow wells (5A16), some cooling water return flow wells (5A19), some industrial process water and waste disposal wells (5W20), some aquifer recharge wells (5R21), salt water intrusion barrier wells (5B22), subsidence control wells (5S23), radioactive waste disposal wells (5N24), experimental technology wells (5X25), and aquifer remediation wells (5X26).

1.3 SUMMARY OF FINDINGS*

1.3.1 HYDROGEOLOGIC CONSIDERATIONS

Half of the population of the United States currently is served by ground water, and studies show that demand for this resource is increasing at a rate of 25 percent per decade. The use of ground water is increasing at a faster rate than is the use of surface water. The degree to which each State depends upon ground water varies from less than one percent of total water withdrawals (District of Columbia) to 85 percent (Kansas).

The largest single use for ground water is irrigation, and the major areas of usage are the southwestern, midwestern, and southern States. The second largest use for ground water in the United States is as a drinking water supply. Forty-eight percent of the population relies on ground water as a drinking water supply. Roughly two-thirds receive drinking water through public supplies, and the remainder are supplied through domestic wells.

Ground water aquifers are of two primary types, unconfined and confined. Unconfined, or water table, aquifers are the most common. Under unconfined conditions, the water table is exposed to the atmosphere such that the upper surface of the saturated zone is free to rise and decline through openings in the soil matrix. Available data suggest that most Class V injection is into or above unconfined aquifers. Confined, or artesian, aquifers are isolated from the atmosphere at the point of discharge by impermeable strata. The confined aquifer is subject to higher hydraulic pressure than atmospheric pressure, and certain high-tech Class V wells inject into these aquifers.

Waste disposal or other fluid emplacement through injection wells are potential causes of contamination to USDW. The distribution of contaminants within an aquifer can occur as discrete bodies, or "slugs," resulting from low volume or short term incidents of waste disposal/fluid injection. Cumulative effects of numerous slugs, or continual disposal of highly concentrated waste/injection fluid, or large volumes of waste/injection fluid from a single facility can cause widespread contamination. The degree of contamination ranges from slight deterioration in natural quality to the presence of toxic levels of heavy metals, organic compounds, inorganic contaminants, and radioactive materials.

* Findings are a compilation of data submitted by the States.

TABLE 1-1

CLASS V INJECTION WELL TYPES	
WELL CODE	NAME OF WELL TYPE AND DESCRIPTION
	DRAINAGE WELLS (a.k.a. DRY WELLS)
5F1	Agricultural Drainage Wells - receive irrigation tailwaters, other field drainage, animal yard, feedlot, or dairy runoff, etc.
5D2	Storm Water Drainage Wells - receive storm water runoff from paved areas, including parking lots, streets, residential subdivisions, building roofs, highways, etc.
5D3	Improved Sinkholes - receive storm water runoff from developments located in karst topographic areas.
5D4	Industrial Drainage Wells - include wells located in industrial areas which primarily receive storm water runoff but are susceptible to spills, leaks, or other chemical discharges.
5G30	Special Drainage Wells - are used for disposing water from sources other than direct precipitation. Examples of this well type include: landslide control drainage wells, potable water tank overflow drainage wells, swimming pool drainage wells, and lake level control drainage wells.
	GEOTHERMAL REINJECTION WELLS
5A5	Electric Power Reinjection Wells - reinject geothermal fluids used to generate electric power - deep wells.
5A6	Direct Heat Reinjection Wells - reinject geothermal fluids used to provide heat for large buildings or developments - deep wells.
5A7	Heat Pump/Air Conditioning Return Flow Wells - reinject groundwater used to heat or cool a building in a heat pump system - shallow wells.
5A8	Groundwater Aquaculture Return Flow Wells - reinject groundwater or geothermal fluids used to support aquaculture. Non-geothermal aquaculture disposal wells are also included in this category (e.g. Marine aquariums in Hawaii use relatively cool sea water).

TABLE 1-1

CLASS V INJECTION WELL TYPES

WELL CODE	NAME OF WELL TYPE AND DESCRIPTION
	DOMESTIC WASTEWATER DISPOSAL WELLS
5W9	Untreated Sewage Waste Disposal Wells - receive raw sewage wastes from pumping trucks or other vehicles which collect such wastes from single or multiple sources. (No treatment)
5W10	Cesspools - include multiple dwelling, community, or regional cesspools, or other devices that receive wastes and which must have an open bottom and sometimes have perforated sides. Must serve greater than 20 persons per day if receiving solely sanitary wastes. (Settling of solids)
5W11	Septic Systems (Undifferentiated disposal method) - are used to inject the waste or effluent from a multiple dwelling, business establishment, community, or regional business establishment septic tank. Must serve greater than 20 persons per day if receiving solely sanitary wastes. (Primary Treatment)
5W31	Septic Systems (Well Disposal Method) - are used to inject the waste or effluent from a multiple dwelling, business establishment, community, or regional business establishment septic tank. Examples of wells include actual wells, seepage pits, cavitettes, etc. The largest surface dimension is less than or equal to the depth dimension. Must serve greater than 20 persons per day if receiving solely sanitary wastes. (Less treatment per square area than 5W32)
5W32	Septic Systems (Drainfield Disposal Method) - are used to inject the waste or effluent from a multiple dwelling, business establishment, community, or regional business establishment septic tank. Examples of drainfields include drain or tile lines, and trenches. Must serve more than 20 persons per day if receiving solely sanitary wastes. (More treatment per square area than 5W31)
5W12	Domestic Wastewater Treatment Plant Effluent Disposal Wells - dispose of treated sewage or domestic effluent from facilities ranging from small package plants up to large municipal treatment plants. (Secondary or further treatment)

TABLE 1-1

CLASS V INJECTION WELL TYPES

WELL CODE	NAME OF WELL TYPE AND DESCRIPTION
	MINERAL AND FOSSIL FUEL RECOVERY RELATED WELLS
5X13	Mining, Sand, or Other Backfill Wells - are used to inject a mixture of fluid and sand, mill tailings, and other solids into mined out portions of subsurface mines whether what is injected is a radioactive waste or not. Also includes special wells used to control mine fires and acid mine drainage wells.
5X14	Solution Mining Wells - are used for in-situ solution mining in conventional mines, such as stopes leaching.
5X15	In-situ Fossil Fuel Recovery Wells - are used for in-situ recovery of coal, lignite, oil shale, and tar sands.
5X16	Spent-Brine Return Flow Wells - are used to reinject spent brine into the same formation from which it was withdrawn after extraction of halogens or their salts.
	OIL FIELD PRODUCTION WASTE DISPOSAL WELLS
5X17	Air Scrubber Waste Disposal Wells - inject wastes from air scrubbers used to remove sulfur from crude oil which is burned in steam generation for thermal oil recovery projects. (If injection is used directly for enhanced recovery and not just disposal it is a Class II well.)
5X18	Water Softener Regeneration Brine Disposal Wells - inject regeneration wastes from water softeners which are used to improve the quality of brines used for enhanced recovery. (If injection is used directly for enhanced recovery and not just disposal it is a Class II well.)
	INDUSTRIAL/COMMERCIAL/UTILITY DISPOSAL WELLS
5A19	Cooling Water Return Flow Wells - are used to inject water which was used in a cooling process, both open and closed loop processes.

TABLE 1-1

CLASS V INJECTION WELL TYPES

WELL CODE	NAME OF WELL TYPE AND DESCRIPTION
5W20	Industrial Process Water and Waste Disposal Wells - are used to dispose of a wide variety of wastes and waste-waters from industrial, commercial, or utility processes. Industries include refineries, chemical plants, smelters, pharmaceutical plants, laundromats and dry cleaners, tanneries, laboratories, petroleum storage facilities, electric power generation plants, car washes, electroplating industries, etc.
5X28	Automobile Service Station Disposal Wells - inject wastes from repair bay drains at service stations, garages, car dealerships, etc.
	RECHARGE WELLS
5R21	Aquifer Recharge Wells - are used to recharge depleted aquifers and may inject fluids from a variety of sources such as lakes, streams, domestic wastewater treatment plants, other aquifers, etc.
5B22	Saline Water Intrusion Barrier Wells - are used to inject water into fresh water aquifers to prevent intrusion of salt water into fresh water aquifers.
5S23	Subsidence Control Wells - are used to inject fluids into a non-oil or gas producing zone to reduce or eliminate subsidence associated with overdraft of fresh water and not used for the purpose of oil or natural gas production.
	MISCELLANEOUS WELLS
5N24	Radioactive Waste Disposal Wells - include all radioactive waste disposal wells other than Class IV wells.
5X25	Experimental Technology Wells - include wells used in experimental or unproven technologies such as pilot scale in-situ solution mining wells in previously unmined areas.
5X26	Aquifer Remediation Related Wells - include wells used to prevent, control, or remediate aquifer pollution, including but not limited to Superfund sites.

TABLE 1-1

CLASS V INJECTION WELL TYPES

WELL CODE	NAME OF WELL TYPE AND DESCRIPTION
5X29	Abandoned Drinking Water Wells - include those abandoned water wells which are used for disposal of waste.
5X27	Other Wells - include any other unspecified Class V wells.

Generally, Class V injection is into or above USDW. An USDW is defined as an aquifer or its portion which supplies any public water system or which contains a sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption or contains fewer than 10,000 mg/l total dissolved solids, and which is not an exempted aquifer. Certain special Class V facilities are known to inject fluids below USDW. Potential for contamination to USDW varies and is dependent upon where injection occurs relative to USDW; well construction, design, and operation; injectate quality; and injection volumes. Class V injection practices which discharge directly into USDW are potentially more harmful to USDW than Class V injection above or below USDW because some protection of USDW may be provided by injection above or below USDW.

1.3.2 CLASS V INJECTION WELL INVENTORY

As defined in this report, there are seven general categories of Class V injection wells containing a total of 30 well types. Based on State inventories, there are approximately 173,159 Class V wells in the United States and its associated Territories and Possessions. About 94 percent of all Class V wells belong to four main categories: drainage wells (58%), sewage related wells (25%), geothermal wells (6%), and mineral and fossil fuel recovery related wells (5%).

The numbers of Class V wells broken down by USEPA Regions are as follows:

Region IX:	64,214	37%
Region X:	29,826	17%
Region IV:	27,911	16%
Region V:	17,772	10%
Region VIII:	9,015	5%
Region II:	8,950	5%
Region VII:	6,675	4%
Region III:	4,589	3%
Region VI:	3,843	2%
Region I:	364	<1%

It should be noted that these numbers can be misleading, however, because inventories were not conducted with consistent levels of resources and guidance. There is a high probability that the distribution of wells and the resulting conclusions are not entirely accurate. Fifty-six States had submitted Class V inventory and assessment reports by August 1987 for incorporation into this Report to Congress.

Figure 1-1 is a map of the States and USEPA Regions. At the present time, there are 22 Direct Implementation States (or Possessions or Territories) and 35 Primacy States.

1.3.3 CONTAMINATION POTENTIAL ASSESSMENTS

Contamination potential has been assessed for each well type in this report, using all available data. Because inventory databases varied widely for different well types, a unified system was needed with which to assess each well type equivalently. The assessment incorporates the following parameters:

1. Identification and potential useability of USDW;
2. Typical construction, operation, and maintenance procedures;
3. Chemical and physical characterization of injection fluid; and
4. Typical injected volumes.

Based upon this rating scheme, well types have been assessed qualitatively for contamination potential as high, moderate, or low. Certain Class V well types exhibit such variation in design and injectate quality that a spectrum of ratings (e.g., moderate to low, high to moderate, high to low) resulted. A few well types have an unknown potential for contamination due to extremely limited information. Contamination potentials for Class V wells currently are assessed as follows:

<u>High Contamination Potential</u>

- Agricultural drainage wells, 5F1;
- Improved sinkholes, 5D3 (high to moderate);
- Raw sewage waste disposal wells, 5W9, and cesspools, 5W10;
- Septic systems, 5W11, 5W31, 5W32;

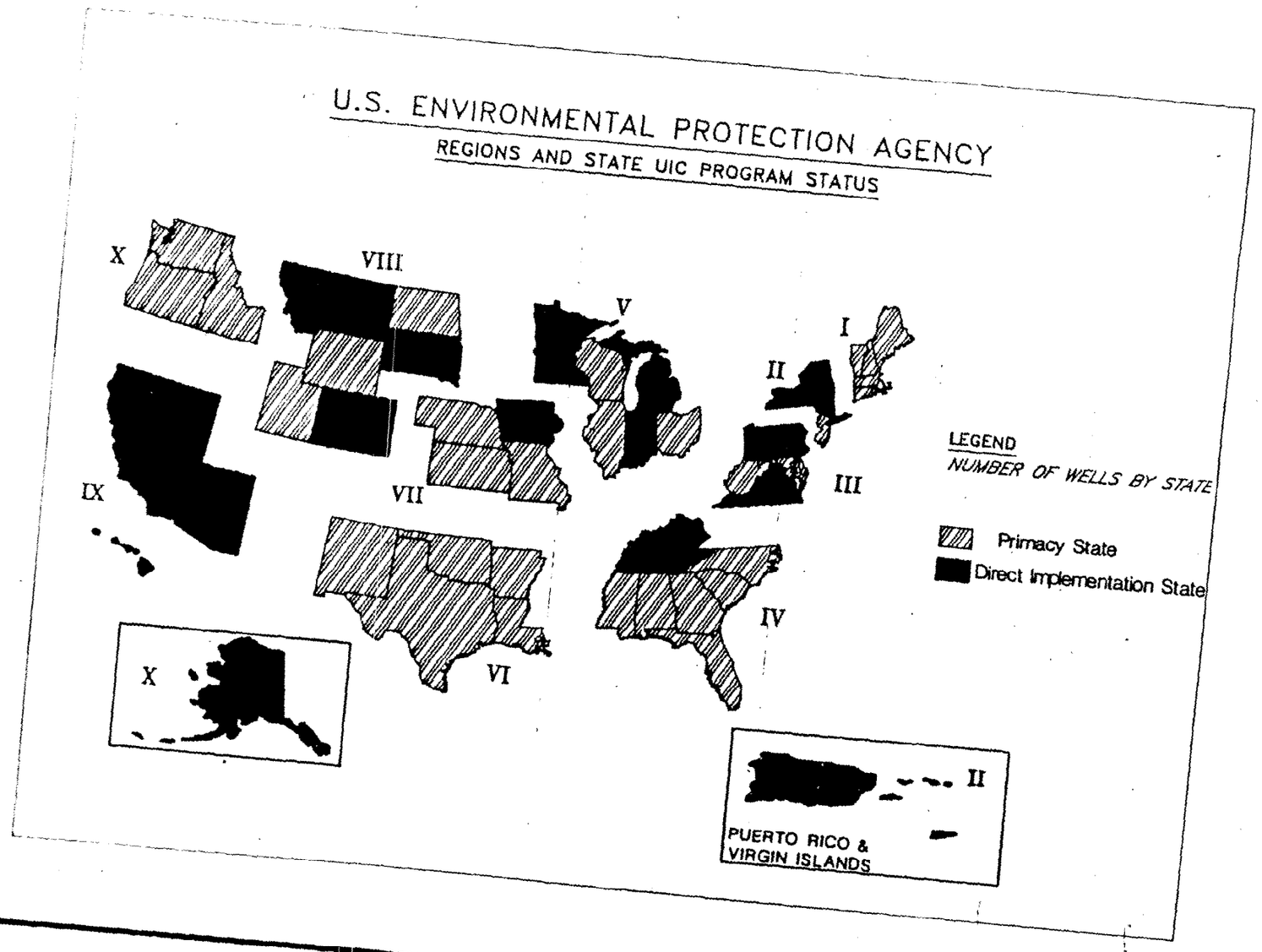

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGIONS AND STATE UIC PROGRAM STATUS
X
VIII
V
I
II
III
IX
VII
IV
VI
X
II
PUERTO RICO &
VIRGIN ISLANDS
LEGEND
NUMBER OF WELLS BY STATE
Primacy State
Direct Implementation State

Figure 1-1

- Domestic wastewater treatment plant disposal wells, 5W12 (high to low);
- Industrial process water and waste disposal wells, 5W20;
- Automobile service station waste disposal wells, 5X28; and
- Aquifer recharge wells, 5R21 (high to low).

Moderate Contamination Potential

- Storm water drainage, 5D2, and industrial drainage wells, 5D4;
- Improved sinkholes, 5D3 (high to moderate);
- Special drainage wells, 5G30 (moderate to low);
- Electric power, 5A5, and direct heat reinjection wells, 5A6;
- Aquaculture return flow wells, 5A8;
- Domestic wastewater treatment plant disposal wells, 5W12 (high to low);
- Mining, sand, or other backfill wells, 5X13;
- In-situ fossil fuel recovery wells, 5X15;
- Cooling water return flow wells, 5A19 (moderate to low);
- Aquifer recharge wells, 5R21 (high to low);
- Experimental technology wells, 5X25 (moderate to low); and
- Abandoned drinking water/waste disposal wells, 5X29.

Low Contamination Potential

- Special drainage wells, 5G30 (moderate to low);
- Heat pump/air conditioning return flow wells, 5A7;
- Domestic wastewater treatment plant disposal wells, 5W12 (high to low);
- Solution mining wells, 5X14;
- Spent brine return flow wells, 5X16;

- Cooling water return flow wells, 5A19 (moderate to low);

- Aquifer recharge wells, 5R21 (high to low);

- Saline water intrusion barrier wells, 5B22;

- Subsidence control wells, 5S23; and

- Experimental technology wells, 5X25 (moderate to low).

Unknown Contamination Potential

- Radioactive waste disposal wells, 5N24; and

- Aquifer remediation wells, 5X26 (including hydrocarbon recovery injection wells).

Additional study is necessary in a number of areas. A primary concern of many States is that the existing inventory database is incomplete. It is recommended by many States that efforts continue in attempting to locate uninventoried Class V facilities and to upgrade the existing database of technical data for inventoried facilities. Also, States recommended that hydrogeologic studies on both local and regional scales may need to be conducted for areas containing sensitive aquifers in order to define the potential impact of the various types of Class V injection practices. Table 1-2 presents a summary of available inventory data, types of fluids injected, and State recommendations.

1.4 CONTENT OF REPORT

Section Two of the report is an overview of the ground water resource and current and projected use of the resource. Several hydrogeologic considerations, important when examining injection well practices, are discussed to provide the reader with an appropriate background. A general understanding of our ground-water resource is essential, considering that over 95 percent of Class V injection wells discharge directly into, above, or between USDW.

The inventory information submitted by the State UIC programs is presented and summarized in Section Three of the report. Inventory numbers are given by well type and by USEPA Regions and States. The sources of the inventory data are primarily State reports; however, inventory information also was obtained from personal interviews, the FURS database (Federal UIC Reporting System), reports other than the State Class V reports, and published literature.

Section Four of the report is presented in two parts. The first part is a discussion of methods used to determine ground-water contamination potential and the criteria important in assessing an individual well type's potential. The second part of Section Four consists of the individual well type assessments for the Class V wells listed in Table 1-1. Each assessment addresses well purpose; inventory and location; construction, siting, and operation; nature of injected fluids and injection zone interactions; hydrogeology and water usage; contamination potential of well type; current regulatory approach; and State recommendations for siting, construction, operation, and corrective or remedial actions. As with the inventory information, most data used in the well type assessments came from States' Class V reports. Additional data were gathered from published literature, unpublished reports, inspection and investigation programs, and personal interviews.

The Summary and Conclusions Section, Section Five, provides an overview of the preceding sections on inventory and assessment and contains a summary table for quick reference. Section Six of the report presents recommendations both for the inventory database and for each Class V well type assessed in the report. The recommendations are a summary of those given by the State reports. The recommendations include consideration of the technical aspects of Class V injection, such as siting, construction, and operation.

Appendix A consists of State Report Summaries for each of the State Class V reports received and reviewed to date. Appendices B and C contain the glossary and list of acronyms and abbreviations used, respectively. Appendix D consists of a general bibliography and other well-type specific bibliographies. Appendix E is a listing of supporting data, mainly case studies, used (to augment State report data) in assessing well types.

TABLE 1-2

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Drainage Wells					
Agricultural Drainage Wells (5F1)	Nationwide: 1,338 wells New York: 150 wells Puerto Rico: no numbers West Virginia: no numbers Florida: no numbers Georgia: 43 wells Kentucky: no numbers Illinois: 6 wells Indiana: 72 wells Michigan: 15 wells Minnesota: 54 wells Oklahoma: no numbers Texas: 108 wells Iowa: 230 wells Missouri: no numbers Nebraska: 5 wells Colorado: no numbers North Dakota: 1 well Idaho: 572 wells Oregon: 16 wells Washington: 66 wells Potentially many times this figure in areas typified by irrigation.	Varies due to differing farming practices and soil types; potential agricultural contaminants include sediment, nutrients, pesticides, organics, salts, metals, and pathogens in some cases.	High	New York - SPDES Permit Florida - Permit Georgia - Banned Illinois - Rule Oklahoma - Rule Iowa - Diversion Permit Missouri - None Nebraska - Rule Utah - Rule Arizona - Permit Idaho - Permit if deeper than 18 feet Washington - Undecided	- Improvement of inventory efforts is essential. (PR, GA, IN, MI, MN, CO, OR) - Locate and properly plug all abandoned wells near Agricultural Drainage Wells. (IA) - Close surface inlets to allow infiltration through soil. (MD) - Raise the inlets above maximum ponding levels. (IA) - Require that injection fluids meet all or some drinking water standards. (NE, OR) - Require irrigation tailwater recovery and pumpback. (OR) - Use only necessary amounts of irrigation water and applied chemicals. (CA) - Require frequent monitoring of drinking water wells in surrounding areas. - Require detailed map with all well locations. (NE) - Require diagram of injection well construction. (NE) - Require siting of wells at least 2,000 ft. away from any stock, municipal, or domestic well. (NE) - Discourage use and encourage elimination of agricultural drainage wells by developing alternate methods. (IA)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Storm Water Drainage Wells (5D2)	Nationwide: 80,000-100,000 wells reported for 39 States	Herbicides, pesticides, fertilizers, deicing salts, asphaltic sediments, gasoline, grease oil, tar and residues from roofs and paving, rubber particulates, liquid wastes and industrial solvents, heavy metals and coliform bacteria.	Moderate	Information applies to both 5D2 and 5D4 unless otherwise specified. Connecticut-Permit (5D2) Massachusetts-Exempt (5D2) New Jersey-NJPDES Permit New York-Permit if injected volume exceeds 1,000 GPD Maryland-Permit (5D4) Alabama-Permit (5D2) Florida-Permit Georgia-Banned Kentucky-Local (5D2), Permit (5D4) South Carolina-Permit (5D2) Tennessee-Permit (5D2) Illinois-Rule Wisconsin-None (5D2) Rule (5D4) Louisiana-Class II Regulations (5D4), Registration of Class V wells not required New Mexico-Registration Oklahoma-Rule Nebraska-Rule Montana-Permit (5D2) Utah-Rule Wyoming-Permit (5D2) Arizona-Registration California-Rule Hawaii-Permit Guam-Permit (5D2) Alaska-Permit (5D2) Idaho-Permit if deeper than 18 feet (5D2) Washington-None	Apply to both storm water and industrial drainage wells: - New wells should be investigated and added to FURS. (KY, UT, WA) - Construction of new industrial drainage wells should be limited or discouraged; storm water sewers,- detention ponds, or vegetative basins are preferred. (OR, IL, KY, TN, UT). - Sand and gravel filters should be added to wells. (KY, TN) - Stand pipes should be constructed at the openings of wells. (KY, TN) - Limit future construction to residential areas. (IL) - All spills should be diverted away from industrial drainage wells (OR, UT, WA) - New construction of wells in areas served by storm water sewers should be prohibited. (CA, AZ) - Drainage wells should not be constructed within 200 ft. of water supply wells which tap lower water-bearing aquifers. (CA) - Deep wells should be plugged or cemented to avoid mixing between aquifers. (KY, TN) - Depth to water data should be made available to well drillers. (AZ) - Additional studies including use of monitoring wells should be conducted to study possible pollution sources and prolonged effect of industrial drainage wells on ground water. (FL, WI, KS) - An assessment of the effects of storm drainage wells should be conducted prior to completing an inventory because the inventory would be time-consuming and costly. (MT, OR) - Sediments extracted from drainage wells, catch basins, or sediment traps should be disposed in an appropriate landfill. (AZ) - A public awareness program should be implemented. (AZ) - All drainage wells should be identified and plugged. (WV)
Industrial Drainage Wells (5D4)	Nationwide: 3,802 wells reported for 23 States.	Similar constituents to those found in Stormwater Drainage Wells, though generally present in higher concentrations. Heavy metals such as lead, iron, and manganese. Organic compounds.			

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Improved Sinkholes (5D3)	Nationwide: 479 wells New Hampshire: 3 wells Puerto Rico: 10 wells Kentucky: 76 wells Tennessee: 5 wells Indiana: 26 wells Michigan: 103 wells Minnesota: 6 wells Missouri: 250 wells Virginia, West Virginia, Florida, and Ohio: numbers not yet confirmed. Potentially in all areas with limestone and dolomite lithologies at relatively shallow depths.	Runoff, from paved areas, containing lead and petroleum products from automobiles, pesticides from horticulture and lawn care, nitrates from fertilizers, and fecal material from wild and domestic animals; normal fallout from air pollutants may also be present.	High to Moderate	Puerto Rico-Permit Florida-Permit Georgia-Banned Kentucky-Local Tennessee-Permit Indiana-None Michigan-None Minnesota-None Ohio-None Missouri-None	- Training should be required for engineers and drillers in the proper construction of wells with special emphasis on sanitary sealing and protection against corrosion. Training should be slanted toward construction in Karst or limestone formations. (PR) - Careful dye trace studies should be run on any existing or improved sinkhole drainage systems, and occasional monitoring of both entering and exiting fluids should be run after the system is in operation. (MO)
Special Drainage Wells (5G30)	Nationwide: 1,557 wells Florida: 1,385 wells Louisiana: 1 well Montana: 55 wells Hawaii: 1 well Idaho: 7 wells Washington: 108 wells. Potentially present in all Regions.	Highly variable, depending on system design; for landslide control, ground water is generally used; swimming pool drainage fluid may contain lithium hypochlorite, calcium hypochlorite, sodium bicarbonate, chlorine, bromine, iodine, cyanuric acid, aluminum sulfate, algaecides, fungicides, and muriatic acid.	Moderate to Low	Florida-Permit/Rule Louisiana-Class II Regulations, Registration of Class V wells not required Nebraska-Rule Montana-Permit Hawaii-Permit Idaho-Permit if deeper than 18 feet.	- Random sampling and analysis of swimming pool wastewater for possible contaminants should be required. (FL)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Geothermal Reinjection Wells					
Electric Power Reinjection Wells (5A5)	Nationwide: 89 wells Texas: numbers not confirmed California: 65 wells Nevada: 16 wells Idaho: 4 wells Alaska: 4 wells	Vapor-Dominated Resource heavy metals (arsenic, boron, selenium), sulfates, and dissolved solids. Hot Water-Dominated Resource heavy metals (arsenic, boron, selenium), chlorides, dissolved solids, and acidic pH.	Moderate	Texas-Permit Nebraska-Rule Utah-Permit California-Permit Nevada-Permit Idaho-Permit	Apply to both electric power and direct heat reinjection wells: - Detailed study on the types of MIT available for geothermal systems and the resolution of each method. (NV) - Initial analysis of injectate and injection zone water conducted prior to full-scale injection operations; parameters of concern are temperature, inorganic constituents of Primary and Secondary Drinking Water Regulations, alkalinity, hardness, silica, boron, and ammonia nitrogen. (CA, NV) - Injection into non-thermal reservoirs if the thermal injection fluids meet drinking water requirements or if the receiving fluids are of equal or lesser quality. (ID)
Direct Heat Reinjection Wells (5A6)	Nationwide: 21 wells New York: no numbers New Mexico: 2 wells Texas: 1 well Colorado: 2 wells California: 1 well Nevada: 6 wells Idaho: 2 wells Oregon: 6 wells Utah: 1 well	Arsenic, boron, fluoride, dissolved solids, sulfates, chloride.	Moderate	New Mexico-Permit Texas-Permit Nebraska-Rule/Permit Utah-Permit California-Permit Nevada-Permit Idaho-Permit Oregon-Permit if injected volume exceeds 5,000 GPD	

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Heat Pump/Air Conditioning Return Flow Wells (5A7)	Nationwide: 10,028 wells. Potentially present in all regions; more expected in areas characterized by climatic extremes. Reported in all States except the following: Maine, Rhode Island, Vermont, Puerto Rico, Virgin Islands, West Virginia, Alabama, Arkansas, Hawaii, American Samoa, TTPI, Guam, CNMI.	Primarily thermally altered ground water; additives designed to inhibit scaling, corrosion and incrustation when water high in metals and salts, or demonstrating high or low pH, is used.	Low	Connecticut-Permit Massachusetts-Permit if injected volume is greater than 15,000 GPD New Jersey-Rule/Permit New York-Permit Delaware-Permit Maryland-Permit Florida-Permit Georgia-Banned North Carolina-Permit South Carolina-Rule Illinois-Rule Minnesota-Permit Wisconsin-Rule Louisiana-Permit New Mexico-Registration Oklahoma-Rule Texas-Rule Missouri-Registration Nebraska-Rule Montana-None North Dakota-Rule Utah-Permit Wyoming-Permit Arizona-None California-Permit Alaska-Permit Idaho-Permit Oregon-Permit if injected volume is greater than 5,000 GPD Washington-Permit	- More research is needed on the theoretical environmental effects of heat pumps. (MD, AZ, SC) - Authorization by rule is appropriate for properly spaced and operated systems. (SC) - New regulatory programs should be directed at large-scale systems rather than at systems for single-family dwellings. (LA, OK, TX) - Records should be maintained by counties and periodically up-loaded to State databases in order to monitor well densities. (WA) - The State permitting agency should set construction standards and ensure that wells are constructed and operated properly. (FL, KS, MD, NE, SC, WA) - Permits for commercial developments should include requirements for water quality characterizations of both source and receiving water. (WA) - Return wells should be cased through top of injection zone. (IA) - Annular space should be cemented or grouted. (IA, KS, NE, TN) - Adequate spacing between production wells should be practiced. (KS, NE, SC) - Discharge should be into or above the supply aquifer. (LA, IA, KS, SC) - Closed loop systems should be required. (UT, TN) - Discharge should be to the surface rather than to an injection well. (LA) - The waste product should contain no additives or only approved additives (LA, KS, NE) - Volumes and temperatures of injection fluids should be monitored. (NC) - Analyses of receiving fluids should be conducted periodically. (KS, WA) - A licensed water well driller should be employed to install, rework, and/or plug and seal the well. (LA, IL) - New well installation in known or suspected contaminated aquifers should be prohibited. (WA)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Wastewater: Aquaculture Return Flow Wells (5A6)	Hawaii: 7 active wells 3 standby wells 15 proposed wells Potentially found wherever marine or fresh water organisms are cultured in large quantities.	Large volumes of wastewater composed of essentially salt water with added nutrients, bacteriological growth, perished animals, and animal detritus. Effluent typically contains nitrates, nitrites, ammonia, high BOD, and orthophosphate.	Moderate	Nebraska-Rule Utah-Permit Hawaii-Permit Oregon-Permit if injected volume exceeds 5,000 GPD	- Regular sampling and analysis of injection fluid and injection zone fluid should be required (semi-annually). (HI) - Water to be disposed should be filtered and appropriately treated prior to injection. (HI) - Return waters should be carefully monitored at a point before and after treatment to ensure the measures being employed are sufficient to allow the water to be injected. (HI)
Drainage Wastewater Disposal Wells					
Raw Sewage Disposal Wells (5W9)	Nationwide: 980 wells Puerto Rico: 5 wells Pennsylvania: no numbers Illinois: 916 wells Indiana: 22 wells Michigan: 11 wells Minnesota: 10 wells Texas: 10 wells Hawaii: 3 wells Alaska: 3 wells	Generally poor quality, including high fixed volatiles, BOD, COD, TOC, nitrogen (organic, and free ammonia), chloride, alkalinity and grease.	High	Illinois-Banned Nebraska-Rule Utah-Banned Hawaii-Permit Nevada-Banned Alaska-Permit or Rule Oregon-Rule	No recommendations concerning raw sewage disposal wells and cesspools were provided in State reports. However, the use of such disposal methods has been banned in several States.
Cesspools (5W10)	Nationwide: 6,622 wells New Jersey: 1 well New York: no numbers Puerto Rico: 67 wells Indiana: 22 wells Michigan: 18 wells Minnesota: 25 wells New Mexico: 14 wells Texas: 16 wells Nebraska: no numbers Wyoming: 3 wells Arizona: 17 wells California: 46 wells Hawaii: 57 wells Alaska: > 79 wells Oregon: 6,257 wells	Same as for Raw Sewage Disposal Wells.	High	New Jersey-NJPDES Permit New York-Permit if injected volume exceeds 1,000 GPD New Mexico-Banned Texas-Rule Nebraska-Rule Utah-Banned Wyoming-Permit Arizona-Permit California-Banned Hawaii-Permit Nevada-Banned Alaska-Permit or Rule Oregon-Rule	

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Septic Systems (5W11, 5W31, 5W32)	5W11: 26,769 inventoried wells in 31 States 5W31: 4,435 wells in 13 States 5W32: 3,783 wells in 8 States	Varies with type of system; fluids typically 99.9% water (by weight) and .03 suspended solids; major constituents include nitrates, chlorides, sulfates, sodium, calcium, and fecal coliform.	High	Connecticut-Permit if volume injected exceeds 5,000 GPD Massachusetts-Permit if volume injected exceeds 15,000 GPD New Jersey-NJPDES Permit New York-Permit if volume injected exceeds 1,000 GPD Maryland-Permit (5W31) Alabama-Permit Florida-Permit Kentucky-Rule (5W31) South Carolina-Permit (5W32) Minnesota-Rule Wisconsin-Rule (5W31) Louisiana-Rule New Mexico-Registration Oklahoma-Rule Texas-Local Missouri-Permit Nebraska-Rule Montana-Permit North Dakota-Rule Utah-Permit Wyoming-Permit Arizona-Permit California-Permit Hawaii-Permit (5W31) Nevada-Banned (5W31), Permit (5W32) CNMI-None Alaska-Permit or Rule Idaho-Permit if deeper than 18 feet Oregon-Permit if injected volume exceeds 5,000 GPD (5W32) Washington-Permit/Rule	- Further study is recommended. (FL, MT, OR) - Proper construction and installation guidelines should be developed. (MO) - Ongoing training programs for sanitarians is recommended; should include hydrogeology, ground-water flow, theory of septic system operation, and potential risks to human health. (PR, MO, MN) - Siting should be conducted so as not to endanger water wells. (KS, NE) - All systems should be sited and designed individually. (TX) - Local planning groups should be encouraged to establish septic tank density limits. (NE) - Sewage disposal wells for private facilities should be phased out and replaced by alternate methods of treatment and disposal. (TX) - Well constructions should be investigated. (KS) - Statewide monitoring systems should be established and should include inventory methodology and database updates. (WA)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Municipal Wastewater Treatment Plant Effluent Disposal Wells (5W12)	Potentially present in all Regions. 1,099 wells inventoried nationwide in 19 States.	Injected fluid, after secondary or tertiary waste treatment, believed to be generally compatible with receiving formation; may contain high nitrates and fecal coliform if improperly treated.	High to Low	Massachusetts-Permit if injected volume exceeds 15,000 GPD New York-Permit Puerto Rico-Permit Florida-Permit Kentucky-Eliminate Illinois-Rule Indiana-Permit Michigan-Permit Texas-Rule/Permit Nebraska-Rule Utah-Permit Arizona-Permit California-Permit Hawaii-Permit Nevada-Banned Alaska-Permit or Rule Idaho-Rule Washington-Rule	- Operation should ensure that injection is restricted to rates and pressures dictated by site-specific hydrogeologic conditions (should involve monitoring). (WY, AL, HI). - Alternative methods of disposal and feasibility of upgrading existing plants should be evaluated. (VA) - In some cases, wells should be plugged. (KY)
Mineral and Fossil Fuel Recovery Related Wells					
Mining Sand or Other Backfill Wells (5W20)	Nationwide: 6,500 wells Maryland: 1 well Pennsylvania: 811 wells West Virginia: 258 wells Alabama: no numbers Kentucky: 61 wells Tennessee: no numbers Illinois: 5 wells New Mexico: 11 wells Texas: 65 wells Missouri: 4,326 wells Colorado: 2 wells Montana: 10 wells North Dakota: 300 wells Wyoming: 74 wells Nevada: 1 well Idaho: 575 wells	Hydraulic or pneumatic slurries - Solid portion of slurries may be sand, gravel, cement, mill tailings/refuse, or fly ash. - Slurry waters may be acid mine water or ore extraction process wastewater.	Moderate	Maryland-Permit Pennsylvania-Mine operation West Virginia-Mine operation Alabama-Permit Kentucky-Permit Illinois-Rule New Mexico-Unknown Texas-Rule Missouri-None Nebraska-Rule Colorado-Rule Montana-Permit North Dakota-Rule Utah-Rule Wyoming-Permit Idaho-Rule	- Siting, design, construction, and operation should be specified in permit requirements. (IL) - Slurry injection volumes should be monitored and compared to calculated mine volume to prevent catastrophic failure. (WV) - Ground-water monitoring in areas containing potable water. (MD) - Site-specific study is necessary to determine the nature and extent of degradation from mine backfill wells. (MT) - Authorization of mine backfill wells without permits should continue where tailings are injected into formations that are effectively isolated from USDW. (ID)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Solution Mining Wells (5X14)	Nationwide: 2,025 wells New York: 48 wells Michigan: 15 wells New Mexico: 1,073 wells Wyoming: 14 wells Arizona: 870 wells California: 5 wells Potentially in other mining districts.	Weak acid solutions (sulfuric and hydrochloric) Ammonium carbonate Sodium carbonate/bicarbonate Ferric cyanide	Low	New York-Permit New Mexico-Permit Nebraska-Permit Utah-Permit Wyoming-Permit Arizona-Permit California-Permit	- Network of injection wells should not extend beyond surface projection of ore body. (CA) - New types of mechanical integrity tests for implementation with this well type should be studied. (AZ) - Hydrologic monitoring should be conducted to determine a water budget. (AZ)
In Situ Fossil Fuel Recovery Wells (5X15)	Nationwide: 66 wells Colorado: 23 wells Indiana: 1 well Michigan: 1 well Wyoming: 41 wells Potentially in other areas wtih relatively shallow, organic rich sub strata.	Underground coal gasification: - air, oxygen, steam, water, igniting agents such as ammonium nitrate-fuel oil (ANFO) or propane. In situ oil shale retorting: - air, oxygen, steam, water, sand, explosives, igniting agents (generally propane) Purpose in both cases is to initiate and maintain combustion. Combustion products include polynuclear aromatics, cyanides, nitrites, phenols.	Moderate	Texas-Permit Nebraska-Rule Colorado-Rule Utah-Permit Wyoming-Permit	- Conduct complete geologic and hydrogeologic investigations prior to system implementation. (WY) - Remediate zone fluids to minimize future contamination. (WY)
Spent Brine Return Flow Wells (5X16)	Nationwide: 121 wells New York: no numbers West Virginia: 2 wells Indiana: 8 wells Michigan: 33 wells Arkansas: 70 wells Oklahoma: 7 wells North Dakota: 1 well Potentially in Regions having commercially recoverable halogen deposits.	Limited to brines from which halogens or salts have been extracted; Potential for addition of other undefined constituents into waste stream.	Low	New York-Permit Arkansas-Permit Oklahoma-Rule Nebraska-Rule Utah-Rule	- Technical requirements specified in permits should be similar to those for oilfield brine injection wells or solution mining wells. (WV, AR) - Construction requirements should be developed based upon well operating parameters. (AR) - Mechanical integrity tests should be required. (AR) - Semi-annual comprehensive sampling and analysis of fluid and comparison of produced vs. injected fluid should be required. (AR)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
[illegible]					
Cooling Water Return Flow Wells (5A19)	291 wells inventoried nationwide; potentially many times this number, and would be located in all Regions.	Dependent upon type of system, type of additives, and temperature of water; open pipe systems may expose ground water to accidental introduction of surface contaminants, industrial spills, or unauthorized disposal of wastes.	Moderate to Low	Massachusetts-Permit if injection volume exceeds 2,000 GPD New Jersey-NJPDES Permit Alabama-Permit Florida-Permit Georgia-Permit South Carolina-Rule Illinois-Rule Wisconsin-Rule Arkansas-None New Mexico-Registration Iowa-Permit Nebraska-Rule Utah-Permit California-Permit Hawaii-Permit Alaska-Permit Idaho-Permit Oregon-Permit if injected volumes exceed 5,000 GPD Washington-Permit	- Minimum locating requirements for the injection well relative to any nearby municipal supply wells should be established. (NE, SC) - Wells should be grouted from at least 20 feet below land surface to land surface or to the water table. (NE) - Wells should be cased from surface to the top of the uppermost supply and injection zone. (AR) - Cemented annulus from surface to supply/injection zone. (AR) - Require minimum of 2 wells: supply well and return well. (AR, SC) - Wells should be constructed such that spent fluids are injected into source aquifer. (AR) - Open loop return flow wells should be prohibited. (FL, AR, NE, UT) - Wells should be plugged with cement upon abandonment. (AR) - Permit specifications needed: Detailed map showing all area wells. Diagram of injection well design. Diagram of entire system. Type and volume of injectate. (AR, NE)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Industrial Process Water and Waste Disposal Wells (5W20)	1,989 inventoried wells in 33 States.	Potentially any fluid disposed by various industries; can have high dissolved solids, suspended solids, alkalinity, chloride, phosphate, sulfate, total volatiles.	High	Connecticut-Permit Massachusetts-Permit New Jersey-NJPDES Permit New York-Permit Maryland-Permit Pennsylvania-Permit Alabama-Permit Florida-Permit South Carolina-Permit Illinois-Rule Wisconsin-Permit Texas-Class I Regulations Nebraska-Rule Utah-Banned Wyoming-Permit Arizona-Permit California-Permit Hawaii-Permit Alaska-Permit Idaho-Permit if deeper than 18 feet Oregon-Permit	- Inventory efforts should continue with high priority on identifying industrial disposal facilities. (PR, IN, WI, AK, WY) - Assume all industrial waste disposal has a deleterious effect on USDW, warranting immediate action. (PA) - Extensive ground-water evaluation studies should be conducted to identify areas which would be vulnerable to contamination by industrial waste disposal. (PR, AL) - Drainage areas surrounding industrial facilities should be studied and all possible pollution sources noted. (KS) - Inspection of these facilities should be mandatory, and conducted by teams backed by chemical or industrial engineers. (PR) - Monitoring programs should be required and sampling specifications should be tightened. (PR, MD, FL, KS) - Ground-water monitoring should be conducted using a minimum of one upgradient and two downgradient wells. (AZ) - Practice of injecting industrial process water and waste should be discouraged, and wastes routed to on-site treatment facilities or municipal sanitary sewer systems. (FL) - Discharge of industrial process wastes to septic systems should be discouraged. (PR, NE) - These wells should be permitted only when injection is into ground water containing greater than ten-thousand mg/l TDS. (FL)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
[illegible]	Nationwide: 99 wells Connecticut: 1 well Rhode Island: 3 wells Vermont: 10 wells New Jersey: 18 wells New York: 3 wells Virginia: 1 well Florida: no numbers Illinois: 5 wells Indiana: 2 wells Michigan: 27 wells New Mexico: no numbers Iowa: 1 well Missouri: 5 wells Utah: 2 wells Nevada: no numbers Idaho: 21 wells	Waste oil, antifreeze, floor washings (including detergents, organic, and inorganic sediment) and other petroleum products.	High	Connecticut-Permit New Jersey-NJPDES Permit New York-Permit Florida-Permit Illinois-Rule Nebraska-Rule Utah-Banned Idaho-Rule	- Inventory update is vital. Guidelines for construction, operation, and overall regulation of these wells need to be established. (NY, PR) - Permits should show construction features, a plan to utilize separators and holding tanks, and a plan to sample and analyze injected fluids. (IA) - Underground holding tanks should be required. (UT) - Local building code and sewer pretreatment inspection should identify areas where discharge to sewers is prohibited. (UT)
Recharge Wells					
Aquifer Recharge Wells (SRI)	Nationwide: 3,558 wells New Hampshire: 1 well New York: 3,000 wells Florida: 349 wells Illinois: 1 well Minnesota: 1 well New Mexico: 30 wells Texas: 44 wells Kansas: 4 wells Nebraska: 4 wells Wyoming: 32 wells Arizona: 51 wells California: 52 wells Idaho: 7 wells Washington: 7 wells Potentially found in areas characterized by large withdrawals for drinking water or irrigation far in excess of recharge.	Dependent upon source; water quality changes noted include adsorption, ion exchange, pre-precipitation and dissolution, chemical oxidation, biological nitrification and denitrification, aerobic or anaerobic degradation, mechanical dispersion, and filtration.	High to Low	New Jersey-Rule/Permit Florida-Permit Illinois-Rule New Mexico-Registration Texas-Permit Nebraska-Rule Utah-Rule/Permit Wyoming-Permit Arizona-Permit California-Permit Idaho-Permit if deeper than 18 feet	- Injection fluid should be of generally equivalent or better quality than injection zone fluid. (NE) - Standards for injectate quality must be on a case by case basis. (AZ) - Regular injectate sampling should be conducted. (NE) - Use of proper design, construction and operation is essential. (FL, NE)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Saline Water Intrusion Barrier Wells (5R22)	California: 155 wells Florida: 2 wells Potentially found in coastal areas typified by abundant fresh water withdrawals for irrigation and/or drinking water.	Varies with type of source; examples include advanced treated sewage, surface urban and agricultural runoff, and imported surface waters.	Low	New Jersey-Rule/Permit Florida-Permit Nebraska-Rule Utah-Rule/Permit California-Permit Washington-Permit	- Pilot studies to define lithologic and hydrogeologic parameters influencing salt water intrusion should be conducted on site-specific basis. (CA) - Characterization of interaction of injectate and formation fluids is necessary. (CA)
Subsidence Control Wells (5S23)	4 wells inventoried for Wisconsin from state reports; it is believed inventory is incomplete; potentially present in desert and coastal areas typified by large, long-term ground-water withdrawals; areas having carbonate aquifers are particularly susceptible to subsidence.	See 'Aquifer Recharge Wells'	Low	Wisconsin-Permit Nebraska-Rule Utah-Rule/Permit	- Injectate quality should be monitored. (CA) - Proper well design, operation, and construction practices should be implemented. (CA) - For additional recommendations, see 'Aquifer Recharge Wells'
Miscellaneous Wells					
Radioactive Waste Disposal wells (5N24)	Unknown number, but existence confirmed for Tennessee, New Mexico, Idaho, and Washington in State reports.	Variety of radioactive materials, including Beryllium 7, Tritium, Strontium 90, Cesium 137, Potassium 40, Cobalt 60, beta particles, Plutonium, Americium, Uranium, and radionuclides.	Unknown	Illinois-Rule New Mexico-Banned Oklahoma-Rule Nebraska-Rule Utah-Rule/Permit Idaho-Permit if deeper than 18 feet Washington-Permit	- Discharges should satisfy all known, available, reasonable treatment and control methods. (WA) - Discharge to cribs and french drains should be pretreated prior to disposal. (WA) - Permits, permit compliance, and enforcement actions should be negotiated annually with EPA through the State/EPA Agreement Program. (WA)
Experimental Technology Wells (5X25)	225 wells in State reports; Potentially located in every Region.	Wide variety of injected constituents; highly acidic or basic compounds for solution mining; domestic wastewater containing high total suspended solids, fecal coliform, ammonia, BOD, pH; air is used in certain water recovery projects.	Moderate to Low	Alabama-Permit Florida-Permit Mississippi-Rule North Carolina-Permit Illinois-Rule New Mexico-Permit Nebraska-Rule Utah-Rule/Permit Wyoming-Permit Arizona-Permit California-Permit Hawaii-Permit Nevada-Permit	- Wells should not be sited and operated so as to permit injection into Class IIB aquifers. (CA) - Detailed hydrogeological studies should be conducted prior to any proposed injection. (CA) - Chemical analysis of waste stream periodically. (CA) - Mechanical integrity tests should be developed and conducted regularly (CA, AZ)

TABLE 1-2, continued

SUMMARY OF CLASS V INJECTION WELL DATA AND RECOMMENDATIONS

TYPE OF INJECTION WELL	LOCATION & NUMBER OF WELLS OR POTENTIAL LOCATION	TYPES OF FLUIDS INJECTED	GROUND-WATER (USDW) CONTAMINATION POTENTIAL	STATE REGULATORY STRUCTURE	RECOMMENDATIONS
Aquifer Remediation [illegible] including [illegible] wells) [illegible]	Nationwide: 355 wells Rhode Island: 2 wells New Jersey: 9 wells Puerto Rico: 1 well Alabama: 1 well North Carolina: 12 wells Indiana: 4 wells Michigan: 59 wells Minnesota: 7 wells Wisconsin: 17 wells New Mexico: 50 wells Oklahoma: 60 wells Texas: 37 wells Kansas: 15 wells Missouri: no numbers Nebraska: no numbers Colorado: 81 wells	Dependent upon hydrogeologic regimen, parameters of the contamination plume, and design of the remediation program; for refinery projects, typical injectate constituents are oil/grease, phenols, toluene, benzene, lead, iron.	Unknown	New Jersey-NJPDES Permit Alabama-Permit North Carolina-Permit Wisconsin-Rule Oklahoma-Rule Nebraska-Permit Utah-Rule/Permit California-Permit	- Implementation of registering and monitoring programs. (KS) - Construction standards should be similar to those established for discharge wells. (OK) Cased from surface through the top of the injection zone. (OK) Screened intervals through sands and gravels. (OK) Annulus should be grouted. (OK) - Injected fluid quality should be better than that of the fluid in the contaminated aquifer but not necessarily of drinking water standards. (FL)
Abandoned Drinking Water Waste Disposal Wells (5D2)	3,050 wells inventoried. Potentially present in all areas having shallow fresh water aquifers.	Potentially any kind of fluid, particularly brackish or saline water, hazardous chemicals and sewage; documentation of nitrate and coliform contamination documented in Nebraska (Exner and Spalding, 1985); Domestic sewage disposal via these wells documented for 75 homes in Minnesota; also documentation for disposal of pesticides within agricultural runoff (Jones, 1973; Exner and Spalding, 1985).	Moderate	Utah-Banned The following states have plugging and abandonment regulations for water wells: Rhode Island, New Jersey, Puerto Rico, Delaware, Maryland, Pennsylvania, Virginia, West Virginia, Alabama, Florida, Georgia, North Carolina, Tennessee, Illinois, Michigan, Minnesota, Ohio, Wisconsin, Arkansas, Louisiana, Oklahoma, Texas, Kansas, Missouri, Nebraska, Colorado, North Dakota, South Dakota, Wyoming, Arizona, California, Nevada, Alaska, Idaho, Oregon, and Washington	- Must establish a better inventory of wells. (PR, IN, MI, MN) - Wells should be properly plugged using cement. (MN)

SECTION 2
HYDROGEOLOGIC CONSIDERATIONS

2.1 IMPORTANCE AND USE OF THE GROUND-WATER RESOURCE

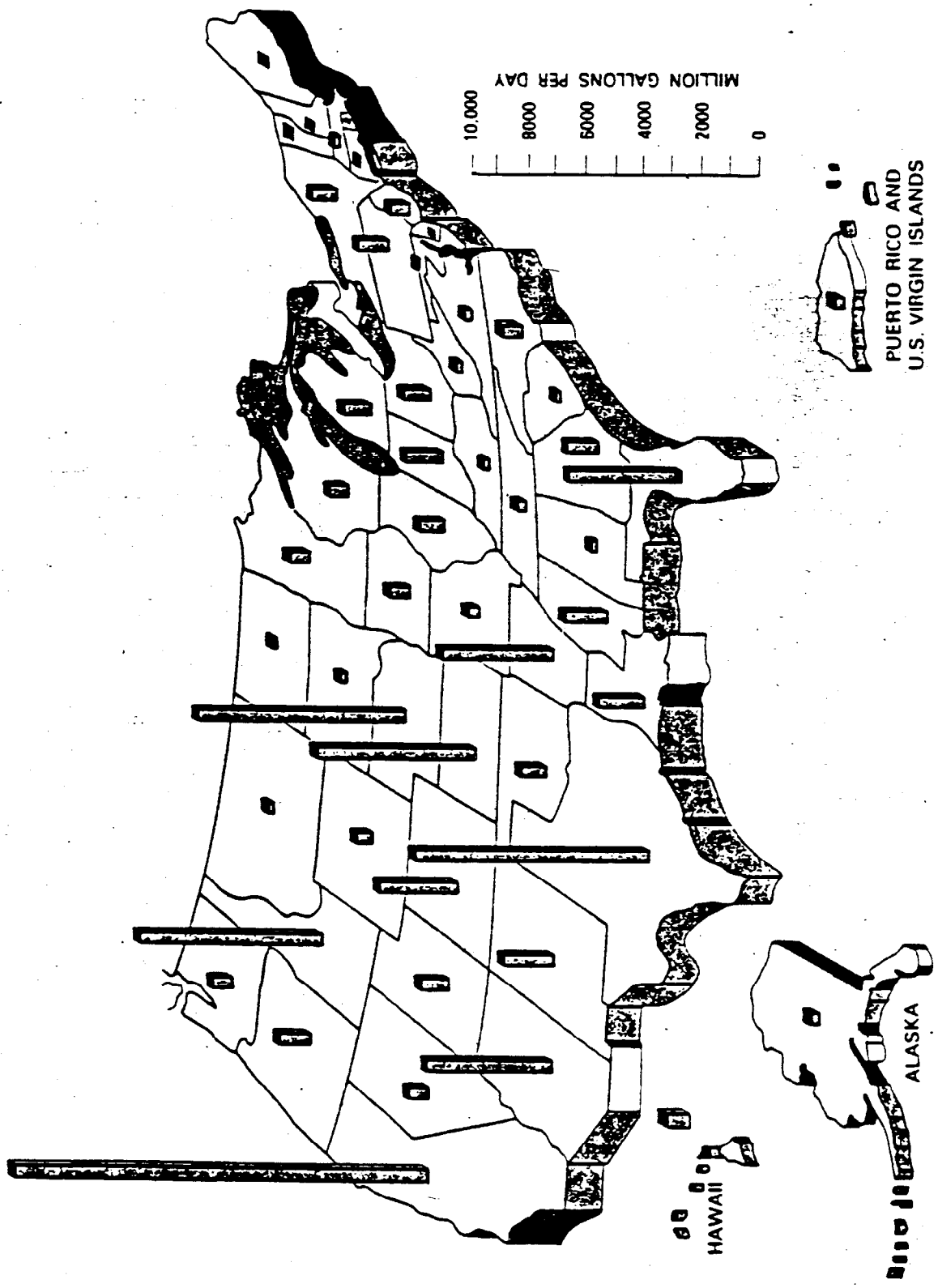
2.1.1 INTRODUCTION

Ground water is one of the most widely used natural resources and is available in at least small amounts at virtually every point on the Earth's surface (Heath, 1985). The availability of the resource is a significant issue in almost every State (Mann, 1985). Ground water serves as the dominant source of drinking water for most rural areas and is the largest source of water for irrigation in arid and semiarid regions of the midwestern and southwestern United States. In addition, ground water is an important source for industrial, urban, and irrigation purposes in humid areas (Heath, 1985). It is a relatively reliable resource and is not subject to the rapid or potentially large fluctuations in availability characteristic of surface water supplies (USEPA, 1977).

The development of ground water as a resource has led to declining ground-water levels in many areas of the country. These declines may lead to streamflow depletion, land subsidence, saltwater intrusion, and increased pumping costs for producers of water (Mann, 1985). The importance of ground water as a resource in the United States is represented in Figure 2-1. Half of the United States population is served by ground water, and studies show that ground-water use within this country is increasing at a rate of 25 percent per decade (USEPA, 1977). In many areas of the country, the ground-water resource is the only high quality economic source of water available.

Ground water contamination has been detected at sites in virtually all parts of the United States and regionally in some of the most heavily populated and industrialized areas. In almost all cases, ground-water contamination has been discovered only after a drinking water supply has been affected. Most of the time the level of contamination at the point of use does not exceed the health-based standards.

Consequences of ground-water contamination vary depending on 1) the potential hazard to health or the environment, 2) current use of the affected resource, 3) public concern, 4) regulatory requirements, and 5) funding available to study and mitigate the problem. In the most serious cases, water supply wells have been abandoned, uses of recreational areas have been altered, expensive remediation programs have been initiated, and new water supplies have been developed.



GROUNDWATER WITHDRAWALS IN 1980 FOR THE UNITED STATES; PUERTO RICO AND U.S. VIRGIN ISLANDS

(from Heath, 1985)

Figure 2-1

2.1.2 GROUND-WATER USE

Trends in water development during the last three decades demonstrate that the use of ground water for all purposes has been increasing at a faster rate than has the use of surface water (Heath, 1985). In 1980, nationwide ground water withdrawals ranged from less than one percent of total water withdrawal in the District of Columbia to 85 percent in Kansas (Heath, 1985). In addition, this survey demonstrated that in ten States, ground-water withdrawals represented more than half of the States' total water usage. The above figures are exclusive of thermoelectric power generation, for which surface water use still exceeds ground-water withdrawals.

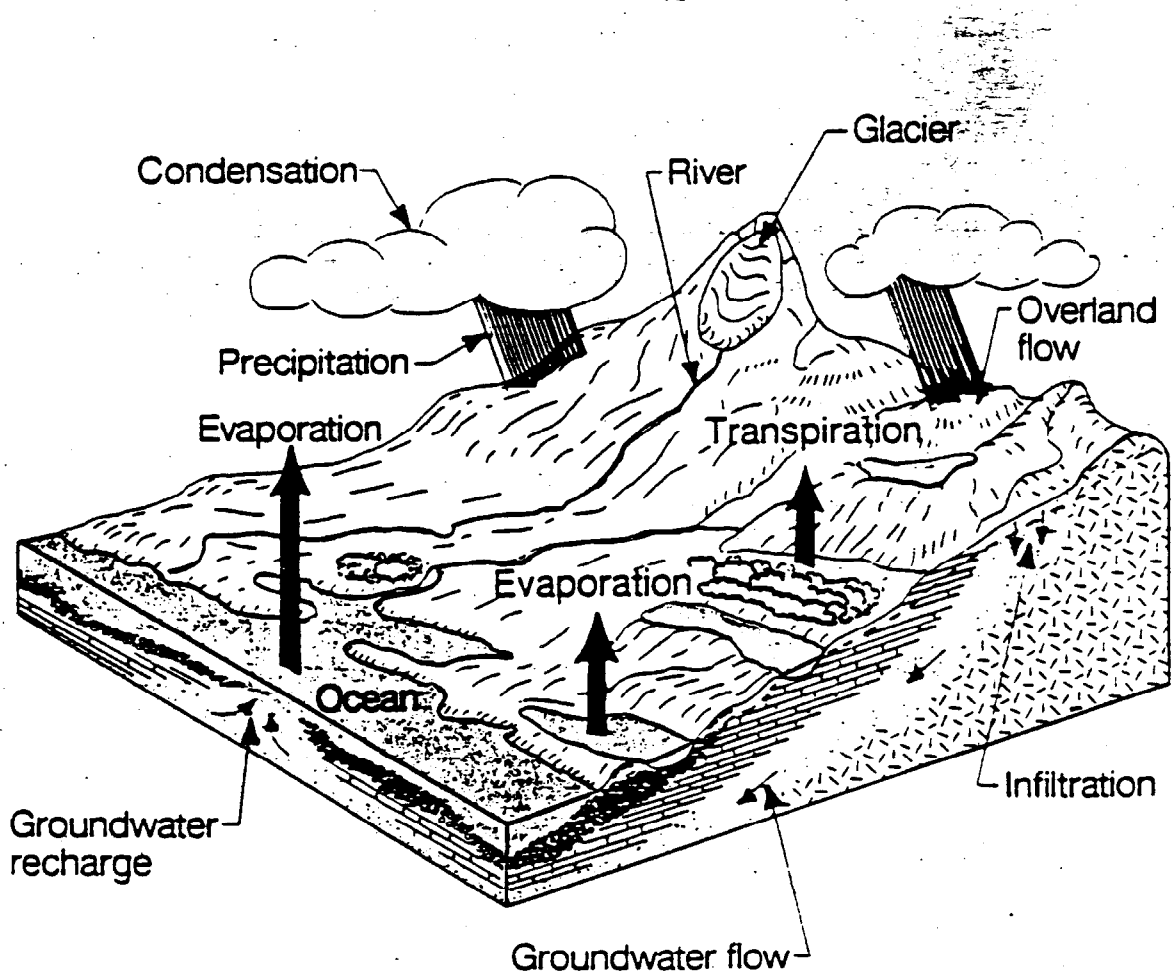
At this time, the largest use of ground water is for irrigation (Heath, 1985). States with the largest ground-water use for this purpose are California, Hawaii, Illinois, Indiana, Kansas, Minnesota, and Wisconsin. Other States in the southern United States that rely heavily upon ground water for irrigation practices are Arkansas, Florida, Louisiana, Mississippi, and Texas.

Forty-eight percent of the United States' population depends upon the ground-water resource as a drinking water supply. Thirty-nine percent of the ground-water-dependent population receive drinking water through public supplies and the other nine percent through individual domestic wells (USEPA, 1977). According to Heath (1985), the percentage of the United States population served by groundwater ranges from 30% in Maryland to 89% in New Mexico. Rural populations in the nation receive 94% of their drinking water from ground-water sources, whereas the populations served by public drinking water supplies get 35% of that supply from ground water (USEPA, 1977). Total withdrawal of ground water in 1984 was 8.8 billion gallons (27,000 acre-feet) per day of which 38% was used for drinking water (Heath, 1985).

2.2 PHYSICAL PROPERTIES OF GROUND-WATER AQUIFERS AND GROUND-WATER CONTAMINATION

2.2.1 PHYSICAL PROPERTIES

Under natural conditions, movement of ground water is from areas of recharge to areas of discharge. Ground water may be discharged to springs, ponds, lakes, or streams, lost by evapotranspiration to the atmosphere, or discharged directly into the ocean in coastal areas (Mann, 1985). This situation constitutes the hydrologic cycle, represented in Figure 2-2. In general, an equilibrium prevails in which long-term ground-water recharge is balanced by long-term discharge from the ground-water system (Mann, 1985).



HYDROLOGIC CYCLE

(from Driscoll, 1986)

Figure 2-2

Aquifers are of two primary types: unconfined and confined. Unconfined aquifers, also referred to as water table aquifers, are the most common. Under unconfined conditions, the water table is exposed to the atmosphere through openings in the overlying regolith (Driscoll, 1986). Water in unconfined aquifers, regardless of depth, is under the pressure exerted by the overlying water. The upper limit of the saturated zone in these aquifers is known as the water table. The pressure on fluids at the water table is equal to atmospheric pressure.

Ground water existing under confined or artesian conditions is isolated from the atmosphere at the point of discharge by impermeable strata (Driscoll, 1986). The confined aquifer generally is subject to pressures higher than atmospheric pressure, but it is possible for unconfined conditions to exist (laterally) in the recharge areas of confined aquifers. Unconfined and confined ground-water conditions are illustrated in Figure 2-3.

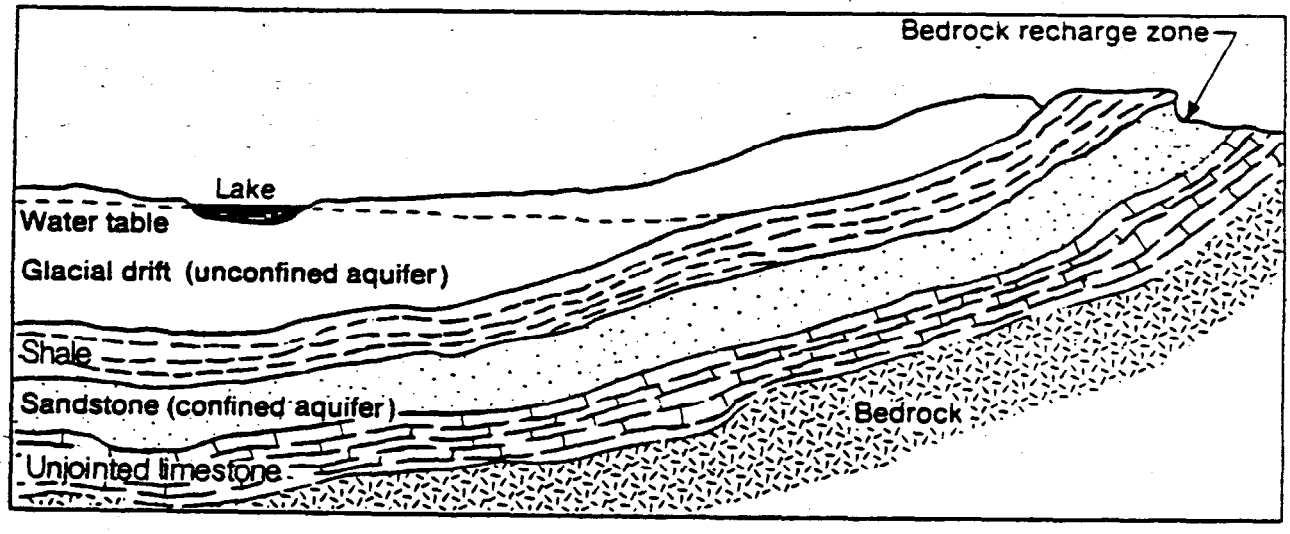
A third ground-water condition which can exist is due to variations in the ability of confining beds to retard water movement. Virtually all confining beds are capable of transmitting ground water if a sufficient hydraulic gradient and/or a total head differential exists between the aquifers. Beds that transmit measureable flows are termed "semi-confining," and the associated aquifers are considered to be semi-confined (Mann, 1985).

Intergranular pores, fractures, or openings resulting from solution in an unconfined aquifer are saturated with water below a free surface, known as the water table (Mann, 1985). As the volume of ground water in storage varies, the water table rises or falls accordingly. In confined aquifers, pores, fractures, and solution openings are completely filled with water. The water is confined under pressure by an overlying bed exhibiting low hydraulic conductivity (Mann, 1985). Changes in the amount of ground water stored under these conditions occur through elastic expansion and contraction of the porous material and of the water in response to pressure changes. In some instances, changes in ground-water storage can occur through the inelastic compaction of fine-grained sediments with associated subsidence of the land surface (Mann, 1985).

Five criteria have been proposed to differentiate between ground-water systems (Heath, 1982):

1. the aquifers and confining beds that make up the ground-water system;

2. the types of primary and secondary porosities, solution cavities, or fractures;



RELATIONSHIP OF SUBSURFACE STRATA TO OCCURRENCE OF CONFINED AND UNCONFINED AQUIFERS

(from Driscoll, 1986)

Figure 2-3

3. the composition of the dominant aquifer material, namely whether or not it is soluble, insoluble, or consists of both material types;

4. the storage coefficient and transmissivity of the dominant aquifer; and

5. the recharge and discharge conditions of the entire ground-water system.

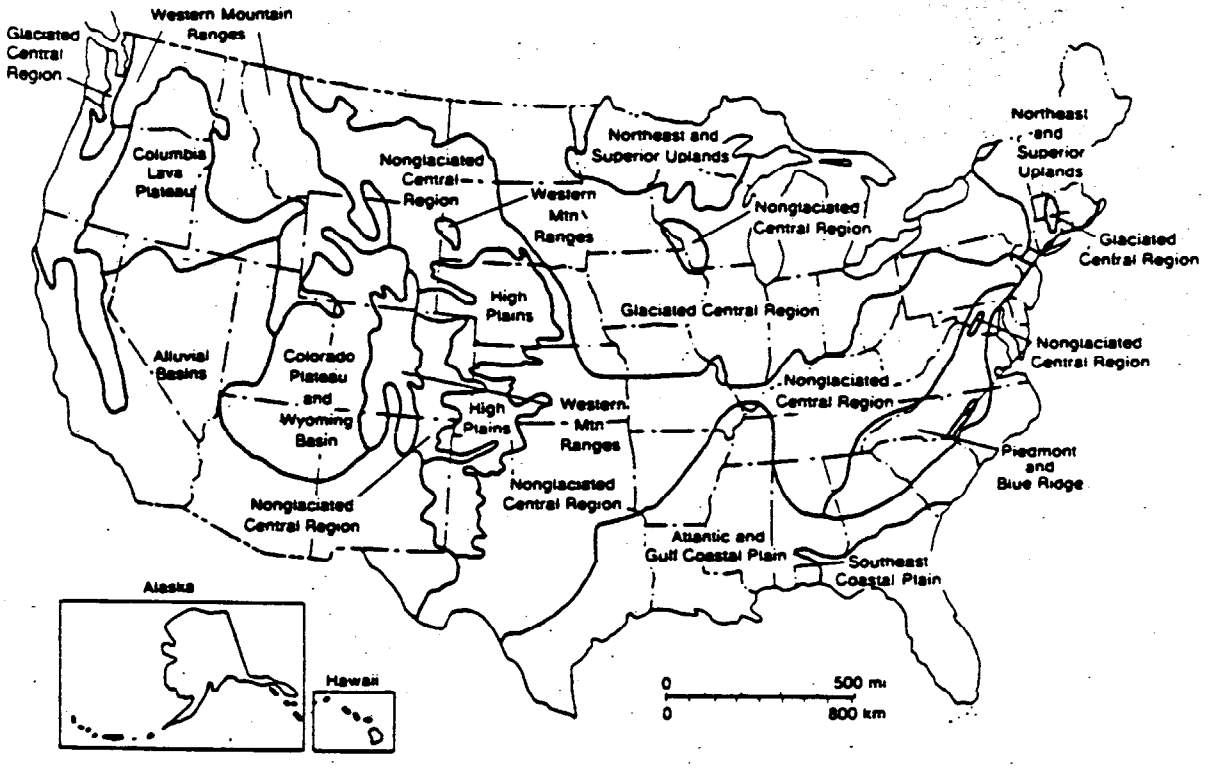
Based upon these criteria, the U.S. Geological Survey has proposed 13 ground-water regions for the conterminous United States. These regions are displayed in Figure 2-4. Note that Alaska and Hawaii are considered separate hydrogeologic regions. Geologic settings for aquifers and typical well yields for those aquifers are presented for each region in Table 2-1.

2.2.2 GROUND-WATER CONTAMINATION

For the purposes of this report, ground-water contamination is defined as the degradation of ground water's natural quality as the result of human activity (USEPA, 1977). The Safe Drinking Water Act defines a contaminant as "any physical, chemical, biological or radiological substance or matter in water."

Contamination processes begin with contaminant sources, namely waste disposal practices (USEPA, 1977). Leakage, percolation, or discharge of contaminants into water supply aquifers occur either intentionally or accidentally and can involve a variety of waste constituents. As the contaminant travels through the soil or rock media into the ground-water aquifer, it can be modified by various attenuation processes. These processes vary greatly in their effectiveness, and some toxic substances can be highly mobile. Attenuation of pollutants within the aquifer, like ground-water movement, can be extremely slow. Movement of these contaminants can occur as 1) individual bodies or "slugs," 2) local plumes caused by continual flow of leachate, and 3) masses of degraded water (USEPA, 1977).

The degree of contamination that can occur within ground-water aquifers ranges from a slight degradation in natural quality to the presence of toxic concentrations of heavy metals, organic compounds, and radioactive materials (USEPA, 1977). These constituents can be present in varying concentrations within certain Class V waste streams. It is important to note that simply removing the source of contamination does not clean up the aquifer once it has been contaminated. This contamination can result in portions of aquifers being condemned for use as drink-



GROUNDWATER REGIONS OF THE UNITED STATES

(from Driscoll, 1986)

Figure 2-4

TABLE 2-1. GEOLOGIC SETTING AND TYPICAL WELL YIELDS FOR PRINCIPLE AQUIFERS WITHIN MAJOR GROUND-WATER REGIONS (HEATH, 1982)

Region No.	Region	Geologic Situation	Well Yield (gpm)	Well Yield (m^3/day)
1	Western Mountain Ranges	Mountains with thin soils over fractured rocks, alternating with narrow alluvial and, in part, glaciated valleys	10-100	50-500
2	Alluvial Basins	Thick alluvial (locally glacial) deposits in basins and valleys bordered by mountains	100-5,000	500-30,000
3	Columbia Lava Plateau	Thick lava sequence interbedded with unconsolidated deposits and overlain by thin soils	100-20,000	500-100,000
4	Colorado Plateau & Wyoming Basin	Thin soils over fractured sedimentary rocks	10-1,000	50-5,000
5	High Plains	Thick alluvial deposits over fractured sedimentary rocks	100-3,000	500-20,000
6	Nonglaciated Central Region	Thin regolith over fractured sedimentary rocks	100-5,000	500-30,000
7	Glaciated Central Region	Thick glacial deposits over fractured sedimentary rocks	50-500	300-3,000
8	Piedmont & Blue Ridge	Thick regolith over fractured crystalline and metamorphosed sedimentary rocks	50-500	300-3,000
9	Northeast and Superior Uplands	Thick glacial deposits over fractured crystalline rocks	20-200	100-1,000
10	Atlantic & Gulf-Coastal Plain	Complexly interbedded sands, silts, & clays	100-5,000	500-30,000
11	Southeast Coastal Plain	Thick layers of sand & clay over semiconsolidated carbonate rocks	1,000-20,000	5,000-100,000

TABLE 2-1,
continued

12	Alluvial Valleys	Thick sand and gravel deposits beneath floodplains and terraces of streams	100-5,000	500-30,000
13	Hawaiian Islands	Lava flows segmented by dikes, interbedded with ash deposits and partly overlain by alluvium	100-5,000	500-30,000
14	Alaska	Glacial and alluvial deposits in part perennially frozen and overlying crystalline, metamorphic, and sedimentary rocks	10-1,000	50-5,000

ing water supplies. It is considerably more difficult to reclaim a polluted aquifer than to clean up a surface water supply (Canter and Knox, 1986; USEPA, 1977).

2.3 RELATIONSHIP OF CLASS V INJECTION TO UNDERGROUND SOURCES OF DRINKING WATER

2.3.1. GENERAL DISCUSSION

Underground sources of drinking water (USDW) have been targeted for protection under the Safe Drinking Water Act, and are bodies of water recoverable in "significant" quantities, having less than or equal to 10,000 mg/l Total Dissolved Solids (TDS). Typically, Class V wells are those that inject into or above USDW. However, certain Class V wells inject below USDW. Examples of such well types are geothermal reinjection wells, spent brine return flow wells, some of the mineral and fossil fuel recovery related wells, select radioactive waste disposal wells, and certain experimental technology wells. Potential for contamination by Class V injection can vary greatly and is largely dependent upon where injection occurs relative to USDW, construction and operation features of wells, and injectate quality and volumes.

2.3.2. RELATIONSHIP OF CLASS V INJECTION TO USDW

As discussed, certain Class V wells inject fluids below USDW. These wells often inject large fluid volumes. Depending on the compatibilities of the injectate and the USDW (i.e., physical and chemical characteristics), this could adversely impact (degrade) USDW if proper planning is not conducted. In many areas studied, USDW exist to depths of several thousand feet. Aquifers at these depths are confined, probably both above and

below. Proper planning can assure that injection will occur below a lower confining layer. If proper construction and operation are practiced, including regular mechanical integrity testing, injection below USDW can pose minimal threat of contamination to USDW.

The inventory indicates that most Class V injection is above USDW. Wells of this type include many of the drainage wells and domestic waste water disposal wells. Attenuation of contaminants in shallow soils and unconsolidated sediments is the controlling parameter in shallow USDW contamination. If injection wells are sited and constructed properly, contaminants may be attenuated, thereby reducing the potential for harm to USDW.

Injection into USDW is the type of Class V activity potentially most harmful, and representatives of each Class V well type probably are presently injecting into USDW. Depending upon the nature of the injected fluids, injection directly into USDW could result in broadscale degradation within USDW.

SECTION 3
CLASS V INJECTION WELL INVENTORY

The Class V injection well inventory is characterized by extreme variations in database completeness. In general, inventories for "high-tech" Class V wells are more accurate than those for "low-tech" wells. A number of factors may be responsible for this disparity. High-tech Class V injection wells are typically associated with special industries or large scale remediation and disposal projects. They also tend to be small in number, localized, and easy for regulatory agencies to inventory and monitor. In addition, several agencies at the local, county, and state levels may be regulating these operations through drilling and waste discharge permits. Furthermore, owners/operators of high-tech wells generally are more informed about existing regulations, such as reporting requirements, than are owners/operators of some types of low-tech wells. As a result, files maintained by high-tech well operators tend to be more complete, whereas no such files may exist for many low-tech wells.

A number of inspection programs have been conducted that target high-tech Class V injection wells. These inspections have provided valuable inventory data for facilities inspected, as well as for other facilities owned by the same owner/operator. All these factors have resulted in a generally complete inventory database for high-tech wells and a generally poor to nonexistent one for low-tech wells.

The current regulations (40 CFR 144.24) state that injection into Class V wells is authorized by rule until future regulations are established. Owners or operators of Class V injection wells authorized by rule are required to submit specific inventory information within one year of the effective date of an applicable underground injection control program in their State. The inventory information required as specified in 40 CFR 144.26(a) includes the following:

1. facility name and location;
2. name and address of legal contact;
3. ownership of facility;
4. nature and type of injection well(s); and
5. operating status of injection well(s).

For programs administered by USEPA, owners/operators of the following types of Class V injection wells are required to supply additional inventory information [40 CFR 144.26(b)(1)(iii)]:

1. sand or other backfill wells;

2. radioactive waste disposal wells;

3. geothermal energy recovery wells;

4. brine return flow wells;

5. wells used in experimental technology;

6. municipal and industrial disposal wells other than Class I; and

7. any other Class V wells, at the discretion of the Regional Administrator.

The additional information to be provided by these owners/operators includes [40 CFR 144.26(b)(2)(ii-x)]:

1. location of each well or project by Township, Range, Section, and Quarter-Section; or by latitude and longitude to the nearest second, according to the conventional practice in the state;

2. date of completion of each well;

3. identification and depth of the formation(s) into which each well is injecting;

4. total depth of each well;

5. casing and cementing record, tubing size, and depth of packer;

6. nature of injected fluids;

7. average and maximum injection pressure at the well head;

8. average and maximum injection rate; and

9. date of the last mechanical integrity test, if any.

Per 40 CFR 146.52(b), within three years of approval of each UIC program, whether administered by the individual State or by the USEPA, a report must be submitted by the Director of the UIC Program to USEPA and must contain the following:

1. information on the construction features of Class V wells and the nature and volume of injected fluids;

2. an assessment of the contamination potential of Class V wells using available hydrogeological data;

3. an assessment of the available corrective alternatives where appropriate and their environmental and economic consequences; and

4. recommendations for both the most appropriate regulatory approaches and for remedial actions where appropriate.

Appendix A contains State Report Summaries on each report received to date. Summaries for each State report include:

1. status of the UIC program:

   a. primacy - implemented by the state

   b. direct implementation (DI) - implemented by the USEPA;

2. title, author, date, and status of the report;

3. hydrogeology and water usage;

4. number of injection wells by type, and their compatibility with numbers reported by Federal Underground Injection Control Reporting System (FURS);

5. assessed contamination potentials of each well type ("high," "moderate," or "low," where applicable);

6. applicable regulatory systems for each well type ("permit," "rule," or "none," where applicable);

7. inventory strategies;

8. availability of case studies and bibliographies; and

9. recommendations.

3.1 INVENTORY METHODS (STRATEGIES)

Several methods were used to gather inventory data. Strategies employed for different States and Territories are listed on the State Report Summaries in Appendix A. Some inventory methods were common to several states. For example, inventory efforts often were initialized by publishing notices about the UIC program in the local newspapers. Generally they

requested information required by 40 CFR 144.26. Another commonly used method entailed mailing questionnaires to County Health Departments/Sanitarians, registered water well drillers, and public facilities such as schools, churches, etc. In addition, visits to various government agencies were made to question personnel who might be knowledgeable about current Class V activities and to search various files for existing Class V well registrations and permits. National Pollutant Discharge Elimination System (NPDES) permits generally were reviewed where available. Also, mailing lists and telephone contacts were compiled from local telephone directories and directories of related professional organizations (e.g., National Water Well Association).

The USEPA has instituted a computer database system for maintaining the inventory data of all classes of injection wells. The Federal UIC Reporting System (commonly referred to as FURS), contains general facility, well type, number, and status information for each inventoried injection facility. Generally, the FURS inventory data for Class V injection wells, on a national basis, are incomplete and dated. In preparing this report, well data provided in the State reports and additional correspondence were considered in addition to the FURS data.

3.2 INVENTORY RESULTS

According to the most recently submitted inventory figures, there are approximately 170,000 Class V injection wells in the United States, its Territories, and Possessions. Table 3-1 lists the number of wells reported to date for each State, Territory, and Possession. Also provided is the total for each well type and for each Region. Figure 3-1 illustrates the distribution of Class V wells by State. Table 3-2 is a summarized version which lists totals by Region and by general well type category. Figure 3-2 illustrates the distribution of Class V wells by Region. Please refer back to Table 1-1 for a list of well type subclassifications recognized by the USEPA for the purpose of this study. Figure 3-3 illustrates the distribution of inventoried Class V wells by general well type category.

At this time it is prudent to emphasize that the reported inventory figures should be interpreted <u>cautiously</u>. The inventory collection is an on-going process, and figures are subject to change frequently and dramatically. There are always questions about what practices are Class V as opposed to other classes of wells, and which practices are considered well injection. There is also, from time to time, confusion about what Class V subcategory to which a particular injection practice should be assigned.

Furthermore, it should be emphasized that many of the numbers included in the table are <u>estimates</u> and that records are not necessarily available for each well listed. For example, the estimated number of drainage wells (5D2 plus 5D4) in Arizona

ranged from 25,000 to 100,000 wells. Based on verbal communication with various State agencies, the range was narrowed down to between 40,000 and 60,000 wells. For the sake of simplicity, the table indicates 50,000 wells.

In another case, the number of heat pump/air-conditioning return flow wells (5A7) in Oklahoma was reported to be "in the hundreds." Again for the sake of simplicity, the table lists "100" heat pump/air-conditioning return flow wells.

As a final example, the number of septic systems (5W11) in Florida was reported to be 19,000. This number was derived using a mathematical equation to estimate the "total" number of septic systems. Nineteen thousand represents one percent of the "total" number. This number was derived because only one percent of the total number of septic systems are believed to serve more than 20 persons. Florida has actual records on approximately 850 septic systems. The remaining estimated figures are too numerous to describe.

3.3 INVENTORY DISTRIBUTION

The geographical distribution of the wells inventoried to date is difficult to accurately describe for several reasons. First, efforts made to compile inventories differed significantly among States and Regions. While some States were successful at actually locating and keeping records on each reported well, other States made blanket estimates and had little to no documentation to support the estimates. In States where the USEPA was responsible for conducting the inventory, levels of effort varied significantly.

Second, record-keeping systems among States vary drastically. Inventories were easier to conduct and resulted in more accurate figures for States which require permits or registrations of injection wells. In many cases, file searches were quicker, and were likely to be more accurate than reliance on a network of contacts.

Third, the response rates differed significantly among various groups who were contacted for information. Whereas one State may have derived its most significant information from the Soil Conservation Service (SCS), for example, another State might have had less success with the SCS and found County Health Departments to be its most valuable source of information. It should be noted here that different groups have varying levels of interest in the different well types; therefore, the inventory figures provided by different groups vary accordingly. For example, the SCS may provide more information on agricultural drainage wells (5F1) while County Health Departments are likely to provide more information on septic systems (5W11). Table 3-3 illustrates the varying response rates of several groups which were contacted by mail in a portion of Region V.

Table 3-1: REPORTED CLASS V INJECTION WELLS

REGION & STATES	TOTAL # WELLS	DRAINAGE 5F1	5D2	5D3	5D4	5G30	GEOTHERMAL 5A5	5A6	5A7	5A8	DOMESTIC WASTEWATER 5W9	5W10	5W11	5W31	5W32	5W12	MINERAL & FOSSIL FUEL 5X13	5X14	5X15	5X16	INDUSTRIAL 5A19	5W20	5X28	RECHARGE 5R21	5X22	5S23	MISCELLANEOUS 5X24	5X25	5X26	5X29
REG 1	364	0	22	3	16	0	0	0	24	0	0	0	97	0	0	72	0	0	0	0	14	99	14	1	0	0	0	0	2	0
Connecticut	84	0	3	0	0	0	0	0	12	0	0	0	62	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	0	0
Maine	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
Massachusetts	132	0	19	0	0	0	0	0	10	0	0	0	27	0	0	72	0	0	0	0	3	1	0	0	0	0	0	0	0	0
New Hampshire	38	0	0	3	16	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	13	0	1	0	0	0	0	0	0
Rhode Island	80	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	8	59	3	0	0	0	0	0	2	0
Vermont	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	10	0	0	0	0	0	0	0
REG 2	8950	150	2504	10	1116	0	0	x	181	0	5	68	1260	85	63	22	0	48	0	x	6	401	21	3000	0	x	0	0	10	0
New Jersey	379	0	1	0	1	0	0	0	181	0	0	1	143	0	0	0	0	0	0	0	5	20	18	0	0	0	0	0	9	0
New York	7172	150	2500	0	1100	0	0	x	x	0	0	x	x	x	x	21	0	48	0	x	0	350	3	3000	0	x	0	0	0	0
Puerto Rico	1352	x	3	10	15	0	0	0	0	0	5	67	1073	85	63	1	0	0	0	0	1	28	0	0	0	0	0	0	1	0
Virgin Islands	47	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
REG 3	4589	x	273	x	6	0	0	0	2291	0	x	0	8	903	0	5	1070	0	0	2	x	30	1	0	0	0	0	0	0	0
Delaware	164	0	0	0	0	0	0	0	164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maryland	1271	0	0	0	3	0	0	0	368	0	0	0	0	890	0	0	1	0	0	0	0	9	0	0	0	0	0	0	0	0
Pennsylvania	1026	0	155	0	0	0	0	0	24	0	x	0	0	13	0	4	811	0	0	0	x	19	0	0	0	0	0	0	0	0
Virginia	1864	0	116	x	3	0	0	0	1735	0	0	0	6	0	0	1	0	0	0	0	x	2	1	0	0	0	0	0	0	0
West Virginia	264	x	2	x	x	0	0	0	0	0	0	0	2	0	0	0	258	0	0	2	0	0	0	0	0	0	0	0	0	0
REG 4	27911	43	2072	81	2	1385	0	0	3998	0	0	0	19001	736	200	556	61	0	0	0	75	318	x	349	2	0	1	18	13	0
Alabama	144	0	9	0	0	0	0	0	0	0	0	0	1	0	0	0	x	0	0	0	33	98	0	0	0	0	0	2	1	0
Florida	25557	x	1539	x	x	1385	0	0	2671	0	0	0	19000	0	0	553	0	0	0	0	35	20	x	349	2	0	0	3	0	x
Georgia	163	43	2	0	2	0	0	0	111	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
Kentucky	1360	x	484	76	x	0	0	0	x	0	0	0	0	736	0	3	61	0	0	0	0	0	0	0	0	0	0	0	0	0
Mississippi	12	0	0	0	0	0	0	0	7	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
North Carolina	99	0	0	0	0	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12	0
South Carolina	493	0	31	0	0	0	0	0	60	0	0	0	0	0	200	0	0	0	0	0	2	200	0	0	0	0	0	0	0	0
Tennessee	93	0	7	5	0	0	0	0	70	0	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0	0	1	0	0	0
REG 5	17777	147	4997	135	191	0	0	0	1164	0	959	65	4557	2635	0	41	5	15	2	41	90	527	34	2	0	4	1	8	87	2095
Illinois	1764	6	697	0	47	0	0	0	57	0	916	0	0	0	0	1	5	0	0	0	10	16	5	1	0	0	1	2	0	0
Indiana	3816	72	2180	26	8	0	0	0	236	0	22	22	895	105	0	27	0	0	1	8	22	30	2	0	0	0	0	0	4	156
Michigan	7575	15	623	103	9	0	0	0	760	0	11	18	2693	2511	0	2	0	15	1	33	52	9	27	0	0	0	0	4	59	630
Minnesota	2106	54	30	6	8	0	0	0	34	0	10	25	588	16	0	11	0	0	0	0	4	1	0	1	0	0	0	2	7	1309
Ohio	2360	0	1341	x	118	0	0	0	73	0	0	0	361	0	0	x	0	0	0	0	x	467	0	0	0	0	0	0	0	x
Wisconsin	151	0	116	0	1	0	0	0	4	0	0	0	0	3	0	0	0	0	0	0	2	4	0	0	0	4	0	0	17	0
REG 6	3843	108	57	0	5	1	x	3	1146	0	10	30	66	0	0	0	76	1073	x	77	7	4	0	74	0	0	2	12	147	945
Arkansas	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	1	0	0	0	0	0	0	0	0	0
Louisiana	11	0	0	0	5	1	0	0	5	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Mexico	1237	0	5	0	0	0	0	2	27	0	0	14	10	0	0	0	11	1073	0	0	6	2	0	30	0	0	1	6	50	0
Oklahoma	168	x	x	0	0	0	0	0	100	0	0	0	x	0	0	0	0	0	0	7	0	0	0	0	0	0	1	0	60	0
Texas	2356	108	52	0	0	0	x	1	1014	0	10	16	56	0	0	0	65	0	x	0	0	2	0	44	0	0	0	6	37	945
REG 7	6375	235	10	250	0	0	0	0	1502	0	0	x	5	0	0	0	4326	0	0	0	16	0	6	8	0	0	0	2	15	x
Iowa	262	230	6	0	0	0	0	0	17	0	0	0	3	0	0	0	0	0	0	0	5	0	1	0	0	0	0	0	0	0
Kansas	419	0	3	0	0	0	0	0	394	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	0	0	0	0	15	0
Missouri	5324	x	0	250	0	0	0	0	741	0	0	0	2	0	0	0	4326	0	0	0	0	0	5	0	0	0	0	0	x	0
Nebraska	670	5	1	0	0	0	0	0	650	0	0	x	x	0	0	0	0	0	0	0	8	0	0	4	0	0	0	2	x	x
REG 8	9015	x	7250	0	321	55	0	3	219	0	0	3	422	0	0	x	386	14	64	1	6	36	2	7	0	0	0	137	81	7
Colorado	115	x	2	0	0	0	0	2	2	0	0	0	0	0	0	0	2	0	23	0	1	0	0	0	0	0	0	2	81	x
Montana	4587	0	4500	0	0	55	0	0	20	0	0	0	2	0	0	0	10	0	0	0	x	0	0	0	0	0	0	0	0	0
North Dakota	438	1	0	0	0	0	0	0	135	0	0	0	0	0	0	0	300	0	0	1	1	0	0	0	0	0	0	0	0	0
South Dakota	49	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Utah	3088	0	2743	0	321	0	0	1	7	0	0	0	x	0	0	0	0	0	0	0	3	4	2	0	0	0	0	0	0	7
Wyoming	738	0	5	0	0	0	0	0	7	0	0	3	420	0	0	x	74	14	41	0	0	32	0	7	0	0	0	135	0	0
REG 9	64214	0	59483	0	4	1	81	7	53	25	3	120	1312	73	1279	358	1	875	0	0	26	209	0	103	155	0	0	45	0	0
Arizona	51207	0	50000	0	x	0	0	0	x	0	0	17	143	19	3	1	0	870	0	0	0	72	0	51	0	0	0	32	0	0
California	12178	0	9175	0	x	0	65	1	53	0	0	46	1165	48	1276	22	0	5	0	0	20	93	0	52	155	0	0	2	0	0
Hawaii	617	0	129	0	4	1	0	0	0	25	3	57	0	7	0	335	0	0	0	0	6	44	0	0	0	0	0	6	0	0
Nevada	46	0	15	0	x	0	16	6	x	0	0	0	3	0	x	0	1	0	0	0	0	0	x	0	0	0	0	5	0	0
American Samoa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr. Terr. of P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guam	164	0	164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CNMI	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REG 10	29826	654	16910	0	2141	115	8	8	150	0	3	6336	60	3	2241	45	575	0	0	0	51	365	21	14	3	0	120	3	0	3
Alaska	2542	0	66	0	0	0	4	0	7	0	3	79	8	3	2123	4	0	0	0	0	2	230	0	0	0	0	0	0	0	3
Idaho	2533	572	1165	0	0	7	4	2	20	0	0	0	52	0	0	9	575	0	0	0	49	46	21	7	0	0	4	0	0	0
Oregon	7120	16	776	0	0	0	0	6	13	0	0	6257	0	0	0	32	0	0	0	0	0	20	0	0	0	0	0	0	0	0
Washington	17631	66	14903	0	2141	108	0	0	110	0	0	0	0	0	108	0	0	0	0	0	x	69	0	7	0	0	116	3	0	0
TOTAL	173159	1337	92568	479	3802	1557	89	21	10028	25	990	6622	26769	4435	3763	1099	6500	2025	66	121	291	1999	99	3558	157	4	124	225	335	3050

NOTE: Some numbers in this table are estimated. "X" indicates well type reported, no numbers available.

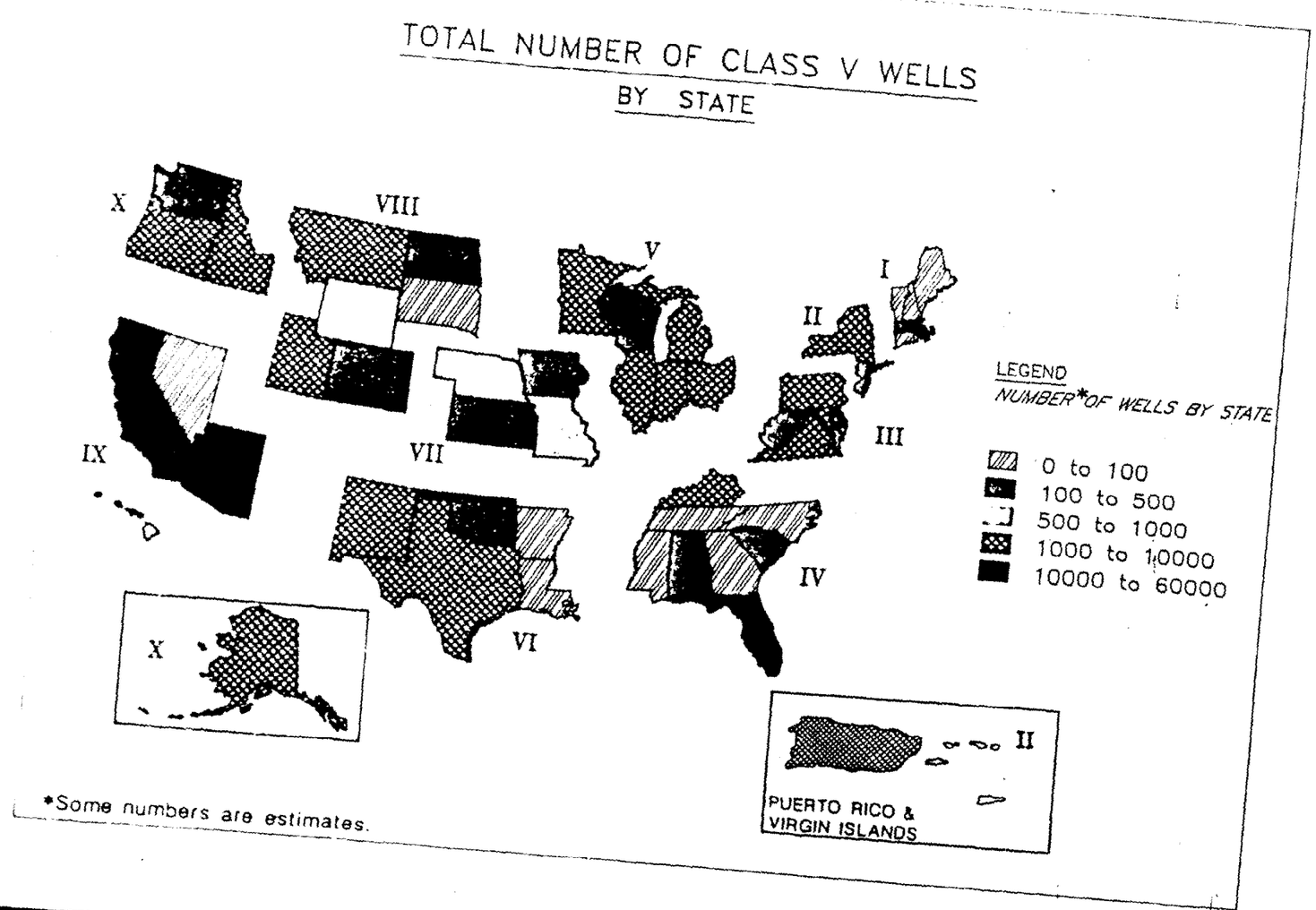

TOTAL NUMBER OF CLASS V WELLS
BY STATE
X
VIII
V
I
II
III
IX
VII
IV
VI
X
II
PUERTO RICO &
VIRGIN ISLANDS
LEGEND
NUMBER*OF WELLS BY STATE
0 to 100
100 to 500
500 to 1000
1000 to 10000
10000 to 60000
*Some numbers are estimates.

Figure 3-1

TABLE 3-2: CLASS V INJECTION WELL NATIONAL INVENTORY BY REGION & WELL CLASSIFICATION

EPA REGION	TOTAL #WELLS	DRAINAGE	GEOTHERMAL	DOMESTIC WASTEWATER	MINERALS & FOSSIL FUEL	INDUSTRIAL	RECHARGE	MISCELLANEOUS
I	364	41	24	169	0	127	1	2
II	8950	3780	181	1503	48	428	3000	10
III	4589	279	2291	916	1072	31	0	0
IV	27911	3583	2998	20493	61	393	351	32
V	17772	5460	1164	8237	63	651	6	2191
VI	3843	171	1149	106	1226	11	74	1106
VII	6675	495	1802	5	4326	22	8	17
VIII	9015	7627	222	425	465	44	7	225
IX	64214	59488	166	3146	876	235	258	45
X	29826	19820	166	8688	575	437	14	126
TOTAL	173159	100744	10163	43688	8712	2379	3719	3754

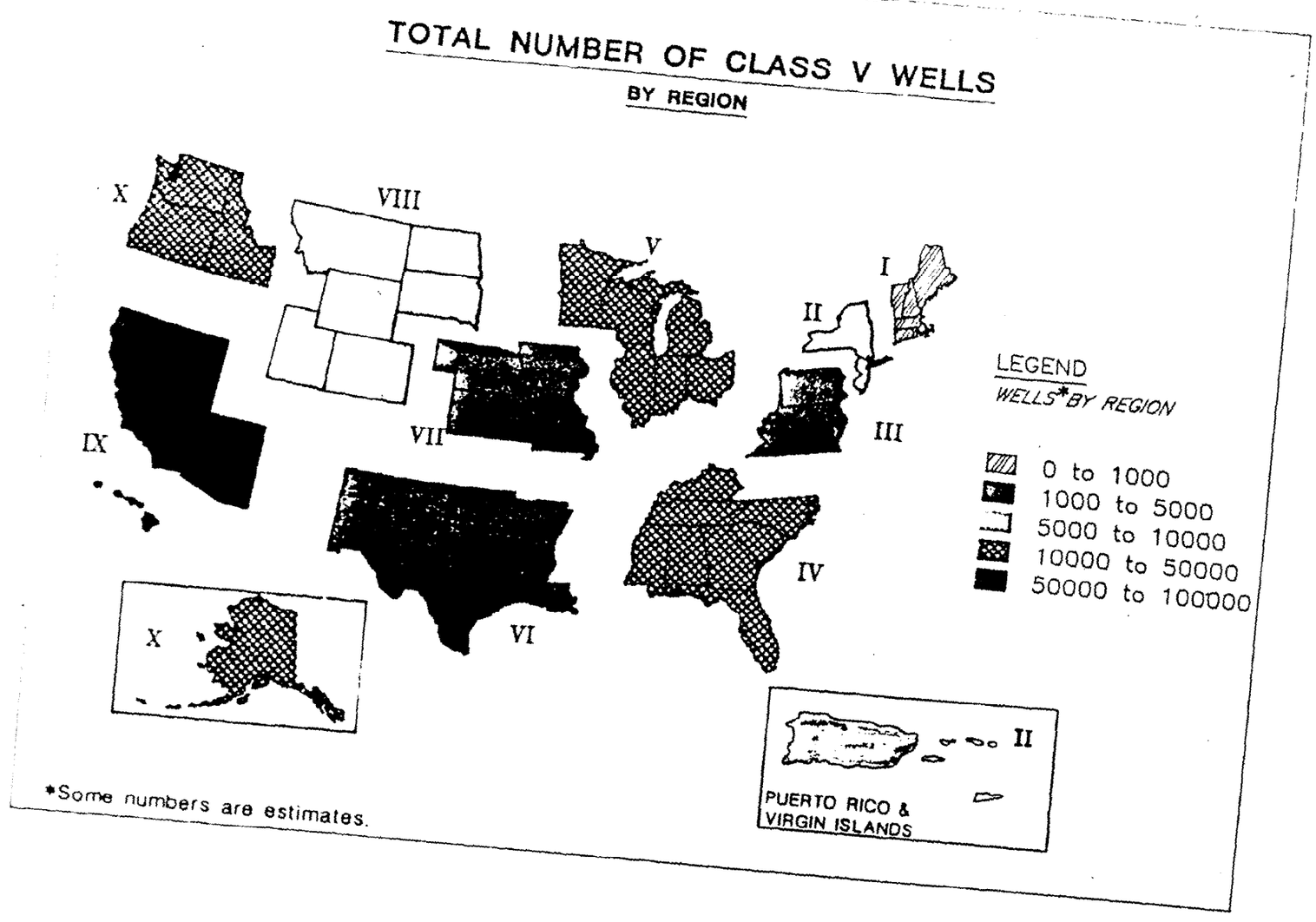
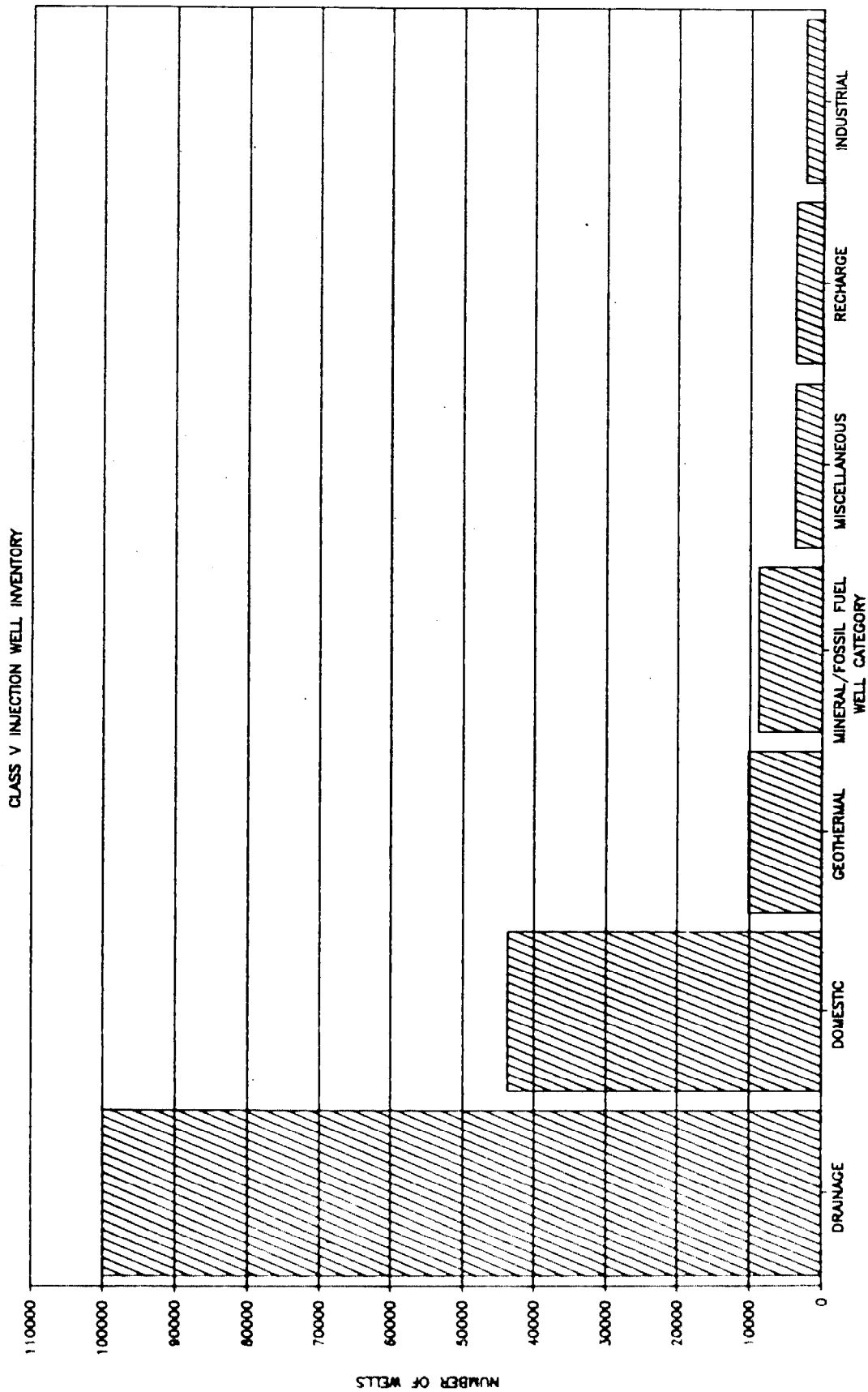

TOTAL NUMBER OF CLASS V WELLS
BY REGION
X
VIII
V
I
II
IX
VII
III
IV
VI
X
II
PUERTO RICO &
VIRGIN ISLANDS
LEGEND
WELLS* BY REGION
0 to 1000
1000 to 5000
5000 to 10000
10000 to 50000
50000 to 100000
*Some numbers are estimates.

Figure 3-2



BAR GRAPH ILLUSTRATING
CLASS V INJECTION WELL INVENTORY
DISTRIBUTION BY WELL TYPE

Figure 3-

TABLE 3-3

RESPONSE RATES OF VARIOUS GROUPS CONTACTED BY REGION V FOR INVENTORY INFORMATION

GROUP	RESPONSE RATE (%)		
	Indiana	Michigan	Minnesota
Agricultural extension agencies	39	35	23
City officials	25	29	48
County Health Departments	7	77	51
Drilling companies	17	11	9
Soil Conservation Service	31	48	59

Fourth, confusion about how to classify injection wells frequently was apparent. The most common error involved the distinction between heat pump/air-conditioning return flow wells (5A7) and cooling water return flow wells (5A19). Several inventories combined these two types based on the misconception that cooling water refers to air-conditioning return flow water. In actuality, "cooling water" is intended to describe fluids used to cool industrial products, industrial processes, and machines used by manufacturers, utilities, etc.

Another classification problem frequently encountered was distinguishing between sewage disposal systems (5W10, 11, 31, and 32) and industrial disposal wells (5W20). This problem is inherent to the classification system (Table 1-1) and is not easily resolved. In general, the classification system is based more on differing waste stream components rather than on differing well construction components. With this in mind, it is suggested that facilities which inject industrial waste into septic systems or cesspools be classified as industrial disposal facilities (5W20) rather than cesspool or septic system facilities (5W10, 5W11). Consequently, sewage disposal facilities would be limited to those facilities which inject solely sanitary wastes (and are multi-family, domestic, or public facilities serving more than 20 persons per day). Because this clarification was not provided prior to conducting the inventories, many industrial disposal facilities are included in the figures representing septic systems and cesspools under the heading, "Domestic Wastewater Disposal Wells."

Furthermore, confusion ensued when waste stream components included more than one of the described sub-classifications. For example, some facilities reported injecting both cooling water and industrial process wastewater. In Illinois, raw sewage, cooling water, and industrial process wastewater are all injected

into abandoned coal mines. Mixed waste streams are difficult to inventory and even more difficult to assess. Facilities, injecting mixed waste streams were classified under the category of highest contamination potential. In the cases described above, the facilities were classified as industrial disposal facilities.

In summary, it is difficult to draw conclusions about the geographical distribution of Class V injection wells. The distribution would very likely change significantly if actual inventory figures were compiled under a study conducted to produce comparable data. "State" totals range from 0 wells in American Samoa and Trust Territories of the Pacific Islands (TTPI) to more than 25,000 wells in Florida and 50,000 wells in Arizona. To date, Region IX reports the largest inventory with over 64,000 wells. The bulk of Region IX's inventory, however, lies in the estimated number of drainage wells (5D2 plus 5D4) in Arizona: 50,000 wells. Approximate inventory figures by Region are shown on Table 3-4.

TABLE 3-4

TOTAL INVENTORY FIGURES BY REGION

Region	Total # of Wells
Region IX	64,214
Region IV	27,911
Region X	29,826
Region V	17,772
Region VIII	9,015
Region II	8,950
Region VII	6,675
Region III	4,589
Region VI	3,843
Region I	364

Although correlation between the number and distribution of wells is difficult, a few trends can be distinguished among well types.

3.3.1 DRAINAGE WELLS

The highest number of drainage wells is reported in Arizona (Region IX). Region X also reports a relatively high number of drainage wells. These high numbers are consistent with the hydrogeological conditions inherent to Regions IX and X. It is

difficult to distinguish storm water drainage wells (5D2) from industrial drainage wells (5D4) within the current inventory, but industrial drainage wells might be expected to be located in highly populated (industrialized) areas with appropriate hydrogeological conditions. High numbers of improved sinkholes (5D3) are expected in areas with "karst" topography such as Region IV, Region V, Puerto Rico, and Missouri.

3.3.2 GEOTHERMAL REINJECTION WELLS

Relatively high numbers of geothermal reinjection wells were expected in areas with high geothermal gradients such as the West Coast of the United States. The reported inventory figures support this hypothesis as most electric power reinjection wells (5A5) and direct heat reinjection wells (5A6) are located in Regions IX and X.

Technology concerning heat pump/air-conditioning return flow wells (5A7) is available nationwide. Data indicate that heat pump/air-conditioning return flow wells are present in all Regions of the United States. It should be noted that high geothermal gradients are not required for efficient usage of groundwater source heat pumps.

3.3.3 DOMESTIC WASTEWATER DISPOSAL WELLS

Domestic wastewater disposal wells are prevalent in every Region of the United States. Generalizations beyond that fact are difficult to make. However, fewer domestic wastewater disposal wells are probably located in more highly populated areas because those areas are more likely to be served by sewer systems. An exception to this generalization may be older cities.

One reason it is difficult to recognize any trends in the distribution of domestic wastewater injection wells is that they are exceedingly difficult to inventory. State and local regulations and record-keeping systems differ drastically. If records of individual systems are not kept by the State, it is difficult to identify these wells.

Another reason it is difficult to recognize trends is that some disposal systems were not included in some inventory efforts. For example, only septic systems with associated "wells" were inventoried in some States, while other States included both septic systems with "wells" and those with "drainfields." Both types will be included in the Class V inventories for this report. Without consistent inventories, it is impossible to make comparisons.

3.3.4 MINERAL AND FOSSIL FUEL RECOVERY WELLS

Inventory figures of these well types are believed to be relatively complete. These well types generally are limited to

States with related available natural resources. They seem to be well documented and regulated within their respective industry regulations.

3.3.5 INDUSTRIAL DISPOSAL

Problems with compiling inventories and recognizing usage trends of industrial disposal wells are similar to the problems associated with domestic wastewater disposal wells. Accurate records are not kept in many states. Furthermore, often there is reluctance on the part of owners/operators to report their industrial disposal wells for fear of "government interference." Also, injectate quality often is suspect, and recent public awareness campaigns concerning environmental protection may have made the owners/operators wary.

3.3.6 RECHARGE AND MISCELLANEOUS WELLS

Limited information was provided on recharge and miscellaneous wells. Presumably these well types will see increased usage in the future. Region V reports a relatively high number of abandoned drinking water wells (5X29); however, it should be noted that they are not necessarily used for the disposal of waste. The numbers reported indicate the number of abandoned drinking water wells on which they have records. There is no evidence to suggest that they are all being used to dispose of waste. Due to the difficulty in determining which wells actually are being used for disposal, the Agency is assuming a worst-case scenario and will include all abandoned drinking water wells in the inventory until data demonstrate otherwise. Where waste streams can be identified, well type classifications are revised to reflect the source of the waste streams.

3.4 EVALUATION OF THE DATABASE

Conducting an initial inventory search for Class V injection wells and then maintaining the inventory database with periodic updates is a complicated task. However, it is one that is essential to the program because a solid inventory is the basis for solid assessments. Some Class V wells were not regulated before the USEPA UIC program. Consequently, an unknown number of Class V injection wells probably remain "undiscovered" to this day since records of their existence either were not kept or were lost.

The inventory of Class V wells is considered to be poor to fair (i.e., incomplete). Many states were confident that most existing well <u>types</u> were identified even though the <u>numbers</u> of each type were thought to be low. Several factors contribute to the lack of detail and completeness (inventory vs. existing wells).

As described earlier, levels of effort among States and among Regions differed significantly. Second, the amount and type of information available for each well type differ among States, among Regions, and among well types. Third, different information sources responded to requests for information inconsistently. Fourth, several problems in classifying well types were evident.

It is essential to continue collecting inventory information and updating databases in order to reasonably assess the groundwater contamination potential of Class V injection wells.

3.5 RECOMMENDATIONS

The Class V injection well inventory continues to change. New wells continue to be constructed, and "undiscovered" existing wells continue to be identified. Several States recommended that additional resources and efforts be devoted to improving the Class V injection well database. All data should be computerized, including records of questionnaires, permit record files, and support documentation. Every effort should be made to establish a uniform classification and numbering system.

As a result of the States' efforts in inventorying Class V wells, several important lessons have been learned concerning strategies for obtaining a complete inventory on which to base assessments. Based on the inventory methods used by the States, the following recommendations for where and how to best find inventory information on both general and well specific levels are presented.

3.5.1 GENERAL

Currently there are at least 30 types of Class V injection wells, rather than only the 11 types that FURS recognizes. Not all States have all 30 types. However, because there are so many well types, States may have to employ more than one strategy when conducting and updating inventories.

The States in USEPA Region VIII recommend that the Agency make a request to Congress for funding to conduct an effort similar to the Surface Impoundment Assessment study. This study could be conducted with a more consistent approach and would provide a firm foundation for making regulatory changes.

When conducting mailed questionnaire surveys, some states found that telephone surveys used to ascertain appropriate "targets" enhanced mailed responses. Attachments to the questionnaires explaining the UIC program and follow-up telephone calls for data verification also have been useful in obtaining cooperation.

Some states recommended that every time an inventory search is conducted by State, Federal, local, or consultant entity, documentation of the strategy and date is essential so future inventory searches can build upon previous knowledge.

Current yellow pages, industry directories and association mailing lists, and agency and community listings were recommended for use by many states because they provide a good base of addresses and telephone numbers. Examples of directories include the Thomas Register and State Red Book of companies and industries; the Pennwell series of directories such as the Worldwide Refining and Gas Processing Directories; the telephone directory government blue pages; State association of governments or cities listings; and City, County, or State listings of business and commerce. Idaho reports that computerized directory systems, such as the Electronic Yellow Pages, allow statewide searches by specified categories and can provide addresses on printed mailing labels.

Some States have had good inventory results posting public notices in newspapers and various trade journals. Results are directly proportional to the notice's general content and ease of reading, location, and period of time the notice was posted.

Permits or other records needed during drilling and installation of a well may have been filed with the State agency which requires permits for water wells. However, the files may not be segregated by well type.

Many States require that all water well drillers be licensed with the State and that drillers register all completed wells and supply well logs. In these States, registration forms could be re-designed to indicate "well purpose." Well drillers should be better informed of the Class V UIC Program in order to identify specific injection well types.

Contamination potential assessments of the various Class V well types is, in part, dependent on 1) hydrogeologic characteristics and water usage in a given area, and 2) the population at risk. Numerous States recommended that efforts should be initiated to standardize the type and amount of information available on Class V injection wells.

3.5.2 SPECIFIC

In describing their inventory efforts, many States identified methods utilized to inventory specific well types. Recommendations based on these methods follow.

1. Agricultural Drainage Wells (5F1)

   Many States have entities which can be contacted concerning existence of agricultural drainage wells such as county extension services; irrigation, water, or drainage

districts; septic tank and dry well installers and drillers; local or regional water quality or resource boards; county environmental health departments; local consultants and university groups, especially at the A & M universities; the USDA Soil Conservation Service offices; and USGS State offices or State geological surveys.

Often the farmer is the only person who really knows of the existence of agricultural drainage wells. If the farmer is informed of the potential contamination of USDW posed by these wells, he may volunteer information when asked. Iowa State University Cooperative Extension Service put together an information brochure, "Agricultural Drainage Wells in Iowa," for distribution to farmers and others to provide information on the effects of these wells on water supplies. Publications of this type may help to improve the inventory database by informing the public not only of their responsibility to report Class V wells but also the reason behind the requirements.

2. Storm Water and Industrial Drainage Wells (5D2, 5D4)

These wells are among the hardest types to effectively inventory if a State has not been registering them since the time of installation. Obviously, if a State has had no problems with drainage, then this type of well probably will not have been used. There are several potential places to search for storm drainage well records. These include the State or Federal highway department, city engineers, public works directors, architectural engineers - either private or public (certain areas may have been designed to be drained by these wells), drillers or "dry" well installers, State water resource divisions or boards, State health departments or environmental protection agencies, and USGS State offices or State geological surveys. Another key means of locating drainage wells is to check local zoning requirements for sewage and storm water control. Some local zoning departments also have records showing actual well locations. City zoning maps may be used to determine industrial sectors of the cities. A percentage of storm drainage wells located in industrial sectors may be "industrial drainage wells" (5D4), because the probability of chemical or hazardous substance spills and leaks is greater in industrial settings.

Public notices about storm drainage wells to the general population may be a good strategy to use. Fieldwork also may be necessary (in probable areas) when all other means fail.

3. Improved Sinkholes (5D3)

Sinkholes are found in areas of the United States underlain by karst limestone formations (approximately 20% of the

United States.). In many locations, naturally occurring sinkholes may have been improved to enhance acceptance rates of storm drainage or any fluids (e.g., sewage, industrial process water and waste products). Inventory strategies used for storm drainage wells also may be used to find improved sinkholes.

4. Electric Power Geothermal Reinjection Wells (5A5)

These wells are used in thermally active areas of the United States, notably the western states and in the Gulf Coast. Many geothermal electric power plants discharge to reinjection wells. Entities holding records on these wells include oil companies and other operators involved in geothermal electric power generation, the Geothermal Resources Council (based in San Francisco), State oil and gas divisions, energy or corporation commissions, departments of minerals (these are State level agencies), U.S. Bureau of Land Management (for developments on Federal leases), the U.S. Geological Survey, and the U.S. Department of Energy. States such as California and Nevada have permit programs for these wells.

5. Direct Heat Geothermal Reinjection Wells (5A6)

These wells also are used in thermally active areas of the United States but do not require as high groundwater temperatures as geothermal electric power operations. Many of these wells are shallower than electric power reinjection wells and may or may not reinject spent water.

In Oregon, wells which inject into a formation other than the source aquifer must apply for a permit with the Department of Environmental Quality. Other wells which reinject into the source aquifer or discharge to the surface do not need a permit. In California and Nevada, large direct heat operations file for permits with the California Department of Oil and Gas and the Nevada Department of Minerals. Public service commissions also may be involved if the direct heat operation is very large or serves as a public utility company. The Geothermal Resources Council and State and U.S. Geological Surveys are good information sources.

6. Heat Pump/Air Conditioning Return Flow Wells (5A7)

Historically, the best sources of information for heat pump/air conditioning return flow wells have been the State tax commissions since many States gave tax credits (or provided other incentives) for these systems. Idaho, Michigan, and Oregon offer such tax credits. Michigan and Ohio give property and sales tax incentives for groundwater heat pumps. In Massachusetts, heat pumps are exempted from State sales tax. Nevada has a program to reduce the valua-

tion of alternative energy systems for property tax purposes.

In addition to State tax records, inventory information may be available through heat pump installers and distributors. The telephone yellow pages should list such companies. Also, the National Water Well Association, which is an advocate of ground-water heat pumps, has a plethora of information on heat pump companies, state laws, etc.

7. Aquaculture Return Flow Wells (5A8)

Aquaculture is the practice of rearing water animals or cultivating water plants in a controlled environment. Most operations are for profit, however, some aquaculture is experimental or for public interest (e.g. Marineland of the Pacific). The source of water may be ground water, wastewater from power plants or other industries, surface water or ocean water. Thus, only some aquaculture wastewater disposal wells are really return flow wells. Disposal wells are only one of the methods of wastewater discharge available. Sources of information for these wells include the State or local USDA office; the telephone yellow pages under Fish Hatcheries, Fish Farms, Seafood, Aquaculture; State listing of commerce, industry, or business; and research or public display aquariums.

8. Domestic Wastewater Disposal Wells (5W9, 5W10, 5W11, 5W31, 5W32, 5W12)

Historically, disposal of sewage wastes has been handled at the county and/or city level. Some States do maintain records of sewage disposal systems and almost all counties/cities maintain such records. In order to increase the inventory of these Class V injection wells, personal, telephone, and written queries (in decreasing order of effectiveness) should be made with the county/city sanitarians and public works directors. The nature and availability of sewage disposal well records vary from State to State and county to county. Experience has shown that often, records of these types of wells are extensive paper files and information is very difficult, if not almost impossible, to extract. Building a Class V inventory database of such wells may prove to be a long, tedious process which requires significant resources.

The city public works department director should be the person to contact for information on sewage treatment plant effluent disposal methods. Most plants discharge to surface waters; however, in some locations wells may be used (e.g. Hawaii, Florida). Some cities are using highly treated sewage wastewater (effluent) for aquifer recharge projects or saline water barrier projects (e.g., Palo Alto, California saline water intrusion barrier project).

9. Mineral and Fossil Fuel Related Wells (5X13, 5X14, 5X15, 5X16)

Records and other information on these wells related to energy and mineral recovery may be found by contacting the U.S. Bureau of Mines, U.S. Department of Energy, U.S. Geological Survey, State bureaus of mines, State departments of energy, corporation commissions, State departments of minerals and economic geology, State geological surveys, State water resources /protection boards, and the mining and energy industries themselves. For operations on Federal land, the U.S. Bureau of Land Management may hold records.

10. Cooling Water Return Flow Wells (5A19)

Most users of cooling water return flow wells are utilities (electric power generation) and industries. Often, the State water resources/protection boards or comparable agencies have records for such wells. If no State records are kept, then contact should be made with the utilities' and industries' process engineers or plant supervisors/ directors. The State public service commissions should have listings of all utilities in the States. Directories, such as the Thomas Register, California Red Book (other states may have similar directories), the Pennwell Oil and Gas Directory series, and others will give industry addresses, telephone numbers, and other pertinent information.

11. Industrial Process Water and Waste Disposal Wells (5W20)

It is difficult to obtain records for this grouping of wells. In addition to the large number and variety of industries, commercial ventures, and businesses, many industries may be reluctant to provide information on their waste disposal practices. The types of directories listed above for 5A19 wells and the telephone yellow pages can be consulted for information on locations of industries.

The State water resources agencies or environmental health/protection agencies may have a permit program or keep records on these wells, especially if they are "high technology" wells. Additionally, industries which were denied NPDES (surface water) discharge permits may be disposing of waste through injection wells.

12. Automobile Service Station Waste Disposal Wells (5X28)

The wells referred to in this Class V category inject a variety of wastes from car dealer and gasoline service stations including waste oil, engine cleaning solvents, brake fluid, transmission fluid, antifreeze, and other fluids from the repair bays; car wash effluent (detergent, oil and grease, sediments, heavy metals); and minor spills

of gasoline and oils. Many automobile service stations participate in waste oil and other recycling programs and are connected to the city sewer lines. Sometimes oil and grease interceptors - separators are required by a State plumbing code. But many other stations may be using private waste and wastewater discharge systems such as "dry" wells and septic systems (which may receive wastes other than domestic wastes).

Finding the stations which inject their wastes and wastewaters is difficult because (1) the number of automobile service stations is great, and (2) city or county officials will have to be contacted to determine which stations are on the sewer system and if they are allowed to dispose of all their wastes in the sewer system. Many service stations could be contacted and queried on their waste disposal systems through the oil companies. A significant number of stations are privately owned and would have to be contacted individually. Furthermore, many stations may be reluctant to provide information about their waste disposal practices or may not have detailed information on wells and septic systems they use. Information on automobile service stations may be available now through the Underground Storage Tank (UST) Programs initiated by the Hazardous and Solid Waste Amendments of 1986, (HWSA), and Superfund Amendments and Reauthorization Act (SARA) amendments (e.g., UST owner operation inventory surveys).

13. Recharge Wells (5R21, 5B22, 5S23)

Most recharge projects are under the direction of or directly report information to the State, regional, or local water resources agency or similar agency. Permits and extensive monitoring/testing programs usually are required since important USDW are directly affected by recharge projects.

14. Radioactive Waste Disposal Wells (5N24)

The Nuclear Regulatory Commission (NRC) licenses and regulates commercial nuclear facilities under the Energy Reorganization Act of 1974. In the past, facilities managed by The Department of Energy (DOE) may have used wells to dispose of some low-level radioactive waste. Some States may regulate these wells through water resources boards, health departments, or environmental protection agencies.

Radioactive waste disposal wells may be used by national and private nuclear research laboratories, national and private processing and manufacturing plants, nuclear power plants, the military, and various smaller entities using nuclear materials such as hospitals, oil and service companies, mining and energy companies, etc.

15. Experimental Technology Wells (5X25)

Many of the wells falling into this category are used in pilot scale solution mining operations. Inventory information for these wells should be available through the same entities named for 5X14 wells.

Other types of experimental technology wells include thermal storage project wells, air injection wells for water table recharge, tracer study wells, aquifer remediation wells, and oil shale and coal gasification related wells. The State water resources or protection boards, research or academic institutes, or mining boards may have inventory data for the various facilities.

16. Aquifer Remediation Related Wells (5X26)

Aquifer remediation related wells have been increasing in number in the last 10 to 20 years, especially since the inception of federal programs such as RCRA and CERCLA. Many contaminant spills, leaks, and other discharges are being remediated in part by injection-extraction well systems. For example, this type of clean-up technology is being used near Denver, Colorado, at the Rocky Mountain Arsenal. Additionally, several companies are remediating long-term oil leaks from refineries, terminals, storage areas, and pipelines using extraction-injection systems. Contacting appropriate State or Federal water protection agencies which may be involved in or have initiated several of these clean-ups may help to improve inventories. Many industries whose sites have experienced contamination are starting aquifer and soil contamination remediation programs on their own initiative. Contacting their environmental staffs and private consulting firms (employed to clean-up their facilities) may result in better inventories.

17. Abandoned Drinking Water Wells Used for Waste Disposal (5X29)

These wells are very difficult to obtain information on for the Class V inventory. State water well laws on reporting new wells and on plugging and abandonment may be used to inventory these wells. Most information on these wells may come from individuals reporting specific waste disposal operations. Wells installed and abandoned before regulation programs began may remain unknown.

SECTION 4
CONTAMINATION POTENTIAL ASSESSMENTS

This section of the report presents assessments for each of the Class V well types recognized to date. An assessment rating system was developed, based on the type, degree of detail, status, and amount of data available, to qualitatively assess the contamination potential of each well type.

In addition to the assessments, an overview of current regulatory approaches and technical recommendations have been included for each well type. The regulatory overviews discuss the current approaches Federal, State, and local agencies have taken to control well usage. The technical recommendations for each well type include siting, construction, operation, and maintenance recommendations. Corrective and remedial action recommendations are also presented, where applicable. The recommendations are based on those provided in State reports or supporting data. Assessments and recommendations for the various well types are summarized in Sections 5 and 6 (refer to Table 5-16).

An explanation of the rating system is presented below, followed by the various well type assessments.

4.1 RATING CONTAMINATION POTENTIAL

The objective of this rating system is to qualitatively assess the consequences of Class V injection practices with regard to current or potential beneficial uses of any USDW in communication (connected) with injection zones. According to "Guidelines For Ground-water Classification Under the USEPA Ground-water Protection Strategy," (USEPA, 1986, final draft) data such as hydrogeologic and well/reservoir surveys are needed to determine ground-water classification of injection zones and any USDW connected to injection zones. Other necessary data include general knowledge of aquifer characteristics; typical well construction, operation, and maintenance; chemical composition of injected fluids; and injected fluid rates/volumes and water budgets.

It should be emphasized that this rating system is only qualitative. It is used in this report as a tool to prioritize and designate certain well types or facilities for further study or regulatory oversight. The validity of the rating(s) will be increased when additional documented studies of Class V injection practices become available.

Furthermore, it should be noted that no amount of siting review, mechanical integrity testing, construction requirements, or injection fluid monitoring can eliminate the high pollution potential of some injection wells. Available data indicate that well closure will be necessary in many individual cases.

4.1.1 PARAMETERS USED AS CRITERIA IN DETERMINING CONTAMINATION POTENTIAL

The rating system utilizes four criteria to assess each well type's contamination potential. First, the injection zone must be identified as either being or not being an USDW. All hydraulically connected aquifers also must be identified. The "Guidelines for Ground-Water Classification Under the USEPA Ground-Water Protection Strategy" are used in this rating system to determine which aquifers or injection zones are USDW. The guidelines carry the USDW identification one step further by providing USDW subclassification (Class I, IIA, IIB, IIIA, and IIIB). Subclassification may be useful when prioritizing uses of limited resources. Second, a determination must be made as to whether or not typical well construction, operation, and maintenance for each well type will allow injection or fluid migration into USDW. Third, the typical fluids injected must be characterized with respect to the National Primary and Secondary Drinking Water Regulations and the Resource Conservation and Recovery Act Regulations. Finally, the contamination potential of typical injected fluids must be determined with respect to existing water quality in the injection zones and hydraulically connected aquifers. Sections 4.1.1.1 through 4.1.1.4 provide further explanation of each rating system criteria.

4.1.1.1 USDW Identification Using the Draft Guidelines for Ground Water Classifications

Classification Review Area (CRA)

Defining the area around the well is the first step in making a ground water classification decision. The Guidelines specify the initial CRA as the area within a two-mile radius of the boundary of the facility or activity under review. Under certain hydrogeologic conditions an expanded or reduced CRA is allowed. For example, the Classification Review Area can be subdivided or expanded to reflect the presence of one or more ground-water units which may have significantly different uses and values. The degree of interconnection between these ground-water units must be characterized to determine if contamination to all or some units would occur due to contamination of one unit. Interconnection is also a criterion for differentiating subclasses of Class III aquifers.

Ground-water units are mappable, three-dimensional bodies delineated on the basis of three types of boundaries:

- o Type 1 - Permanent ground-water flow divides.
- o Type 2 - Laterally and vertically extensive, low-permeability, confining beds.
- o Type 3 - Permanent fresh-water/saline-water contacts (saline is defined as waters with greater than 10,000 mg/l TDS).

A low to intermediate degree of interconnection is expected through undisrupted Type 2 boundaries. Because they are prone to alteration/modification due to changes in ground-water withdrawals and recharge, Type 1 and Type 3 boundaries imply an intermediate degree of interconnection. A high degree of interconnection is assumed when conditions for a lower degree of interconnection are not demonstrated.

Once the Classification Review Area (CRA) has been delineated, information regarding public and private wells, demographics, hydrogeology, and surface water and wetlands is collected. A classification decision is then made based on the criteria for each aquifer class as described below.

Class I - Special Ground Water

Class I ground water is defined as a resource of particularly high value. USEPA identifies three parameters that characterize Class I ground water: highly vulnerable, irreplaceable, and ecologically vital.

Highly vulnerable ground water is characterized by a relatively high potential for contaminants to enter and/or be transported within the ground-water flow system. The draft Guidelines provide two options, for which public comment was solicited, for determining vulnerability based on hydrogeologic factors. Option A uses a standard numerical ranking system known as DRASTIC (Aller et. al, 1985) with numerical cutoff points. Option B relies on a qualitative "best professional judgment" approach which may include use of numerical or alternative techniques.

An irreplaceable source of drinking water is ground water that serves a substantial population, and whose replacement by water of comparable quality and quantity from alternative sources in the area would be economically infeasible or precluded by institutional constraints. There are two options, which were presented for public comment, for judging irreplaceability. Option A relies on a standard methodology using one or more numeric cutoff values for size of population served and economic feasibility. Option B is a qualitative "best professional

judgment" approach which may include use of quantitative approaches as part of the assessment.

Ecologically vital ground water supplies a sensitive ecological system located in a ground-water discharge area that supports a unique habitat. Unique habitats include habitats for plant and animal species that are listed or proposed for listing under the Endangered Species Act. Certain Federally managed and protected lands may include unique habitats.

Class II - Current and Potential Sources of Drinking Water and Ground Water Having Other Beneficial Uses

Class II ground water includes all non-Class I ground water that is currently used (Subclass IIA) or is potentially available (Subclass IIB) for drinking water or other beneficial use.

Subclass IIA includes current sources of drinking water. Ground water is classified as IIA if within the CRA there is either one or more operating drinking water wells or springs, or there is a water supply reservoir watershed or portion thereof that is designated for water quality protection by either a state or locality.

Subclass IIB is a potential source of drinking water. This ground water can be obtained in sufficient quantity to meet the needs of an average family (e.g., 150 gallons per day), has total dissolved solids (TDS) of less than 10,000 milligrams per liter (mg/l), and is of a quality that can be used without treatment or that can be treated using methods reasonably employed by public water systems.

Class III - Ground Water Not a Potential Source of Drinking Water and of Limited Beneficial Use

Class III ground water has either a TDS concentration of over 10,000 mg/l or is contaminated by naturally occurring conditions or by the effects of broadscale human activity such that it cannot be cleaned up using standard public water supply treatment methods. Two subclasses of Class III Ground Waters have been defined. Subclass IIIA ground water has a high to intermediate degree of interconnection with adjacent ground-water units or with surface water, while Subclass IIIB ground water has a low degree of connection with adjacent surface waters or ground-water units.

Treatment Methods. Technology-based and economically-based tests for reasonably employed treatment methods were presented in the Final Draft Guidelines for public comment. The technology-based test is a simple listing of treatment technologies and

their applications. Known or potential water treatment systems have been classified by USEPA into three categories:

- Methods in common use that should be considered reasonably employed in public water treatment systems
- Methods known to be in use in a limited number of cases that, in some regions because of special circumstances, may be considered reasonably employed in public water treatment systems
- Methods not in use by public water-treatment systems.

Methods in common use include aeration, air stripping, carbon adsorption, chemical precipitation, chlorination, flotation, fluoridation, and granular media filtration.

Methods known to be used under special circumstances include desalination (e.g., reverse osmosis, ultrafiltration, electrodialysis), ion exchange, and ozonation. In most USEPA Regions, these treatment methods should not be considered methods reasonably employed by public water systems. However, in certain USEPA Regions, because of special ground-water quality or water scarcity circumstances, these methods may be considered reasonably employed.

Treatment methods not in use by public water treatment systems include distillation and wet air oxidation. These methods are considered new to public water treatment although they have been applied for industrial purposes in the past. Since their application to water treatment is experimental at this time, they should not be considered treatment methods reasonably employed in public water systems.

Treatment capacity to handle certain concentrations or combinations of contaminants may not be economically feasible, even though the basic technologies are available. If questions of capacity arise, the economic-based test should be applied.

4.1.1.2 Well Construction, Operation, and Maintenance

Since Class V well types are so diverse, well construction, operation, and maintenance will vary accordingly. In assessing contamination potential, a determination must be made on whether or not typical construction, operation, and maintenance for each well type will allow injection or fluid migration into USDW. It will be necessary to rate only those components applicable to the well type in question. In subsequent statements, the term "adequate" is used in addressing certain aspects of injection well construction. This is a qualitative term.

Aspects of typical construction/design which should be considered in making an assessment include:

1. Is casing used in the well and, if so, what is the casing program, and is it adequate? That is, is the casing of sufficient thickness and depth to protect 1) shallow fresh ground-water zones, and 2) deeper zones not intended to receive injection fluids?

2. Is cement used and, if so, what volumes are present and where?

3. Are tubing and packer part of the injection program?

4. Is the wellhead assembly adequate, if present? Can wellhead pressures and injection rates be monitored at the wellhead, and are manual shutoff valves present? Does the wellhead assembly protect against spillage or illicit disposal into the well?

Operational aspects to be considered include:

1. Are injection pressures, rates, and volumes monitored and, if so, are the data regularly analyzed?

2. Is the injection fluid analyzed regularly?

3. Is the facility operating under a permit?

4. Is there potential for abuse (e.g. illicit disposal, excessive wellhead pressure, or improper monitoring) under present operational procedures?

Maintenance aspects to be considered include:

1. Has a program been established to regularly conduct mechanical integrity tests (MIT)?

2. Have plans for proper plugging and abandonment been established, and is proper plugging and abandonment possible?

4.1.1.3 Injection Fluid Composition

One of the most important criteria in this rating system is the characterization of injection fluids and injection zone interaction products with respect to receiving USDW. For this

Class V rating system, fluid characterization will be in terms of the National Primary and Secondary Drinking Water Regulations (40 CFR Part 142) and the Resource Conservation and Recovery Act (RCRA) Regulations (40 CFR 261 Subparts C and D). The constituents or parameters listed in these regulations are the only ones which are available for reference under the Safe Drinking Water Act and the UIC regulations. One group of parameters which also should be addressed, but which is without a complete set of standards for comparison, is radioactive materials. Materials which are considered radioactive are regulated by the Nuclear Regulatory Commission and are listed in 10 CFR, Chapter 1, Part 20. Another parameter which should be considered is heat, including any possible chemical and physical reactions resulting from thermal changes in USDW relating to injection practices.

4.1.1.4 Contamination Potential of Injection Fluids

The final factor of this assessment rating system is the contamination potential of typical injected fluids with respect to existing water quality in an injection zone. Constituents must be compared with background level constituents because many USDW naturally exceed the National Primary and Secondary Drinking Water Standards. In making such a judgment, the two major considerations are the type(s) and mass loading[1] of the contaminant(s) injected and the transport and fate of the contaminant(s).

The first consideration, contaminant type and mass loading, should be addressed in terms of contaminant(s) concentrations in the injected fluids and the injection rates and volumes. Factors to be considered for contaminant transport and fate, the second category, include formation lithology, hydraulic conductivity and other physical properties of the particular zone, dilution of injection fluids by natural recharge to the receiving formation, the configuration of hydraulic head in the formation, and effects of attenuation mechanisms such as sorption, ion exchange, precipitation-dissolution reactions, neutralization reactions, and biodegradation.

For the purposes of this rating system, the effects of Class V injection on injection zone water quality are estimated for two possible scenarios. For the first scenario, contamination effects are estimated for the region beyond the facility property

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1. In a fixed elemental volume of the flow domain, mass loading is the total contaminant mass added and is calculated as:

injection rate (volume/time)	x	contaminant concentration (mass/volume)	x	total time of injection

lines (perimeter). Since this approach is not feasible for some well types, potential contamination effects are also considered on a group/area basis. This approach should be taken for well types whose contamination potential can not be estimated in reference to facility boundaries. An example of this would be a study of the impact of storm water drainage wells in an entire city or county.

4.1.2 THE RATING SYSTEM

The rating system consists of a series of questions (see 4.1.2.1 - 4.1.2.3) based on the four major criteria discussed previously. In brief, the four major criteria are aquifer identification; well construction, operation, and maintenance; injection fluid characterization; and injection fluid contamination potential. Ultimately, a well type is designated as having a high, moderate, or low contamination potential or where data are insufficient, an unknown potential to contaminate USDW.

The first step in the rating system is to determine if the well type in question has a high contamination potential. At least three of four questions asked for high contamination potential must yield affirmative answers to rate a particular well type as having a high rating. More specific requirements are described in Section 4.1.2.1. If the well type does not have a high potential, then the questions for moderate contamination potential must be answered. If at least two of the four questions receive affirmative answers, then the well type should be designated as having a moderate contamination potential. If less than two answers are affirmative, then the low contamination potential questions must be addressed. For a well type to rate a low contamination potential, all three low potential questions must be answered affirmatively. If the answers to any of these questions cannot be provided, then the well type should be recognized as having an unknown potential for contaminating USDW. It should be noted that any given well type could have a range of contamination potentials if more than one "typical" scenario exists for that well type (resulting from different hydrogeologic conditions, well constructions, etc.).

4.1.2.1 High Contamination Potential

Answer "YES" or "NO" to the following questions. Please note that the term "typical" will have varying definitions based on well types and geologic/geographic settings. In general, the term "typical" is intended to suggest commonly practiced standards (such as industry standards, commercial standards, etc.) or circumstances most likely to occur.

1. (a) Is injection into or above a Class I or Class II USDW?

or

(b) Is injection below the lowermost USDW but with the potential for fluids to migrate into a Class I or Class II USDW?

2. Would typical well construction, operation, and maintenance allow injection or migration into unintended zones containing Class I or II USDW?

3. Do the injection fluids typically:

(a) have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations (40 CFR Part 142)?

or

(b) exhibit characteristics or contain constituents ~~listed as~~ hazardous ~~as stated~~ in RCRA Regulations (40 CFR 261 Subparts C and D)?

4. Based on injectate characteristics and possibilities for attenuation and dilution, does injection occur in sufficient volume or at a sufficient rate to cause an increase in concentration (to above background levels) of substances listed in the National Primary or Secondary Drinking Water Regulations, or to endanger human health or the environment:

(a) beyond the facility perimeter?

or

(b) in a region studied on a group/area basis?

Facility perimeter is defined as (1) the legal property lines, whether the surface and underground rights are leased or owned, of the facility with which an injection well is associated; or, (2) project boundary lines as defined in other applicable Federal, State, or local permits to operate the facility.

A high contamination potential for the well type is indicated if all four questions are answered affirmatively or if conditions described below are met. If questions 1(a) or 1(b), and 3(a) or 3(b), and 4(a) or 4(b) are answered affirmatively, then the well type has a high contamination potential. Alternatively, if questions 2, and 3(a) or 3(b), and 4(a) or 4(b) are answered affirmatively, then the well type has a high contamination potential.

Note that if both questions 1(a) and 3(b) are answered affirmatively, then the facility may be operating a Class IV well and appropriate investigations should be conducted.

4.1.2.2 Moderate Contamination Potential

Answer "YES" or "NO" to the following questions.

1. (a) Is injection into or above any USDW?

   or

   (b) Is injection below the lowermost USDW but with the potential for fluids to migrate into an USDW hydraulically connected to the injection zone?

2. Would typical well construction, operation, and maintenance allow injection or migration into unintended zones containing USDW?

3. (a) Are the injection fluids of poorer quality (relative to standards of the National Primary or Secondary Drinking Water Regulations or RCRA Regulations) than the fluids within any USDW in communication with the injection zone?

   or

   (b) In the event that water quality is unknown for any USDW in communication with the injection zone, do the injection fluids:

      (i) typically contain constituents whose concentrations exceed standards of the National Primary or Secondary Drinking Water Regulations?

   or

      (ii) typically contain constituents or exhibit characteristics defined as hazardous in the RCRA Regulations?

4. Based on injectate characteristics and possibilities for attenuation and dilution, does injection occur in sufficient volume or at a sufficient rate to cause an increase in concentration (to above background levels) of substances listed in the National Primary or Secondary Drinking Water Regulations, or to endanger human health or the environment:

   (a) beyond the facility perimeter?

   or

   (b) in a region studied on a group/area basis?

If at least two questions are answered affirmatively, then the well type should be rated as having a moderate contamination potential.

Note that if both questions 1(a) and 3(b) are answered affirmatively, then the facility may be operating a Class IV well and appropriate investigations should be conducted.

4.1.2.3 Low Contamination Potential

Answer "YES" or "NO" to the following questions.

1. (a) Is injection into or above any USDW?

   or

   (b) Is injection below the lowermost USDW, but with little or no potential for migration of fluids into any USDW hydraulically connected to the injection zones?

2. Would typical well construction, operation, and maintenance ensure that fluids are injected and remain in the intended zones?

3. Are the injection fluids typically:

   (a) of equivalent or better quality (relative to standards of the National Primary or Secondary Drinking Water Regulations or RCRA Regulations) than fluids within any USDW in communication with the injection zone?

   or

   (b) of poorer quality (relative to standards of the National Primary or Secondary Drinking Water Regulations or RCRA Regulations) than fluids within any USDW in communication with the injection zone

   BUT

   are injected in volumes/rates and contaminant concentrations insufficient to change current or potential beneficial uses of the water found within any USDW in communication with the injection zone?

If all three questions are answered affirmatively, then the well type should be rated as having a low potential to contaminate USDW. If any of the 11 questions asked could not be answered, then the well type must be categorized as having an unknown potential. The information that is known about such well types then may be examined and used as a guide in delineating recommendations (e.g. chemical analyses of the injected fluids should be obtained on a semi-annual basis). Table 4-1 presents the rating system in table form.

TABLE 4-1
RATING CONTAMINATION POTENTIAL

	AQUIFER IDENTIFICATION	WELL CONSTRUCTION, OPERATION, AND MAINTENANCE	INJECTION FLUID CHARACTERISTICS	INJECTION FLUID CONTAMINATION POTENTIAL
HIGH	1a) Injection into or above Class I or II USDW OR b) Injection below lowermost USDW, potential exists for fluid migration into Class I or II USDW.	2) Typical well construction, operation, and maintenance allow injection or migration into unintended zones containing Class I or II USDW.	3) Injection fluids typically: a) contain constituents in concentrations exceeding National Primary or Secondary Drinking Water Regulations, OR b) exhibit characteristics or contain constituents listed as hazardous per RCRA Regulations.	4) Based on injectate characteristics and possibilities for attenuation/dilution, injection occurs in sufficient volumes/rates to cause contamination of groundwater: a) beyond the facility perimeter OR b) regionally on a group/area basis.
MODERATE	1a) Injection into or above any USDW OR b) Injection below lowermost USDW, potential exists for fluid migration into USDW.	2) Typical well construction, operation, and maintenance allow injection or migration into unintended zones containing USDW.	3a) Injection fluids typically are of poorer quality (relative to National Primary or Secondary Drinking Water Regulations or RCRA Regulations) than fluids within any USDW in communication with the injection zone, OR b) In the event that water quality is unknown for any USDW in communication with the injection zone, injection fluids typically contain constituents in concentrations exceeding National Primary or Secondary Drinking Water Regulations or are listed or exhibit characteristics included in RCRA Regulations.	4) Based on injectate characteristics and possibilities for attenuation/dilution, injection occurs in sufficient volumes/rates to cause contamination of groundwater: a) beyond the facility perimeter OR b) regionally on a group/area basis
LOW	1a) Injection into or above any USDW OR b) Injection below lowermost USDW, with little or no potential for fluid migration into any USDW.	2) Typical well construction, operation, and maintenance ensure that fluids are injected into and remain in intended zones.	3) Injection fluids typically: a) are of equivalent or better quality (relative to National Primary or Secondary Drinking Water Regulations or RCRA Regulations) than fluids within any USDW in communication with the injection zone OR b) are of poorer quality (relative to National Primary or Secondary Drinking Water Regulations or RCRA Regulations) than fluids within any USDW in communication with the injection zone...	.....BUT are injected in insufficient volumes/rates and contaminant concentrations to change current or potential beneficial uses of any USDW in communication with the injection zone.

4.2 WELL TYPE ASSESSMENTS

Each well type assessment presented in this report addresses well purpose; inventory and location; construction, siting, and operation; nature of injected fluids and injection zone interactions; hydrogeology and water usage; contamination potential of the well type; current regulatory approach; and recommendations for siting, construction, operation, and corrective or remedial actions. Each well type assessment also contains a table summarizing number of wells, current regulatory system, availability of case study information, and the contamination potential of the well type as reported by each State. Because each State approached the task of identifying the items listed above in a different manner, descriptive terms were not consistent. Therefore, the following list of explanations is provided.

Confirmed Presence of Well Type: where available, numbers of wells within each State are indicated. If States report that the well type is known to exist, but numbers are not available, then the word "yes" is substituted for number of wells. Likewise, where no wells are known to exist, "no" is substituted. "N/A" indicates that the information is not available.

Regulatory System: regulatory systems are defined as "permit," "rule," "none," or "N/A" (not available). In some cases, qualifiers such as well depth or injectate volume are also indicated. Where injectate volume is indicated, "K" represents one thousand. For example, "Permit > 15K GPD" indicates that permits are issued for wells which inject more than 15,000 gallons per day.

Case Studies/Info. Available: where case studies were provided by the States, the table lists "yes." Where case studies were not provided by the States, the table lists "no." "N/A" indicates that information was not available.

Contamination Potential Rating: this column indicates how each State rated the contamination potential of the well type. In some cases, States did not rate contamination potential as "high," "medium," or "low." Instead, they <u>ranked</u> contamination potential as compared with other well types. In these cases, the table indicates, for example, "2nd HIGHEST/10 TYPES." That is, out of 10 types of wells found within a State, the State identified this well type as having the 2nd highest contamination potential.

In other cases, the States refrained from <u>rating</u> or <u>ranking</u> contamination potentials and merely identified whether or not the well type had any potential to contaminate ground water. For these States, the table lists "positive" or "negative." Where

descriptive terms such as "variable," "deleterious," or "unknown" were provided by the States, these terms also have been noted.

In some cases the States are noted for not providing detailed information in many of the subclass assessments. It should be noted that major modifications were made to the Class V classification system in the fall of 1986. The system was expanded to reflect 32 well types rather than 11 well types as were recognized by FURS.

4.2.1 DRAINAGE WELLS

4.2.1.1 Agricultural Drainage Wells (5F1)

Well Purpose

Proper management of agricultural land requires that adequate drainage of surface runoff and subsurface flow be provided for a well-aerated root zone for optimum crop growth (Ochs, 1980). Land on which sufficient natural drainage does not exist necessitates artificial outlets such as drainage ditches, channels, or wells. For example, in some parts of Iowa where the soils are classified as poorly drained and the topography is low and flat, land now being intensively farmed could not be used for agricultural purposes without drainage provided by wells (Iowa ADW Assessment Report). The USEPA defines agricultural drainage wells (5F1) as wells that receive fluids such as irrigation tailwaters or return flow, other field drainage (i.e., resulting from precipitation, snowmelt, floodwaters, etc.), animal yard runoff, feedlot runoff, or dairy runoff. These wells most commonly are used in the western half of the United States primarily for disposing irrigation return flow and controlling salinity in the root zone (Ochs, 1980). Injection of irrigation return flow, along with other agricultural waste fluids, qualifies these drainage wells as Class V, defined by 40 CFR, Section 146.5(e)(1).

Inventory and Location

Compiling a national inventory of agricultural drainage wells has been complicated by inconsistencies between the State reports and the Federal UIC Reporting System (FURS) listings over the existing number of these wells. States were asked to verify the FURS listings in their inventory and assessment reports or to note reasons why the verification was not possible. However, these verifications have not been received from many States. In addition, it is suspected that the numbers of this well type may be underestimated in both the States' inventories and the FURS listings, but the exact degree of underestimation is unknown. Many States have entities, such as irrigation districts, that can be contacted for information on this well type. However, there

may be many wells that are not located in these districts. Also, by noting the number of farming operations in the United States, the relative ease of constructing an agricultural drainage well, the lack of permit requirements, and the reluctance of many well owners to admit to the wells' existence, it seems likely that there are many unreported and unverified wells. In some cases the farmer or rancher may be the only one who knows that a particular agricultural drainage well exists.

Some States know or suspect that these wells exist, yet cannot or have not been able to verify the information and, therefore, do not know the correct number of wells. In California, authorities are aware of the use of drainage wells (commonly called dry wells) to dispose of irrigation tailwater, but the exact number of wells is unknown. In the State of Iowa, researchers have noted that many methods to inventory agricultural drainage wells have been attempted, but none have proven very successful. Large discrepancies as to the actual number of these wells exist among the different inventories. For example, in 1981 Iowa University estimated that there are 700 agricultural drainage wells in Iowa; whereas, the Iowa Geological Survey (IGS) estimated that there are 328 agricultural drainage wells in the State. The IGS estimate was later adjusted to 230 for statistical reasons. The FURS inventory also reports only 230 agricultural drainage wells for the State of Iowa. State inventories from Illinois, Oklahoma, and Colorado note that although numbers are not available, the existence of agricultural drainage wells is suspected. Texas officials have identified and verified 108 wells, but suspect there may be an additional 100 in existence. Also, Georgia has reported both confirmed and unconfirmed wells. The State of Minnesota has banned agricultural drainage wells; however officials there suspect some still exist because some have been located since the ban.

Specifically 1,338 agricultural drainage wells have been inventoried. In total, the majority of known agricultural drainage wells are located in Iowa, Idaho, Texas, and Indiana. Their distribution throughout the United States is presented in Table 4-2.

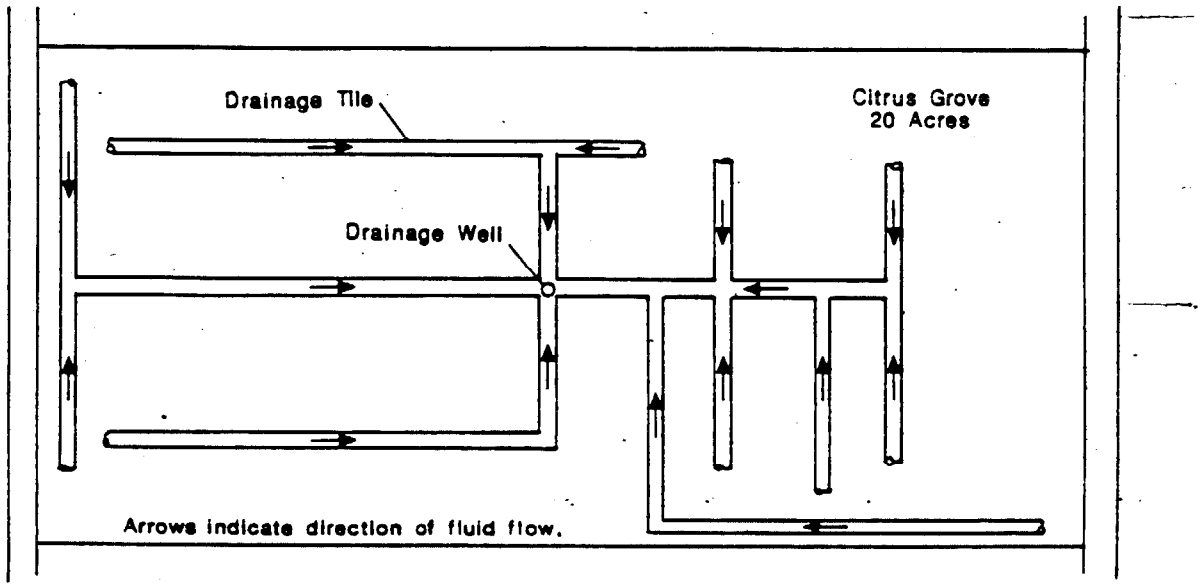
Well Construction, Operation, and Siting

The design of agricultural drainage wells varies depending on site conditions, age of the well, and whether the primary concern is for disposal of surface and/or subsurface return flows. Figure 4-1 shows a typical collection and disposal system used for injecting subsurface return flows. These drainage systems are common in areas where percolation of water past the root zone is impeded by impermeable soils. This may lead to the formation of perched water, which may be detrimental to plant life. The drainage lines shown in Figure 4-1 typically are packed in gravel to facilitate percolation. The lines usually

TABLE 4-2: SYNOPSIS OF STATE REPORTS FOR AGRICULTURAL DRAINAGE WELLS(5F1)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	150 WELLS	SPDES PERMIT	NO	VARIABLE
Puerto Rico	II	YES	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	YES	N/A	NO	HIGH
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	YES	PERMIT	NO	N/A
Georgia	IV	43 WELLS	BANNED	NO	LOW/UNKNOWN
Kentucky	IV	YES	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	6 WELLS	RULE	YES	N/A
Indiana	V	72 WELLS	N/A	NO	N/A
Michigan	V	15 WELLS	N/A	NO	N/A
Minnesota	V	54 WELLS	BANNED	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	YES	RULE	NO	N/A
Texas	VI	108 WELLS	N/A	YES	HIGH
Iowa	VII	230 WELLS	DIVERSION PERMIT	YES	HIGH
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	YES	NONE	NO	HIGH
Nebraska	VII	5 WELLS	RULE	NO	HIGH
Colorado	VIII	YES	N/A	NO	HIGH
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	1 WELL	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	RULE	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	PERMIT	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	572 WELLS	PERMIT>18 ft	YES	2ND HIGHEST/14 TYPES
Oregon	X	16 WELLS	N/A	NO	2ND HIGHEST/3 TYPES
Washington	X	66 WELLS	UNDECIDED	NO	UNKNOWN/HIGH

NOTE: SOME NUMBERS ON THIS PAGE MAY BE ESTIMATES.



TYPICAL SUBSURFACE RETURN FLOW
COLLECTION SYSTEM

(from Texas Dept. of Water Resources, 1984)

Figure 4-

are constructed of perforated plastic, but clay and concrete also are used. Figure 4-2 is a general diagram showing an agricultural drainage well system for both surface and subsurface flow. In this type of system, surface water can enter directly into the tile lines through surface inlets. In some cases, surface flow also may enter into the tile lines due to the development of cracks in the lines and within the soil profile that allow rapid inflow of ponded water.

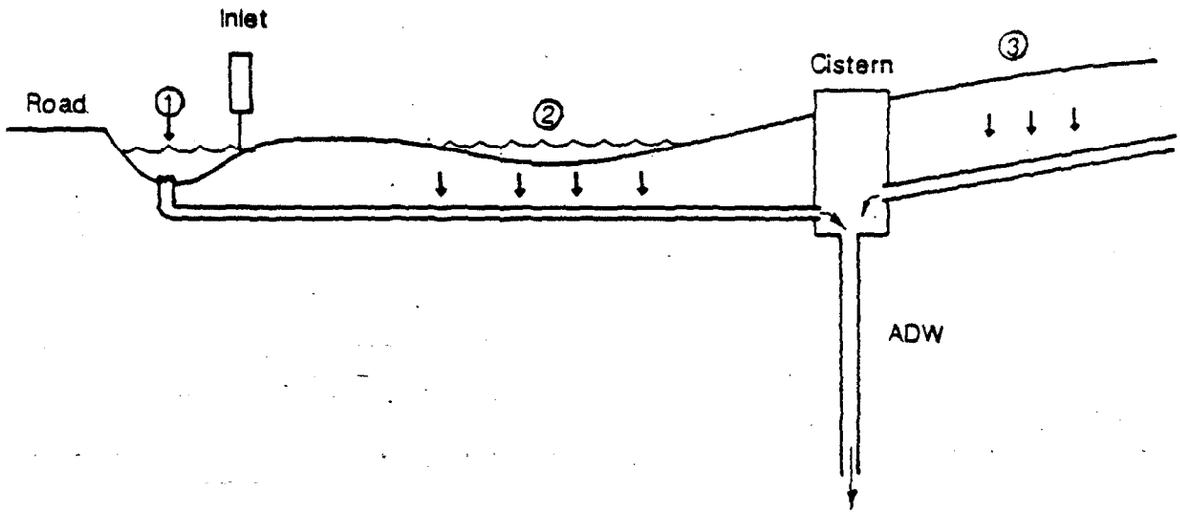
Generally, an agricultural drainage well system consists of a buried collection basin or cistern, one or more tile lines entering the cistern, and a drilled, or dug, cased well. The well may be a "dry well" (situated above the water table) or may be installed into a water bearing formation. Figure 4-3 shows two typical agricultural drainage wells. These wells usually are constructed with 4- to 6-inch diameter casings. The intake to the well is raised above the cistern bottom so the lower section of the cistern can act as a settling basin for sediment.

Construction features vary from State to State. Wells in Idaho are grouped by capacity for descriptive purposes. Large-capacity wells drain 80 to greater than 640 acres, while small-capacity wells drain 80 acres or less of irrigated land. Casing diameters range from 3 to 8 inches for small-capacity wells, to 9 to 24 inches for large-capacity wells. The large wells in Idaho generally have screened or inverted inlets, settling ponds, and surface seals. Small wells may not have screened inlets, settling ponds, or surface seals. Large wells usually inject into the saturated zone while small wells usually inject into the vadose zone (IDWR, 1987).

Agricultural drainage wells usually are completed in the shallowest permeable zone that will readily accept drainage fluids. Shallow completions are preferred to keep construction costs low. Therefore, the majority of return flow wells are less than 100 feet deep and operate by gravity flow. Wells in Idaho range in depth from 20 feet to greater than 300 feet below land surface. Casing depths for Idaho wells range from 5 feet to greater than 200 feet below land surface (IDWR, 1987).

Some drainage well systems can be costly to operate and maintain because of susceptibility to corrosion, incrustation, and plugging. Costs can be minimized by using proper design criteria and suitable or compatible materials (Ochs, 1980). Historically, once the well has been completed, little routine maintenance has been performed.

Generally, agricultural drainage wells are found in areas having low soil permeabilities, shallow water tables, and insufficient natural surface drainage. However, additional considerations on the site specific level can determine where these wells



EXPLANATION

①Surface Flow

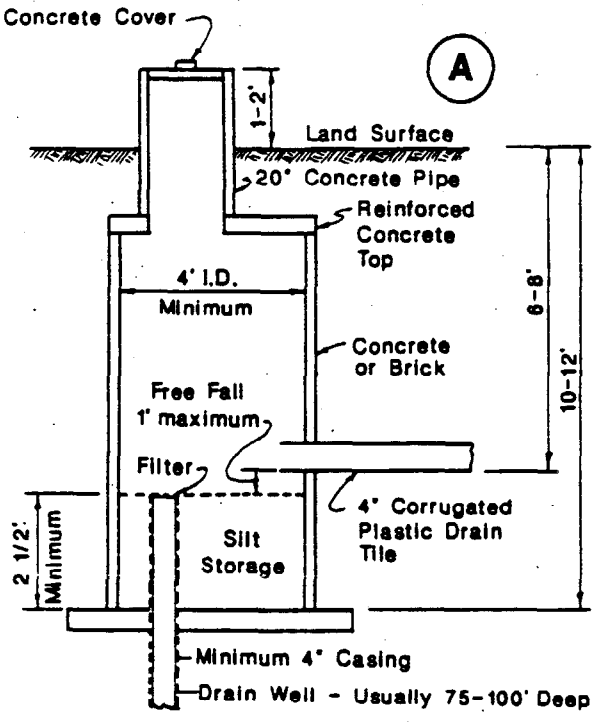
②'Quasi' Surface Flow

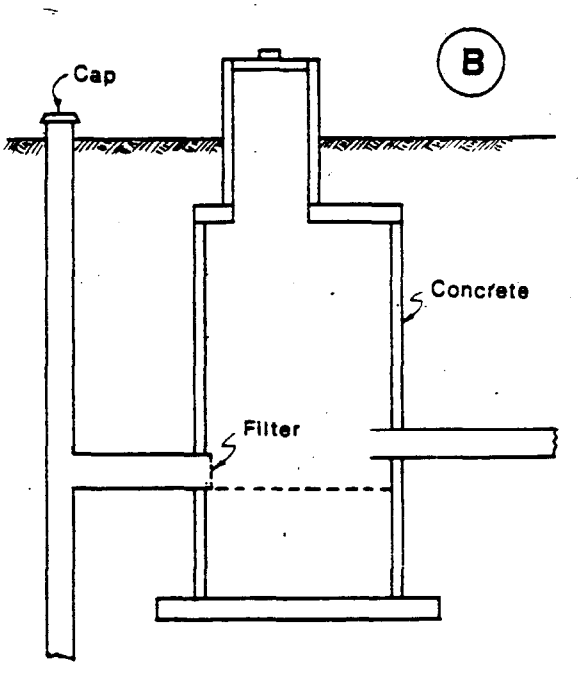
③Subsurface Flow

TYPICAL AGRICULTURAL DRAINAGE WELL IN NORTH-CENTRAL IOWA SHOWING THREE SOURCES OF FLOW

(from Austin and Baker, 1984)

Figure 4





EXCEPT AS INDICATED, MATERIALS AND DIMENSIONS ARE AS SHOWN IN FIGURE TO LEFT.

AGRICULTURAL DRAINAGE WELL SCHEMATICS

A WITH WELL INSIDE CISTERN

B WITH WELL ADJACENT TO CISTERN

(from Texas Dept. of Water Resources, 1984)

Figure 4-3

are located. One such consideration involves drainage of irrigation waters. On land that is irrigated, agricultural drainage wells are used more frequently where supply water is relatively abundant and inexpensive. On the other hand, in areas where supply water is costly, there is little incentive to dispose of irrigation tailwater by injection wells. In this case farmers are more likely to recycle tailwater by collecting and pumping it back into the irrigation supply system. Recycling irrigation tailwaters is a common practice in certain areas of California and Arizona where water is an expensive commodity.

In siting these drainage wells, Ochs (1980) recommends taking the following into consideration: degree of land development, interference with farming or other activities, environmental concerns, need for access for servicing and maintenance, location of surface drainage, and the presence of hydrologic boundaries.

Injected Fluids and Injection Zone Interactions

Injected Fluids. The quantity and quality of agricultural drainage water varies from differences in farming practices (i.e., use of fertilizers, pesticides, herbicides, etc.) and soil types (i.e., clay soils adsorb more pollutants than non-clay soils). However, a general characterization is possible. Potential agricultural contaminants include sediment, nutrients, pesticides, organics, salts, metals, and in some cases, pathogens. These contaminants may be found in agricultural waste fluids on both irrigated and non-irrigated lands. However, as previously noted, agricultural drainage wells are used primarily in the western states to drain irrigation return flow; therefore, the nature of most of the injection fluids entering these wells will more accurately reflect the irrigation return flows.

Irrigation water applied in excess of crop requirements can create drainage problems. The difference between the amount of irrigation water applied to the crop and the amount consumed by the crop or held by the soil matrix is the return flow. Return flows consist of two parts - surface runoff produced during irrigation (commonly termed as tailwater), and subsurface drainage produced from the percolation of irrigated water seeping past the root zone (Ochs, 1980).

With current irrigation practices, only about 50 percent of the water applied is consumed by the crop or held by the soil. Some of the excess water is applied intentionally in order to maintain the correct salt balance in the soil by reducing the salt concentrations in the root zone. This part of the excess water is called the "leaching fraction," and contributes to the subsurface portion of return flow. In addition, excess irrigation water is applied intentionally in many western states due to "beneficial use" requirements of the water appropriation

rights. These appropriation rights stipulate that the first person to develop and put water to beneficial use has the legal right to all the water required to satisfy his needs; however, this right may be lost or reduced by nonuse of the water. Most irrigators have water appropriation rights and have interpreted irrigation as a "beneficial use." Therefore, they use their total water allocation each year to avoid having their future allocation lost or reduced. This practice often results in over-irrigation and can create a substantial amount of return flow (Blackman et al., 1977).

The quality of surface drainage waters can vary significantly depending on the amount of sediment, fertilizer, pesticide, and other residues that are picked up as the water flows across the fields. Generally, the quality of the surface runoff is good with regard to salinity, but may contain large amounts of sediment. Surface runoff also may have significant levels of bacteria and certain pesticides. An analysis of water samples from four agricultural drainage wells in Iowa showed pesticide and bacteria levels were higher in the wells draining surface runoff than those receiving only subsurface flow (Iowa ADW Assessment Report). Subsurface return flow, on the other hand, may contain high concentrations of total dissolved solids, particularly in the semi-arid areas of the country (Ochs, 1980).

Specific fertilizer nutrients most commonly applied to crops, and therefore found in drainage waters, are nitrogen and phosphorus. Nitrogen normally is applied in a highly soluble nitrate form and usually is transported in a dissolved state in subsurface return flows. During an Iowa study of subsurface return flow to agricultural drainage wells, NO_3-N concentrations were higher (10 to 30 mg/l) during periods between runoff events and lower (often <10mg/l) during periods of snowmelt or rainfall runoff when the wells received both surface and subsurface flows (Baker and Austin, 1984). Phosphorus has a high affinity for soil particles and usually is transported on suspended solids found in surface return flows. Both nitrogen and phosphorus can cause increased eutrophication rates when introduced into surface waters. Nitrates are toxic particularly to infants and livestock at high concentrations; they also are suspected carcinogens.

Examples of pesticides commonly detected in significant concentrations in return flows entering agricultural drainage wells are atrazine, bladex, and sencor. Refer to Cherryholmes and Gockel, 1987, for further information concerning these pesticides and others. Bacteria also are detected in high concentrations in irrigation return flows. According to Baldwin, 1977, the primary water pollutant generated by agriculture is sediment from cropland erosion. Sediment causes physical degradation of receiving waters and acts as a transport mechanism for other agricultural pollutants such as pesticides and metals.

A study conducted by Graham, Clapp, and Putkey (1977) on agricultural drainage wells in Idaho identified sediment loads and bacterial concentrations as the most serious threat to ground water quality from return flows. The following table (Table 4-3) shows the quality of the return flows studied by Graham and others. While the data provides a good overview of the problem, it should be noted that the results are for surface return flows only.

Injection Zone Interactions. Most agricultural drainage wells are completed in the unsaturated (vadose) zone or shallow aquifers. The most significant interaction which can occur from the injection of the drainage fluids into these shallow wells is the contamination of an aquifer so it can no longer be used as an underground source of drinking water. High concentrations of pesticides, metals, and fertilizers found in drainage waters can render an aquifer unusable.

Aquifer sensitivity to the injection of agricultural drainage fluids into the vadose zone depends on the thickness of the vadose zone (depth to the water table), the nature of the layered deposits in the zone (i.e., high or low permeability), the degree of confinement of the ground water (presence of a confining zone impeding the migration of the contaminants), and the quality of the ambient ground water. The first three factors affect the rate of movement of the contaminants through the soil matrix (i.e., absorption onto soil particles). In general, contaminants are less likely to reach the aquifer in harmful concentrations when the vadose zone is of sufficient thickness, the permeability low, and the degree of confinement high. The lateral movement of injected wastewater through highly permeable interbeds (normally unsaturated) into uncased or unsealed rural single family domestic wells is the major cause of contamination of domestic ground-water supplies attributed to injection well use in Idaho (IDWR correspondence 1987). Sensitivity to the injection of drainage fluids directly into a water table aquifer depends primarily on the quality of the ambient ground water. Chemical incompatibility between the receiving water and the injected fluids may result in adverse reactions in the formation.

Hydrogeology and Water Use

Agricultural drainage wells are found in areas having poorly drained soils. Most wells are completed in shallow aquifers that have the capacity to receive large volumes of fluid. The prime aquifer units for injection are bedrock aquifers which have undergone dissolution and/or fracturing. The majority of the agricultural drainage wells inventoried inject fluids into such formations. In the State of Iowa, these wells inject drainage fluids into fractured, vuggy carbonate formations. In Idaho, fluids are injected into fractured basalt formations. These

TABLE 4-3

QUALITY OF IRRIGATION WASTEWATER
JUNE 26, 1975 TO AUGUST 24, 1976
(Source: Graham et al, 1977)

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

TABLE 4-3, continued

		Number of Determinations	Low	Mean	High	Idaho Drinking Water Standards	Public Water Supply Criteria	EPA Proposed Drinking Water Standards
Inorganic Chemicals	Alkalinity (mg/l as $CaCO_3$)	10	148	168	198	—	—	—
	Ammonia (mg/l as N)	4	—	—	0.00	—	0.5	—
	Arsenic (mg/l)	[illegible]	—	—	<0.01	0.05	1.0	0.05
	Barium (mg/l)	5	0.04	0.05	0.07	1.0	1.0	1.0
	Boron (mg/l)	10	0.05	0.10	0.18	—	1.0	—
	Cadmium (mg/l)	5	—	—	<0.01	0.05	0.01	0.01
	Calcium (mg/l)	10	40.2	42.4	46.0	—	—	—
	Chloride (mg/l)	10	14.6	16.6	19.9	250	250	—
	Chromium (mg/l)	5	—	—	<0.02	0.05	0.05	0.05
	Copper (mg/l)	5	0.01	0.02	0.02	1.0	1.0	—
	Cyanide (mg/l)	7	—	—	<0.01	0.20	0.20	—
	Iron (mg/l)	5	<0.02	0.02	0.06	0.3	0.3	—
	Lead (mg/l)	5	—	—	<0.05	0.05	0.05	0.05
	Magnesium (mg/l)	10	10.7	14.4	27.6	—	—	—
	Manganese (mg/l)	5	<0.01	0.02	0.04	0.05	0.05	—
	Mercury (ug/l)	5	<1.0	1.0	1.3	2.0	2.0	2.0
	Nitrate (mg/l as N)	10	0.08	0.35	1.82	10	10	10
	Nitrite (mg/l as N)	10	0.00	0.03	0.07	10	10	10
	Orthophosphate (mg/l as P)	10	0.05	0.11	0.22	—	—	—
	Potassium (mg/l)	10	3.91	5.90	11.3	—	—	—
	Selenium (ug/l)	4	0.9	1.2	1.8	10	10	10

TABLE 4-3, continued

		Number of Determinations	Low	Mean	High	Idaho Drinking Water Standards	Public Water Supply Criteria	EPA Proposed Drinking Water Standards
Inorganic Chemicals	Silver (mg/l)	5	---	---	<0.01	0.05	0.05	0.05
	Sodium (mg/l)	10	15.9	17.6	22.8	---	---	---
	Sulfate (mg/l)	10	30.7	33.2	37.4	250	250	---
	Zinc (mg/l)	5	0.01	0.02	0.02	5.0	5.0	---
Physical	Chemical oxygen demand (mg/l)	10	13	24	37	---	---	---
	pH	14	7.94	---	8.94	---	---	---
	Specific conductance (umhos/cm)	49	350	382	445	---	---	---
	Total dissolved solids (mg/l)	9	197	225	290	500	500	---
	Color (C.U.)	9	<5	43	>70	15	75	---
	Temperature (^{o}C)	27	5.6	17.2	35.0	---	29.0	---
	Turbidity (NTU)	48	7.7	86	320	5	5	1
	Total nonfilterable residue (mg/l)	35	9.3	237.1	1652	---	---	---
	Nonfilterable fixed residue (mg/l)	33	0.6	151.8	731.2	---	---	---
	Nonfilterable volatile residue (mg/l)	33	4.1	33.2	108.1	---	---	---
Microbiological	Total coliforms (organisms/100 ml)	45	580	29,000	96,000	2 (MPN)	---	1
	Fecal Coliforms (organisms/100 ml)	45	65	850	13,000	---	---	---
	Fecal streptococci (organisms/100 ml)	38	900	7,400	16,000	---	---	---

aquifers have sufficient capacity to accept drainage fluids and are less likely than sand or gravel aquifers to become plugged.

The disposal of agricultural drainage waters into shallow aquifers leads to a concern for possible ground-water contamination. The formations used for injection of these drainage waters are often the same formations used as sources of local drinking water. Therefore, nearby public or private drinking water wells may be subject to direct contamination from pesticides, nutrients, metals, bacteria, etc. The degree to which a drinking water well may be affected depends on a variety of factors which include: the horizontal and vertical distance from the injection operations; the quality and volume of the injected fluids; the sensitivity of the receiving aquifer; and the concentration of agricultural drainage wells in the area.

In several States, there is sufficient evidence of ground water contamination resulting from injection of agricultural drainage fluids. In the State of Iowa, aquifers used for injection of these drainage fluids also are used for water supply for local farms and communities. Contamination of the supply wells is most prevalent in areas highly concentrated with agricultural drainage wells. Likewise, in Idaho the same aquifers used to inject agricultural drainage waters are used as the main source of water for approximately 140,000 people. Here too, supply wells show signs of contamination. In the State of Texas, agricultural drainage wells inject fluids into a highly mineralized aquifer. Though not an USDW, this aquifer is hydraulically connected to deeper aquifers that may be utilized as USDW in the future. The injection aquifer and the deeper aquifers all exhibit some nitrate contamination resulting from the drainage wells.

Contamination Potential

Based on the rating system described in Section 4.1, agricultural drainage wells are assessed to pose a high potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance may or may not allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. They are likely to be of poorer quality (relative to standards of the National Primary or Secondary Drinking Water Standards) than the fluids within any USDW in communication with the injection zone. Based on injectate characteristics and possibilities for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment in a region studied on a group/area basis.

The most serious threat to USDW from agricultural drainage wells is the potential for aquifer contamination from drainage waters carrying nutrients, pesticides, dissolved solids, pathogens, and metals. These contaminants can have serious health effects if introduced into drinking water supplies. The greatest concentration of soluble contaminants (nitrates, dissolved solids, and soluble pesticides) is introduced by subsurface return flows. On the other hand, surface return flows have the greatest potential of introducing suspended solids with associated contaminants and bacteria into ground water. Drainage waters injected into permeable zones may migrate horizontally rather than vertically. This contaminated water can be introduced into local water supply aquifers through uncased or improperly abandoned wells in the vicinity of the drainage well. Injected fluids also may migrate downward to the water table in the absence of impermeable layers. In addition, contaminated water also may be injected directly into aquifers which are used for local drinking water supplies.

Studies have shown that agricultural drainage wells present a very serious threat of ground-water contamination. In the State of Texas, chemical analyses of fluids injected into these drainage wells show the presence of contaminants above USEPA Safe Drinking Water Act standards with respect to TDS, sulfate, chloride, and nitrate. Also, a recent study by the California Assembly Office of Research found that almost 3,000 supply wells in California are contaminated by 57 different pesticides. At least 22 of the 57 pesticides have been traced to agricultural use (Ground Water Monitor, 1985). No agricultural drainage wells have been inventoried in California to date, however, these wells reportedly exist within the State. In Iowa, water wells located near clusters of agricultural drainage wells have shown nitrate contamination levels greater than USEPA maximum contaminant level standards. Concurrently, in the State of Idaho, the quality of water entering these wells was found to be over that State's drinking water standards for total coliform bacteria and sediment levels. According to a study by Graham and Leach (1979), excessive levels of indicator (total and fecal coliform) bacteria were found in domestic water supplies only during the irrigation season.

Current Regulatory Approach

Agricultural drainage wells are authorized by rule under the federally-administered UIC programs (see Section 1). Very few States regulate agricultural drainage wells as part of their UIC program. The primary reason for this is the lack of complete inventories and ground water contamination assessments for these wells. From the information received from the States to date, only eleven have adopted regulatory policies for these wells. In Oklahoma, the Industrial Waste Division requires registration of all Class V wells, including agricultural drainage wells.

Illinois, Nebraska, and Utah authorize all Class V wells by rule.

Only five States require permits for the construction and operation of these wells. Iowa requires a permit for any diversion of subsurface waters into an aquifer. This diversion permit is required for all agricultural drainage wells, both new and existing. In addition, Iowa's regulations also specify that the disposal of any pollutant, other than heat, in a well is prohibited. Thus, an owner/operator may construct and operate an agricultural drainage well only if he has obtained a diversion permit and has shown that the injection fluids do not contain any pollutants, other than heat. Idaho requires a permit to operate, modify, or construct a new Class V (a) well. In Idaho, Class V (a) wells inject primarily irrigation tailwater and highway runoff. Fluids injected into these wells must meet the State's drinking water standards at the point of injection. Arizona requires a Ground Water Quality Protection Permit for all land use "activities" which may involve disposal of wastes or pollutants causing ground water contamination. Owner/operators of such land use activities must submit a Notice of Disposal describing the site operations. If the operation is deemed to have no adverse effects on ground water, a permit will be issued. Agricultural land use is included in Arizona's definition of "activities." Thus, agricultural drainage wells are subject to this permitting requirement. Both New York and Florida require agricultural drainage wells to be permitted as part of an overall permitting requirement for Class V wells. Agricultural drainage wells have been banned in Georgia.

Recommendations

Currently, there is an undetermined number of agricultural drainage wells in existence in the United States. Several States (including PR, GA, IN, MI, MN, CO, and OR) acknowledge that obtaining the exact number of these wells is a difficult but necessary task. Therefore, each State should continue its research and work to improve its inventory efforts.

General guidelines suggested in State reports for protecting USDW in areas near agricultural drainage wells include:

1. Location and proper plugging of all abandoned wells within the immediate area of the agricultural drainage well (IA);

2. Requiring that fluids meet drinking water standards at the point of injection (NE, OR);

3. Requiring irrigation tailwater recovery and pumpback (OR);

4. Requiring a detailed map of the location of the injection well and all municipal, domestic, and stock wells within one mile of the injection well (NE);

5. Requiring a diagram of the injection well construction (NE);

6. Siting all ADW at least 2,000 feet from any stock, municipal, or domestic well (NE);

7. Closing surface inlets in order to allow infiltration through soil to decrease the transport of bacteria, some pesticides, and sediment to the aquifer (MO);

8. Raising the inlets above the maximum ponding levels (IA);

9. Reducing the volume of irrigation return flow by applying only the quantity of water necessary and only the amount of chemicals necessary to meet crop requirements and maintain the correct soil salt balance (CA); and

10. Discouraging use and encouraging elimination of ADW by developing alternative drainage methods (IA).

4.2.1.2 Storm Water and Industrial Drainage Wells (5D2,5D4)

Well Purpose

Municipalities with rapid growth rates and/or limited storm water sewer systems often experience storm water drainage problems. Increased paved areas can create storm water runoff volumes which overload existing drainage capacities. As a result, these municipalities operate and maintain storm water drainage wells (also called "dry" wells) to dispose of local runoff. In addition, in some municipalities, storm water drainage wells are used to manage runoff on construction sites and newly developed areas. Developers are required, through grading and drainage ordinances, to drain surface runoff on site within 36 hours. The surface runoff is usually drained to a retention area where storm water collects. Many developers use retention basins with drainage wells to dispose of runoff due to their relative low cost as compared to storm sewer systems.

Industrial drainage wells (5D4) are used to dispose of runoff on industrial properties. Commercial facilities [i.e., gas stations] which maintain drainage wells susceptible to chemical spillage are included in this classification. These wells drain storm water runoff and possibly, at times, chemicals from inadvertent spills or intentional discharges of industrial waste.

Inventory and Location

Storm water and industrial drainage wells have been reported in 38 States and Territories. Reported well totals are presented for each State and Territory in Tables 4-4 and 4-5. Well totals for individual States were obtained from State reports, FURS, verbal communication, and case studies sent by various States. Due to the multitude of drainage wells existing in several States, often only estimated well totals were supplied.

Geographical regions which have relatively large numbers of reported drainage wells are the West Coast, the eastern Great Lake States, New York, and Florida. States with over 5,000 reported drainage wells are Arizona, California, and Washington. Approximately 40,000-60,000 drainage wells are estimated to operate in Arizona.

Storm water and industrial drainage wells reportedly number about 90,000 in the United States and its Territories. Although the majority of these wells are storm water drainage wells, a larger percentage than reported of industrial drainage wells are believed to comprise the total.

Construction, Siting and Operation

Four typical well designs commonly are used in the construction of storm water and industrial drainage wells. These designs are shown in Figure 4-4. Drainage wells similar to designs 1, 3, and 4 are constructed in areas where loamy soils and permeable alluvial sands and gravels are prevalent. Drainage wells similar to that shown in design 2 are constructed where consolidated formations predominate.

Drainage wells resembling those shown in designs 1, 3, and 4 all function in a similar manner. These wells, however, have different operational features. In designs 1 and 4, storm runoff collects in one, or a series, of catch basins. Heavier sediments carried in the runoff settle to the bottom of each catch basin. After reaching a certain height in the basin, storm water drains into the injection well. This water flows through a filter screen (in design 4) within the drainage well and into a perforated pipe. As in design 3, storm water is then allowed to percolate through filter material (gravel or small rocks) and into the surrounding strata. In design 1, the catch basin and injection well essentially are consolidated into one drainage well. The upper compartment (a precast concrete vault) functions as a collection sump and sediment trap. When the collected water rises to a sufficient level in the upper compartment, it flows through a screened connecting pipe into the lower part of the well. This water subsequently is discharged through emplaced filter material and into surrounding permeable strata.

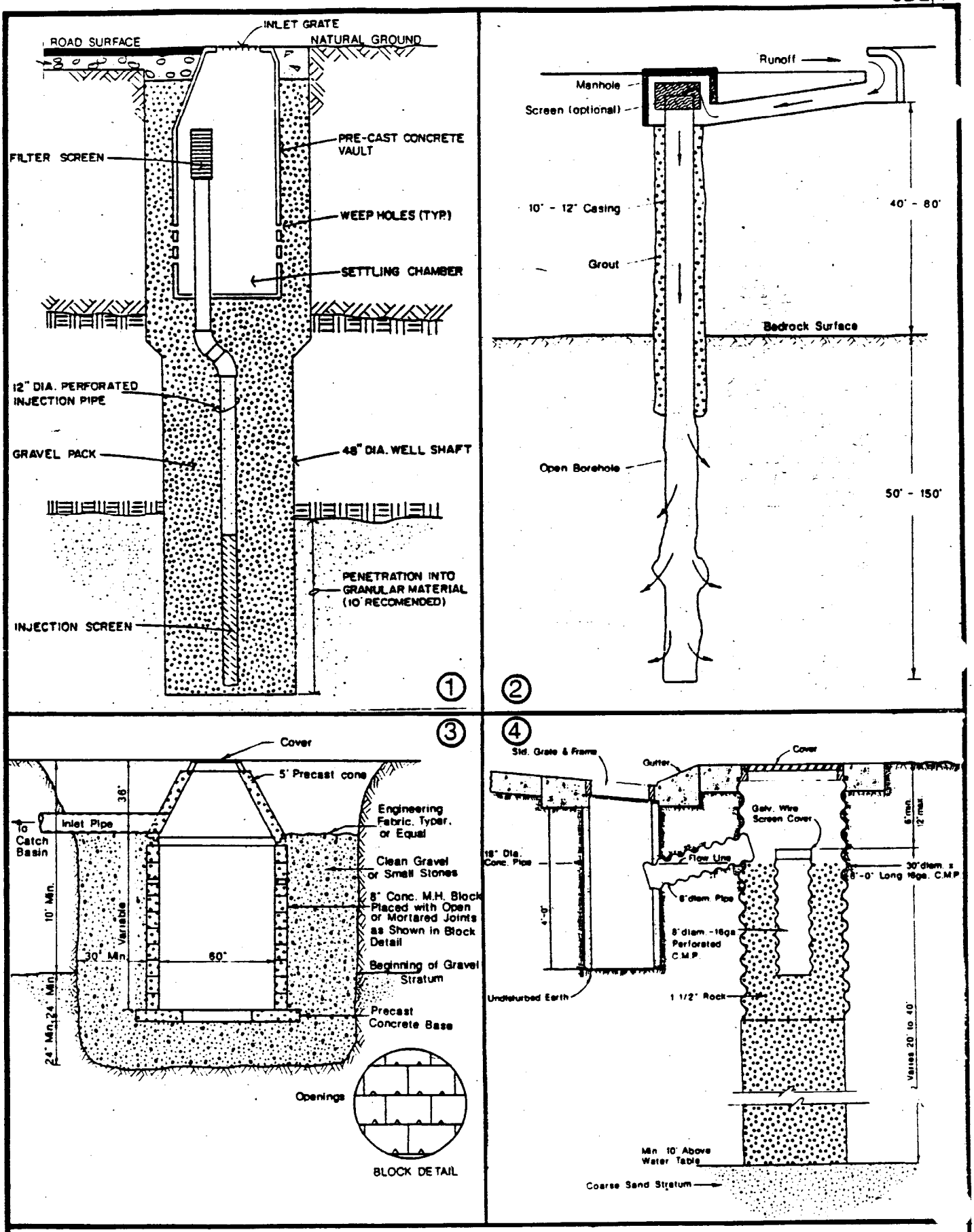
TABLE 4-4: SYNOPSIS OF STATE REPORTS FOR STORM WATER DRAINAGE WELLS(5D2)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	3 wells	PERMIT	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	19 WELLS	EXEMPT	YES	LOW
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	1 WELL	NJPDES PERMIT	NO	N/A
New York	II	2,500 WELLS	PERMIT>1K GPD	NO	POSITIVE
Puerto Rico	II	3 WELLS	N/A	YES	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	155 WELLS	N/A	NO	2ND HIGHEST/6 TYPES
Virginia	III	116 WELLS	N/A	YES	LOW
West Virginia	III	>2 WELLS	N/A	NO	HIGH
Alabama	IV	9 WELLS	PERMIT	NO	VARIABLE
Florida	IV	1,539 WELLS	PERMIT	YES	HIGHEST/8 TYPES
Georgia	IV	2 WELLS	BANNED	NO	NONE(PLUGGED)
Kentucky	IV	484 WELLS	LOCAL	YES	LOW
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	31 WELLS	PERMIT	YES	HIGHEST/3 TYPES
Tennessee	IV	7 WELLS	PERMIT	YES	N/A
Illinois	V	697 WELLS	RULE	YES	N/A
Indiana	V	2,180 WELLS	N/A	NO	N/A
Michigan	V	623 WELLS	N/A	NO	N/A
Minnesota	V	30 WELLS	N/A	NO	N/A
Ohio	V	1,341 WELLS	N/A	NO	HIGH
Wisconsin	V	116 WELLS	NONE	NO	UNKNOWN
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	5 WELLS	REGISTRATION	NO	LOW
Oklahoma	VI	YES	RULE	NO	N/A
Texas	VI	52 WELLS	N/A	NO	LOW
Iowa	VII	6 WELLS	N/A	NO	N/A
Kansas	VII	3 WELLS	N/A	NO	POSITIVE
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	1 WELL	RULE	NO	LOW
Colorado	VIII	2 WELLS	N/A	NO	LOW
Montana	VIII	4,500 WELLS	PERMIT	NO	HIGH
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	2,743 WELLS	RULE	NO	RANGE 2-5(7=HIGHEST)
Wyoming	VIII	5 WELLS	PERMIT	NO	3RD HIGHEST/10 TYPES
Arizona	IX	40K-60K WELLS	REGISTRATION	YES	MODERATE
California	IX	9,175 WELLS	RULE	YES	MODERATE
Hawaii	IX	129 WELLS	PERMIT	NO	MODERATE
Nevada	IX	15 WELLS	N/A	NO	MODERATE
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	164 WELLS	PERMIT	NO	LOW
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	66 WELLS	PERMIT	NO	HIGH
Idaho	X	1,165 WELLS	PERMIT>18 FT	YES	HIGHEST/14 TYPES
Oregon	X	776 WELLS	N/A	NO	N/A
Washington	X	14,903 WELLS	NONE	NO	MODERATE TO HIGH

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	16 WELLS	N/A	YES	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	1 WELL	NJPDES PERMIT	NO	N/A
New York	II	1,100 WELLS	PERMIT>1K GPD	NO	N/A
Puerto Rico	II	15 WELLS	N/A	YES	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	3 WELLS	PERMIT	YES	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	3 WELLS	N/A	NO	N/A
West Virginia	III	YES	N/A	NO	HIGH
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	YES	PERMIT	NO	HIGHEST/8 TYPES
Georgia	IV	2 WELLS	BANNED	NO	NONE(PLUGGED)
Kentucky	IV	YES	PERMIT	NO	LOW
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	47 WELLS	RULE	NO	N/A
Indiana	V	8 WELLS	N/A	NO	N/A
Michigan	V	9 WELLS	N/A	NO	N/A
Minnesota	V	8 WELLS	N/A	NO	N/A
Ohio	V	118 WELLS	N/A	NO	HIGH
Wisconsin	V	1 WELL	RULE	NO	LOW
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	5 WELLS	CLASS II	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	321 WELLS	RULE	NO	RANGE 3-7(7=HIGHEST)
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	YES	REGISTRATION	YES	MODERATE
California	IX	YES	RULE	NO	MODERATE
Hawaii	IX	4 WELLS	PERMIT	NO	MODERATE
Nevada	IX	YES	N/A	NO	MODERATE
American Samoa	II	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	II	NO	N/A	NO	N/A
Alaska	I	NO	N/A	NO	N/A
Idaho	I	NO	N/A	NO	N/A
Oregon	I	NO	N/A	NO	N/A
Washington	I	2,141 WELLS	NONE	NO	MODERATE TO HIGH

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



TYPICAL DRAINAGE WELL DESIGNS

(Drawing adapted from the City of Modesto, CA; McGukin Drilling; City of Crytstal Lake, IL; SMC Martin, Inc.)

Figure 4-4

Depths of storm water drainage wells similar to designs 1, 3, and 4 are dependent upon the regional depths to permeable soils and ground water. Reported depths generally range from 12 to 350 feet. Most wells are installed so that they penetrate at least 5 to 20 feet of permeable materials; this promotes increased drainage within each well. Theoretically, industrial and storm water drainage wells are completed to depths which are at least 10 feet above the underlying ground-water table. This allows the injected waters to be filtered by vadose zone soils before reaching ground water. Drainage wells similar to wells shown in designs 1 and 4 generally cannot dispose of storm water as fast as it falls on site. Parking lots, landscaped areas, and parks commonly are used as storm water retention facilities. These basins hold storm water prior to its injection into drainage wells.

Drainage wells constructed similarly to the well shown in design 2 generally are 40 to 400 feet deep. As previously noted, these wells are completed in consolidated strata. Ground water generally is injected through a filter screen and directly into underlying fractures in limestone, sandstone, or lava flows. Injected waters do not undergo further treatment before reaching the water table. Wells of this design in Virginia are reported to inject between 300 and 500 gallons per minute (gpm). Wells constructed similarly to design 2 comprise a small percentage of the drainage wells reported in the United States and its protectorates.

Injected Fluids and Injection Zone Interactions

Injection Fluids. Urban storm water runoff can acquire significant contaminant loads. Runoff may pick up contaminants from streets, roofs, landscaped areas, industrial areas and construction sites. Substances found in stormwater runoff include:

1. Herbicides; 2. Pesticides; 3. Fertilizers; 4. Deicing salts; 5. Asphaltic sediments; 6. Gasoline, grease, and oil; 7. Tar and residues from roofs and paving; 8. Rubber particulates (from automobile tires); 9. Liquid wastes and industrial solvents; and 10. Asbestos.

Literature values for contaminant concentrations detected in urban runoff are wide-ranging. These values are dependent upon numerous factors including the location of the sampling site, the sampling and analytical methods employed, and the frequency and duration of the precipitation event(s) sampled.

Storm Water Drainage Wells (5D2)

National research concerning the characterization of water quality in urban storm water runoff has been conducted. Storm water runoff entering conventional sewer collection systems and drainage basins has been sampled in cities across the nation. Because drainage wells are not as common as conventional systems, few sampling programs have sampled storm water as it enters storm water drainage wells (5D2).

The Nationwide Urban Runoff Program (NURP) was initiated by the United States Environmental Protection Agency in 1978. This program began in 28 cities to determine, among other objectives, the extent to which urban runoff contributes to regional water quality problems. Urban runoff entering conventional storm water collection systems was sampled. Several major conclusions from the NURP study were as follows (NURP, 1983):

1. Heavy metals (especially copper, lead, and zinc) are by far the most prevalent priority pollutants found in urban runoff. Metal concentrations in urban runoff samples exceeded USEPA's water quality criteria and drinking water standards numerous times.

2. Organic priority pollutants were detected less frequently and at lower concentrations than heavy metals. The most commonly found organic was the plasticizer bis (2-ethylhexyl) pthalate and the pesticide lindane.

3. Coliform bacteria are present at high levels in urban runoff. Median coliform counts for sampled sites are 21,000/100 ml in summer and 1,000/100 ml in the winter.

Other programs sampling storm water runoff injected by storm water drainage wells have been conducted in at least six states. A summary of the analytical findings produced from three of the sampling programs are presented below. Additional information regarding these and other sampling programs is listed in Appendix E.

SMC Martin Inc. - Roanoke, Virginia. Samples of storm water runoff entering 10 storm water drainage wells were collected in residential and commercial areas of Roanoke, Virginia. Runoff from an April precipitation event was sampled and analyzed for major inorganic elements, trace metals, phosphorous and organophosphates. Many of the parameters measured were well below National Primary and Secondary Drinking

Water Regulations. Iron and lead were the only constituents present in concentration above the national drinking water standards. Runoff constituents detected in smaller concentrations were phosphorous, nitrogen, trace metals (except iron and lead) and chlorides.

Geological Survey of Alabama, Alabama Dept. of Environmental Management - Muscle Shoals, Alabama. Urban runoff samples draining into 14 storm water drainage wells in Muscle Shoals, Alabama were collected in October, 1985 and March, 1986. These samples were analyzed for the presence of trihalo-methanes, herbicides, pesticides, and inorganic compounds. The turbidity and color of the drainage well injectates were also analyzed. Herbicides, pesticides, and volatile compounds were not detected. Except for high color and turbidity, the runoff samples chemically met state and national standards for drinking water supplies.

Maricopa Association of Governments - Phoenix, Arizona. This study monitored the seasonal variations of the chemical quality of storm water runoff. Runoff from a paved commercial site in Phoenix, Arizona, was analyzed for organic and inorganic constituents. Possible ground-water contaminants in winter storm runoff were lead, iron, manganese, and diazinon. Iron, lead, manganese, diazinon, and bis (2-ethyl) pthalate were found in summer storm water runoff. Iron, lead, and manganese concentrations were the only constituents found to exceed National Primary and Secondary Drinking Water Regulations.

Industrial Drainage Wells (5D4)

Surface runoff injected by industrial drainage wells can be similar in quality to runoff entering storm water drainage wells. A limited amount of evidence, however, suggests that storm water runoff in industrial areas is relatively poorer in quality. The Fresno, California, NURP project showed that industrial areas had the worst storm water runoff quality of the four land-use types evaluated. Of the 62 non-pesticide constituents monitored, 52 were statistically highest in industrial site runoff. These findings were roughly corroborated in Spokane, Washington, where a study was conducted to determine land use-related loading and the contaminant removal capacity of drainage wells. The Spokane findings showed that industrial and commercial sites clearly contributed greater quantities of total dissolved solids,

chemical oxygen demand, total nitrogen, lead, and zinc (Oregon, 1986). The overall NURP results, which summarized roughly three years of data from 28 projects nationwide, concluded that the geographic location and land-use category appear to be of little utility in predicting the characteristics of urban runoff from unmonitored sites. A recommendation for the further investigation of runoff in industrial areas was offered in the NURP final report.

Because of their siting, industrial drainage wells are susceptible to inadvertent chemical spills and illicit discharges. Among a variety of possible sources, accidental spills can result from chemical loading operations, pipelines, and storage tanks. Two cases of subsurface contamination resulting from industrial drainage wells have been reported. In Arizona, waste solvents from an overflowing storage tank were diluted with water and inadvertently flushed into a drainage well on site. Subsurface soils surrounding the tank pad were confirmed to be contaminated. A more extreme case of contamination was reported in Kansas. A diesel/tar mixture from a newly tarred roof washed into a drainage well during a rain. A nearby city water well was shut down as a result of the injected hydrocarbon mixture.

In summary, the following conclusions regarding drainage well injection fluids can be drawn:

1. Heavy metals such as lead, iron, and manganese frequently are found in urban runoff. Metal concentrations exceeding National Primary and Secondary Drinking Water Regulations are not uncommon.

2. Organic compounds have been found in urban runoff. However, concentrations detected generally are low, and constituents encountered are site dependent.

3. Fluids injected by industrial drainage wells are potentially poorer in quality than those injected by storm water drainage wells. Storm water, accidental chemical spills, and illicit discharges potentially can enter industrial drainage wells.

Injection Zone Interactions. The injection of fluids through drainage wells can occur in the vadose zone or in a saturated stratum. Research programs have been conducted in at least three States to study the attenuation and dilution of runoff contaminants in the injection zone. A summary of the findings of these research programs follows.

Spokane (WA) Water Quality Management Program - Spokane, Washington. In Spokane, Washington, runoff was sampled as it drained into a storm water drainage well. Ground water was sampled and analyzed 50 meters downgradient of the drainage well. The Spokane researcher determined that only 3 percent of the total injected contaminant load in runoff entered the ground-water system. The researcher also hypothesized that this load varied significantly with the density of drainage wells in the area.

University of Montana - Missoula Valley, Montana. Students attending the University of Montana have recently conducted a study in the Missoula Valley. Samples from several drainage wells, two ground-water monitoring wells, and depth discrete lysimeters were collected. These samples were analyzed to see if recharging urban runoff measurably affected the quality of underlying ground water. Ground water and lysimeter water quality data indicated that the vadose zone is effective in attenuating chloride, sodium, and potassium at shallow depths (0 to 15 feet). Percolating recharge water (runoff) appeared to pick up magnesium, sulfate, calcium, bicarbonate, and total dissolved solids as it moved through the vadose zone.

Maricopa Association of Governments - Phoenix, Arizona. Storm water runoff entering two drainage wells at a commercial site in Phoenix, Arizona was sampled. These wells directly injected storm water runoff into ground water below the site. Three monitoring wells were installed within 20 feet of the two drainage wells sampled. None of the potential contaminants identified in the injected runoff were detected in ground water sampled from the monitoring wells. Contaminants detected in the runoff as it entered the well included lead, iron, manganese, diazinon, Dacthal, and bis (2 ethyl) pthalate. The researcher attributed the apparent removal of contaminants to the settling of suspended contaminants in the drainage well and the subsequent filtration of runoff during its passage through saturated sediments.

U.S. Dept. of the Interior, University of Arizona - Tucson, Arizona. Five injection tests were conducted on an experimental dry well at a site near Tucson, Arizona. Simulated drainage waters containing metals, microorganisms, and organic matter were injected into the dry well. Several perched groundwater "tables" formed from the dry well injected fluids. Samples of laterally moving drainage waters were collected at a depth of 25 feet. These samples were withdrawn from a

monitoring well located approximately 40 feet from the dry well. Iron and lead concentrations detected in the laterally moving subsurface water were 40 percent and 20 percent (respectively) of the original concentrations injected. Microorganisms were found to be drastically reduced in laterally flowing water in the vadose zone. E-coli appeared to be attenuated to a lesser extent than fecal streptococci and the bacteriophage f2. Attenuation processes operating during lateral flow in the vadose zone apparently were not effective in preventing the migration of organics (Wilson, 1983). A decrease in total organic carbon (TOC) in later samples indicated that dilution was effective as an attenuation process.

The overall findings of these studies are inconclusive. Results from two sampling studies indicate that 0 to 3 percent of contaminants in urban runoff actually enter ground water. Filtration, adsorption, absorption, and ion exchange reactions are a few of the possible attenuating processes that may be occurring in the injection zone. Data from the University of Arizona study indicate that the attenuation of metals in laterally flowing drainage water (in the vadose zone) is 60 to 80 percent efficient. Fairly high concentrations of organic compounds in drainage well fluids were also detected in the vadose zone. Further research is needed to adequately define the injection zone interactions and prolonged effects of drainage well injectates on underlying ground water.

Hydrogeology and Water Use

Storm water and industrial drainage wells inject surface runoff into unconsolidated and consolidated deposits. The majority of reported drainage wells tap unconsolidated strata (i.e., gravel, sand). Drainage wells are completed in these permeable zones to maximize their drainage capacity. Injected waters percolate through these sediments until underlying ground water is encountered.

Thicknesses of permeable vadose zones lying between the bottom of drainage wells and ground water tables vary significantly. Reported thicknesses generally range from 0 - 350 feet. Thick vadose zones are desirable: injected runoff contaminants more likely are attenuated when sorptive surface areas and filtering media are maximized.

Impervious layers (i.e., silt) underlying injection wells can cause the formation of perched water. Injected waters can also collect above impervious layers and begin to migrate laterally. These runoff waters will continue to laterally migrate until a discontinuity in the retarding layer is encoun-

tered. Upon reaching this discontinuity, injected waters will continue to migrate vertically. In this manner, underlying ground water sources located upgradient or downgradient of a drainage well potentially can be affected.

Drainage wells also are constructed in consolidated formations. Such wells have been reported in Alabama, Virginia, and Kentucky. These wells usually are completed in limestone bedrock. Drainage wells intercept solution channels in the underlying bedrock thereby providing a passage for injected drainage fluids to drain into the subsurface. Drainage capacities of these subsurface networks are known to approach 600 gpm in certain regions. These channels can be quite extensive and often are connected with the underlying aquifer system. Contaminants in surface runoff are not attenuated under these subsurface environments.

Many drainage wells reported in the United States and its Territories inject storm water runoff into or above USDW. The current and potential uses of these aquifers are variable. USDW currently used for municipal and domestic drinking water supplies reportedly underlie many drainage wells in operation. Cities accessing ground water in these areas, however, may pump ground water from deeper zones which are hydraulically separate from shallower water-bearing aquifers. Three sole source aquifers (as designated by the USEPA) are reported to underlie operating drainage wells. These aquifers are located in Fresno, California, Idaho, and Washington. In several sections of the country, researchers noted that ground water was of poorer quality than injected surface runoff.

Contamination Potential

Based on the rating system described in Section 4.1, storm water drainage wells and industrial drainage wells are assessed to pose a moderate potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. The fluid may be of poorer quality, relative to standards of the National Primary or Secondary Drinking Water Regulations or RCRA Regulations, than the fluids within any USDW in communication with the injection zone. Alternatively, they may be of equivalent or better quality, relative to these parameters, than the fluids within any USDW in connection with the injection zone. Based on injectate characteristics and possibilities for attenuation and dilution, injection does not occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation

parameters in ground water, or endanger human health or the environment beyond facility perimeters or in a region studied on a group/area basis.

Storm Water Drainage Wells (5D2). The majority of storm water drainage wells have been reported to inject surface runoff above USDW. In a number of areas (i.e., Modesto, California, and Phoenix, Arizona) storm water drainage wells have been reported to inject directly into an USDW. In many cases, shallow aquifers potentially affected by storm water injectates are hydraulically connected to aquifers currently used as drinking water supplies. Drainage wells therefore can be considered to inject fluids above an USDW of Class IIB or better quality.

Storm water runoff has been sampled extensively in the Nationwide Urban Runoff Program (NURP) and in a number of drainage well sampling projects. Metal contaminants, especially lead and iron, have been shown to be concentrated in runoff at levels exceeding National Primary and Secondary Drinking Water Regulations. These metals typically are present as suspended particles and dissolved ions in solution. The efficiency of storm water drainage wells to filter suspended metals in runoff (prior to injection) has not been documented. These wells therefore are assumed to inject concentrations of metals similar to those detected in typical drainage well influent.

Contamination studies to date have not conclusively shown that area-wide degradation of ground water quality has resulted from drainage well injection operations. Therefore, it cannot be confidently asserted that injection occurs in sufficient volumes to degrade ground-water quality on an area-wide basis. These wells, therefore, are judged to pose a moderate contamination threat to USDW.

Drainage wells judged to pose the highest relative potential to contaminate USDW are those wells which 1) inject surface runoff directly into an USDW or 2) are completed in bedrock and inject runoff into solution channels within the formation. In either case, suspended metals in the runoff have no opportunity to be filtered by subsurface sediments before reaching ground water.

Industrial Drainage Wells (5D4). As with storm water drainage wells, industrial drainage wells are also reported to overlie USDW. A number of these USDW are believed to be hydraulically continuous with underlying drinking water supply aquifers. Injection from industrial drainage wells, therefore, can be considered to inject fluids above an USDW of Class IIB or better quality.

A limited number of studies have attempted to specifically characterize the quality of storm water runoff in industrial areas. As previously discussed, industrial runoff was sampled and analyzed in Fresno, California, and Spokane, Washington. Results from both studies indicated that storm water runoff in industrial areas was of poorer quality than runoff sampled in commercial and residential areas. Industrial runoff typically contained concentrations of trace metals above National Primary and Secondary Drinking Water Regulations. Organic contaminants also were reported to be more commonly detected in industrial runoff (Fresno NURP Project). Inadvertent spills (similar to the cases documented in Kansas and Arizona) also may occur, resulting in the injection of hazardous chemicals into industrial drainage wells. Ground-water contamination beyond the facility perimeter resulting from industrial drainage wells has not been documented. In both cases cited above, contamination was not shown to migrate off site.

Although both drainage well types (5D2 and 5D4) are assessed to moderately endanger USDW, industrial drainage wells pose a greater threat of contamination. This is largely attributable to their 1) poorer quality injection fluids, 2) susceptibility to accidental industrial spills, and 3) availability for abuse through illicit discharges.

Current Regulatory Approach

Storm water and industrial drainage wells are authorized by rule under the Federally-administered UIC programs (see Section 1). Some States and most counties and municipalities with concentrations of storm water and industrial drainage wells regulate these wells. Limited amounts of regulatory information were provided in the State reports. General regulatory approaches taken by the responding States and their municipalities are discussed below.

Some States manage industrial and storm water drainage wells with "blanket regulations." These regulations are broad in scope and generally are applicable to all Class V wells. States using this approach enforce legislation created as a result of the Safe Drinking Water Act or State Administrative Codes. Persons proposing to construct drainage wells are required to obtain general discharge permits. Drainage well permits are granted if wells are not considered to be an endangerment to ground-water quality. States identified to adopt regulatory approaches similar to the one described above include New York, Wyoming, Alabama, Florida, portions of California, and the island of Guam.

A limited number of States reportedly administer State-wide storm water and industrial drainage well programs. Reporting, siting, and construction requirements for drainage wells are enforced by these States. Siting criteria usually include provisions for minimum horizontal setback distances from water supply wells or other wells and separation distances between the bottom of the drainage well and a saturated stratum. Restrictions regarding the type of strata which must lie between the drainage well and an underground source of drinking water also are enforced. Oregon and Arizona are two states known to have drainage well regulations similar to the type described above.

Many counties and municipalities which use drainage wells have and enforce drainage well policies. In most cases, county and municipal regulations are administered to ensure the proper operation of drainage wells. City engineers/inspectors often are called upon to perform percolation tests and inspect drainage plans prior to well construction. Environmentally-related regulations pertaining to drainage wells also are adopted by some local governments. These include minimum setback requirements, depth requirements, and zoning restrictions. Localities banning the construction of storm water or industrial drainage wells include: Fresno, California; Chico, California; southern and central sections of Florida; Georgia; and Tucson, Arizona.

In many instances Federal, State, and local regulations regarding storm water and industrial drainage wells overlap. States usually issue permits for drainage wells but allow local governments or agencies to regulate them. States, however, may directly intervene in the regulatory process. This is most probable where local governments do not enforce requirements equivalent to or stricter than State regulations.

Recommendations

Technical recommendations were offered in some State reports for storm water and industrial drainage wells:

1. New wells should be investigated and added to FURS (KY, UT, WA)

2. The construction of new industrial drainage wells should be severely limited (OR, IL). Storm water sewers, detention ponds, or vegetative basins are the preferred alternatives (UT). If sewers are cost prohibitive, on-site vegetated basins with fine-grained sand beds should be constructed (Grass swales have been discovered in the NURP study to provide moderate improvements in runoff quality).

3. Retention basins might be planned so runoff can be released slowly into the sanitary sewer or treated before entering the well (KY, TN).

4. Sand and gravel filters should be added to wells (KY, TN).

5. Limit future construction to residential areas (IL).

6. Stand pipes should be constructed, several feet in height, at the opening of wells (KY, TN).

7. All spills should be diverted away from industrial drainage wells (OR, UT, WA).

8. The new construction of storm water and industrial drainage wells in areas served by storm water sewers should be prohibited (CA, AZ).

9. Drainage wells should not be constructed within 200 feet of water supply wells which tap lower water-bearing aquifers (CA).

10. Deep wells should be plugged or cemented to avoid mixing between aquifers (KY, TN).

11. Depth to ground water information should be made readily available to drainage well drillers and land planning engineers. Separation distances between the depths of storm water drainage wells and ground water tables should be maximized. Proposed wells which would penetrate perched ground water or water tables should not be constructed (AZ).

12. Additional research should be conducted to study the prolonged effect of industrial drainage wells on ground water quality. Additional research relating to the attenuation of metals and organics under long term discharge conditions from industrial and storm water drainage wells should be conducted (States in Region VIII).

13. Ground-water monitoring programs in industrial areas with many industrial drainage wells are advisable (FL, WI, KS).

14. Sediments extracted from drainage wells, catch basins, or sediment traps should be disposed in an appropriate landfill. Due to possible metal concentrations, these sediments may be considered as hazardous materials (AZ).

15. Assessment of the effects of drainage wells should be conducted prior to completing an inventory because the inventory would be time-consuming and costly (MT, OR).

16. A public awareness program should be implemented (AZ).

17. Drainage wells should be identified and plugged within the shortest possible time frame (WV).

4.2.1.3 Improved Sinkholes (5D3)

Improved sinkholes are natural surface depressions that have been modified or altered by man for purposes of directing fluids into the hole opening. Sinkholes typically form in limestone or dolomite karst regions -- areas exemplified by irregular and "pitted" topography with features such as caverns, swallets, and springs. In general, sinkholes are the result of physical weathering of unconsolidated materials along bedding planes and fractures, and of chemical dissolution of soluble rock formations. Rock types susceptible to sinkhole formation are limestones and dolomites. Both rock types are composed principally of calcium and magnesium carbonate and will dissolve readily under the influence of chemical dissolution. Carbonic acid (the weak acid formed when carbon dioxide dissolves in rain water) and organic acids (formed during the decay of organic matter) increase the acidity of ground water and begin or accelerate the dissolution of the rock.

Chemical dissolution acts to enlarge the void spaces created by physical weathering. The spaces are progressively widened and integrated to form channels which allow for increased ground-water circulation and further dissolution. Eventually, if enough material is washed away, a cavity may develop. The cavity can evolve into a sinkhole if the weathering process undermines the support base such that it can no longer support the roof materials above and collapse occurs.

Sinkholes may be only a few feet in diameter and depth, or they may be many tens or hundreds of feet in diameter and depth. The size attained is controlled principally by the depth to the ground-water level and the kind of support from the remaining limestone or dolomite rocks.

Sinkholes, for their impressive ability to accept large volumes of water, have for years been popular disposal sites for many different types of undesirable wastes, most notably sewage. However, states have vigorously sought to eliminate them as disposal points for sewage. Improved sinkholes today are most likely to receive partially treated domestic wastewater indirectly from the overflow of overloaded septic tank and drainfield systems. Sinkholes remain, however, popular in many areas for the disposal of storm runoff. In Kentucky, for example, permits are issued for drilling into underground channels and caverns in Karst topography in order to reduce surface flooding during heavy rains.

Well Purpose

Improved sinkholes, for the purpose of classification of Class V wells, are sinkholes for which work has been done to increase the amount of fluids they are required to handle; to increase their capacity to handle fluids; or to preserve their capacity to handle fluids. This includes, but is not limited to, channels or pipes installed to direct or accelerate flow to the sinkhole; excavation to enlarge the sinkhole or remove obstructions from the opening; and the installation of casing within the sinkhole or periodic removal of vegetation, debris, etc. from the sinkhole in order to maintain capacity.

Improved sinkholes are used to dispose of storm water runoff from housing and other developments located in karst topographic areas. If located away from the development, the sinkhole may have been improved by channels or pipelines to direct the water to it. If located within the development, the sinkhole may have been "improved" by installing casing (possibly with a grill or screen over it to prevent clogging by debris) and a concrete slab and/or wall around it.

Inventory and Location

Improved sinkholes are limited to those areas where the geology and hydrogeology are favorable for their development. Wherever limestone and dolomite formations exist near or at the surface and where the geologic history has allowed solution channels and cavities to develop in the rock, sinkholes are possible.

Georgia, Indiana, Kentucky, Michigan, Minnesota, Missouri, New Hampshire, Pennsylvania, Puerto Rico, and Tennessee have reported numbers of improved sinkholes. Florida, Ohio, Virginia, and West Virginia confirm their existence, but have not yet provided a number.

The bulk of reported improved sinkholes are in Missouri (250) and Michigan (103), while Indiana reports 26; however, the numbers for many States are still very preliminary. This particular category has received little attention in the past. Accurate records are lacking.

Table 4-6 is a synopsis of information on improved sinkholes from the State reports.

Construction, Siting, and Operation

Construction. Improved sinkhole wells are, for the most part, quite simple. The fact that they are always in Karst limestone geology means that there is usually no need for a well screen within the borehole. The most common "improvement" to a sinkhole is the construction of channels, grading, or laying of pipe to direct surface runoff to the sinkhole. The second most common improvement is the installation of a piece of steel casing in the throat of the sinkhole (to prevent materials and objects from falling in). Depending on the location, some kind of protection screen, grill, or grating may be mounted on top of the casing; or if a casing is not installed, a concrete box with removable grating (for cleaning) may be constructed around and over the sinkhole (Figure 4-5). In general, construction features are dictated by two considerations: (1) the need to get the storm runoff to and into the sinkhole at the rate required; and (2) the need to keep the underground network of conduits free of materials that could plug the sinkhole.

In some areas - notably in Kentucky - drilling machines are used to drill out through the bottom of sinkholes in search of deeper fractures, channels and cavities capable of handling increased volumes of water.

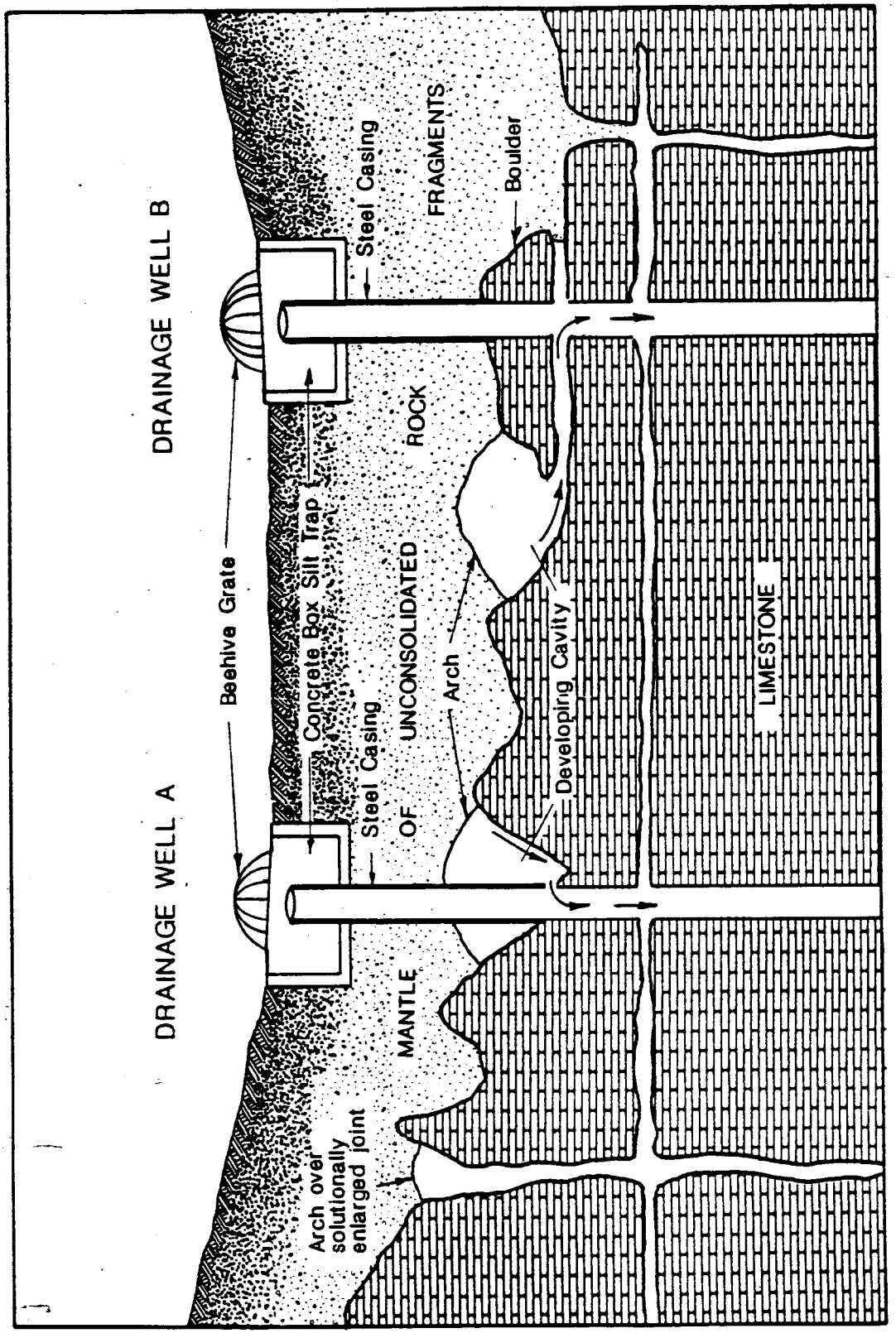
Finally, the owner may opt to pave an area (usually of concrete) around the entrance to the sinkhole, or fence it in.

Siting. In most cases, improved sinkholes have been sited by nature; the owner merely takes advantage of the sinkhole's proven ability to drain storm runoff. It is, however, feasible to drill into sinkhole areas that are mere depressions where water collects during a storm and then infiltrates the soils to the deeper limestones. This option may be taken where the only open sinkholes lie at some distance from the area to be drained, or where they are situated on the land of someone who objects to their use by others.

TABLE 4-6: SYNOPSIS OF STATE REPORTS FOR IMPROVED SINKHOLES(503)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	3 WELLS	N/A	YES	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	10 WELLS	PERMIT	YES	MODERATE TO HIGH
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	YES	N/A	NO	N/A
West Virginia	III	YES	N/A	NO	HIGH
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	YES	PERMIT	NO	HIGHEST/8 TYPES
Georgia	IV	NO	BANNED	NO	N/A
Kentucky	IV	76 WELLS	LOCAL	YES	LOW
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	5 WELLS	PERMIT	YES	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	26 WELLS	NONE	NO	N/A
Michigan	V	103 WELLS	NONE	NO	N/A
Minnesota	V	6 WELLS	NONE	NO	N/A
Ohio	V	YES	NONE	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	250 WELLS	NONE	YES	POSSIBLE
Nebraska	VII	NO	N/A	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	N/A	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



Hypothesized development of arches under and near drainage wells.

Water flows out of drainage well A along a crack where the casing is resting on bedrock and saturates the surrounding mantle. As the water level in the well drops below the crack, channeling of saturated mantle into the well creates an arch.

Drainage well B was only cased to a boulder above bedrock. During floods, as water flows from the perched water above the bedrock into the well, channeling creates an arch.

SINKHOLE DEVELOPMENT
NEAR IMPROVED SINKHOLES

(adapted from "Storm Water Drainage Wells in the Karst Areas of Kentucky and Tennessee." N.C. Crawford & C.G. Groves, Western Kentucky Univ. Bowling Green, KY., Sept., 1984)

Figure 4-5

Operation. In operating improved sinkholes, the owner/operator may need to conduct periodic investigations to detect the possibility of tendencies for other sinkholes to develop in the vicinity (Figure 4-5). Maintenance is required where debris collects on the screen or grating at the entrance.

Injected Fluids and Injection Zone Interactions

The quality of water reaching a sinkhole from storm runoff in non-industrial areas has not received the attention it probably deserves. Now there is a growing awareness that runoff from paved areas may contain lead and petroleum products from the operation of motor vehicles, a wide variety of pesticides from horticulture and lawn care, nitrates from garden and lawn fertilizing, and fecal material from wild and domestic animals and birds. In addition, in areas where air pollution occurs, the normal fallout of air pollutants may add significant amounts of contaminants to the runoff.

Paved areas provide virtually no attenuation of pollutants; the pollutants are swept rapidly along the paved surfaces to the sinkhole without any opportunity for filtration by soils or chemical reaction with clays and other minerals.

Acid rain conditions prevailing in some parts of the country may increase the solubility of heavy toxic metals such as lead, mercury, and cadmium. Acidity of the water should in time be neutralized by the limestones, but with the high rates of runoff associated with many storms these pollutants can be carried great distances through underground channels before the neutralizing action has had time to take place.

The presence of carbon dioxide in rain water (carbonic acid) and any acid rain present will in time enlarge the channels in the limestone through which it flows. The limestone rock is literally dissolved. Rate of solution is proportional to acidity of the water, its velocity through the rock, and the length of time the water is in contact with the rock.

There is also a physical effect of storm water on underground sediments. It is not unusual for a newly improved sinkhole to induce the development of additional sinkholes nearby as a result of surges of storm water within the channels. Alternate inundation and draining of deposits of unconsolidated sands, silts and clays in the vicinity washes away these supporting materials, causing the overburden to collapse into the empty space.

Hydrogeology and Water Use

The limestone and dolomite formations where sinkholes form are in communication with ground water under "water table" conditions. That is to say, the surface of the body of ground water is at atmospheric pressure and is exposed to the atmosphere. Water running into sinkholes moves rapidly downward through the networks of solution channels, fractures, and cavities to become a part of the water table aquifer. The probability that the water table aquifer is to some degree contaminated by surface water is therefore very high.

Pollutants, on arrival at the surface of the water table, move horizontally downgradient, but with some mixing with the ground water. As a result, a degree of protection may be obtained by casing water supply wells to depths well below the lowest ground water. Wisconsin well construction codes require this kind of defense when such ground water constitutes the only usable source of water supply. If geological conditions permit, completely enveloping the casing in a sheath of cement greatly adds to the security and the longevity of the well. In any case, it is considered good practice to chlorinate water withdrawn from such aquifers.

Contamination Potential

Based on the rating system described in Section 4.1, improved sinkholes are assessed to pose a high to moderate potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. The fluids may exhibit characteristics or contain constituents listed as hazardous as stated in the RCRA Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection may occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond facility perimeters or in a region studied on a group/area basis.

Improved sinkholes that drain only non-industrialized developments may constitute significant threats, as the runoff water may contain lead, petroleum products, pesticides, fertilizers, excrement from wild and domestic animals and birds, and, in certain areas, other contaminants from air pollution. Injectate fluid quality can be poor when the drainage area is industrialized or when sewage (Sections 4.2.3.1 and 4.2.3.2) or indus-

trial wastes (Section 4.2.6.2) are injected. Because volumes (sometimes large) are injected through and into channeled and fractured limestone or dolomite, filtration or other attenuative processes are not provided. Therefore, degradation of the local or regional USDW can occur if injection fluid quality is poor.

Current Regulatory Approach

Improved sinkholes are limited to those states with Karst limestone and dolomite formations. Twelve States (including Puerto Rico) have acknowledged having at least one. Since this is a category of well that has not generally been regulated or even registered, it is possible that other States also have them. Improved sinkholes are authorized by rule under Federally-administered UIC programs (see Section 1).

Florida. Florida has not distinguished between improved sinkholes and other drainage wells. The total of all wells in this general category is reported to be 1,539. It is probably safe to assume there are many improved sinkholes. Since these wells do not receive separate recognition in Florida, it may be assumed that they require permits just as the other drainage wells do. These would be issued by the Florida Department of Environmental Regulation (FDER), Division of Environmental Permitting. Most permits are issued without input from the Division of Environmental Programs in Tallahassee, by the district offices.

Missouri. The Missouri Department of Natural Resources manages the State's UIC program. It does not appear that the State issues permits for type 5D3 wells. Nor is there evidence that local governments control these discharges.

Michigan. Permits for discharge to 5D3 wells are issued by the State's Department of Natural Resources (DNR), Groundwater Discharge Permit Section. The section reviews permit applications which subsequently are approved or denied by the Water Resources Commission. Of the 83 county health departments in Michigan, about 52 have developed their own permit programs for various well types, including dry wells.

Indiana. The Stream Pollution Control Board is responsible for the regulation and control of water pollution in Indiana. However, specifically exempted from this control are "discharges composed entirely of storm runoff when uncontaminated by any industrial, commercial, or agricultural activity." From this it would appear that Type 5D3 wells in general do not require permits.

Puerto Rico. The Environmental Quality Board (EQB) is the agency of the Commonwealth of Puerto Rico responsible for regulating and permitting Class V wells. Applicants are required to complete a several-page application form providing details on the source of water, water quality, number and location of wells (sinkholes), etc. In some cases the EQB will specify a sampling/monitoring program that must be followed, with results reported periodically to EQB.

Other States. Information on regulation and permitting of 5D3 wells in other States indicating the existence of such wells is not yet available in sufficient detail to determine whether they have systems in place for this category of injection well.

Recommendations

Siting. No recommendations were given for siting improved sinkholes. The potential to contaminate USDW is inherent to the nature of the well type and the hydrogeologic conditions in which it is sited.

Construction. In the Puerto Rico report, the recommendation was made to require training for engineers and drillers in the proper construction of wells, with special emphasis on sanitary sealing and protection against corrosion. It further recommended that training be slanted toward construction in Karst or limestone formations.

Operation. Improved sinkholes do not require operation. They may require maintenance to prevent plugging of the underground network of channels.

A recommendation in the Missouri report suggested that careful dye trace studies be run on any existing or planned improved sinkhole drainage systems, and occasional monitoring of both entering and exiting fluids be run after the system is in operation. Dye tracing could be used to identify areas downgradient that would be affected in the event of a potentially harmful discharge into an improved sinkhole.

Corrective or Remedial Actions. Remedial actions would be called for if it were revealed that a significant discharge of toxic materials or sewage was being swept into the well.

It is possible that in some areas it may be advisable to prohibit the deepening of such wells so as to avoid exposing deeper, usable aquifers to contamination.

4.2.1.4 Special Drainage Wells (5G30)

Well Purpose

Special drainage wells are used to inject drainage fluids from sources other than direct precipitation. Some of these sources identified to date include:

1. Pump control valve discharges and potable water tank overflow discharges;
2. Land slide control;
3. Swimming pools;
4. Municipal and construction dewatering.

This well type does not include agricultural drainage wells, storm water and industrial drainage wells, or improved sinkholes as they are separately classified and discussed in the previous sections. Special drainage wells are classified as Class V wells under 40 CFR 146.5(e).

With the exception of swimming pool drainage wells, special drainage wells are viewed as wells that are installed for convenience of drainage according to their specific functions. However, these wells are classified as injection wells since the wells receive fluids that are in turn injected to the subsurface.

Inventory and Location

Inventories conducted in six States revealed the following types and numbers of special drainage wells:

State	Well Purpose	Well(s)
Idaho	Potable Water Tank Overflow Drainage	7
Montana	Landslide Control Drainage	55
Florida	Swimming Pool Water Drainage	1,385
Hawaii	Swimming Pool Water Drainage	1
Washington	Drainage of Water Associated with Municipal Dewatering	108
Louisiana	Unclassified Special Drainage	1

Table 4-7 provides a synopsis of information on these wells from the State reports.

The State of Idaho has reported the presence of 7 special drainage wells that receive water from water tank overflow systems and municipal pump check valve systems. Of these seven wells, three deep wells are used at municipal water supply pump stations and are located in the cities of Shoshone, Kimberly, and Moscow. Four shallow wells are used for the disposal of pump leakage at the Idaho National Engineering Laboratory.

The State of Montana Department of Highways has constructed 55 landslide control drainage wells in the central and western parts of the State. The wells are located at three sites: U.S. Route 15 near Craig in western Montana (20 wells); U.S. Route 15 south of Dillon in southwestern Montana (15 wells); and Route 238 south of Leviston in central Montana (20 wells).

The State of Florida Department of Environmental Regulations has listed 1,384 swimming pool drainage wells based on the Department's Groundwater Management System (GMS) database. As many as 96% of these wells are located in Dade County, and 3.5% in Palm Beach County (Figure 4-6). Pinellas County reports the presence of two special drainage wells. Information for some of these wells was verified through a questionnaire survey which was mailed to a random number of pool owners, both public and private. The response to the questionnaire survey aided in obtaining additional information on construction features, although only 31% responded.

The State of Hawaii reports one swimming pool drainage well on the island of Oahu. Numbers of known wells of this type are expected to increase in Hawaii as a result of future inventory efforts.

Washington's report to USEPA on the inventory of Class V wells reported the presence of 106 municipal dewatering wells. Most of these wells were installed at the Chamber Creek Interceptor Tunnel in Tacoma, Washington and have been pulled out and plugged as the tunnel construction phase has been completed. However, according to Mr. L. Goldstein of the Washington Department of Ecology (1987), 62 new wells have been installed at the Bangor Submarine Base.

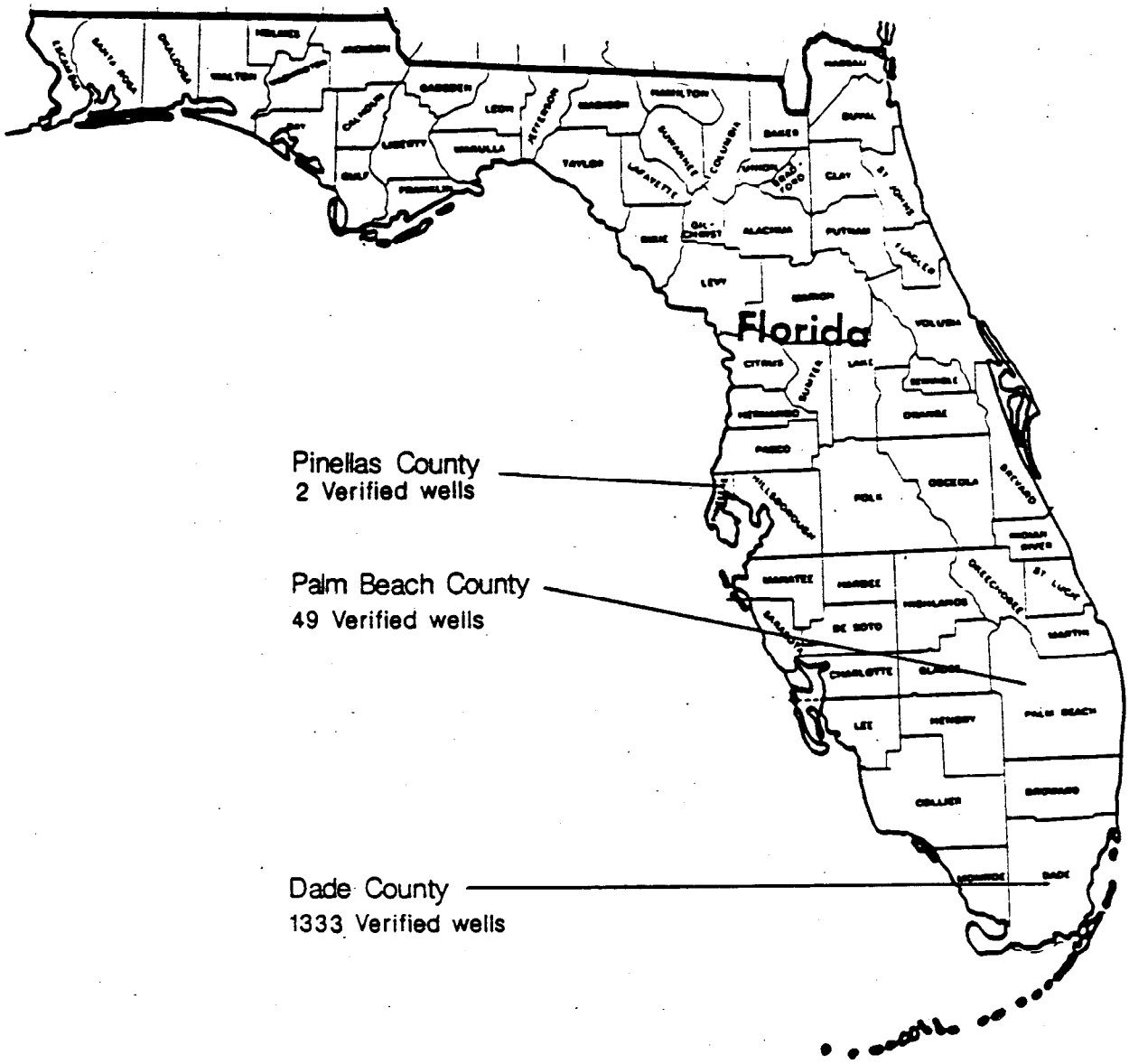
One special drainage well type was mentioned in the report from Louisiana. However, the report did not contain any details on this well type.

As many as 1,557 special drainage wells have been inventoried by the six States. However, it is important to note that special drainage wells with similar well purposes may be in use in other States. There is a strong possibility that many

TABLE 4-7: SYNOPSIS OF STATE REPORTS FOR SPECIAL DRAINAGE WELLS(5G30)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	1,385 WELLS	PERMIT/RULE	YES	LOW
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	1 WELL	CLASS II	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	55 WELLS	PERMIT	YES	LOW
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	N/A	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	1 WELL	PERMIT	NO	UNKNOWN
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	7 WELLS	PERMIT>18 FT	YES	LOWEST/14 TYPES
Oregon	X	NO	N/A	NO	N/A
Washington	X	108 WELLS	N/A	YES	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



MAP OF FLORIDA SHOWING THE LOCATION OF CLASS V SWIMMING POOL DRAINAGE WELLS

(from FDER files, 1986)

Figure 4-6

States may have overlooked this well type or even classified these wells under a different well type. On the other hand, some of these well types may be only found in specific States. For instance, in the state of Montana, special drainage wells are used to combat landslides along highways. No other States have reported use of this procedure to correct landslide problems.

Although landslide control drainage wells only have been inventoried in Montana, they may be found in other areas prone to landslides. A review of available literature suggests additional areas that may have these special drainage wells. Woods, Berry and Goetz (1960), mention some landslide-prone areas and the severity of the landslides. Figure 4-7 and Table 4-8 offer general descriptions of landslide severity by physiographic provinces, while Table 4-9 lists some of the geologic formations which are susceptible to landslides. It is important to note that this data may be incomplete. Also, the list does not imply that special drainage wells are used in all the areas that have the highest rating. In fact, some landslide-prone areas may employ other methods of landslide control such as relocation, bridging, excavating, restoring structures, stabilization with admixtures, blasting, etc. It is evident that in Montana landslide control drainage wells are located in the Northern Rocky Mountains, an area which has a high severity rating as indicated in Table 4-8.

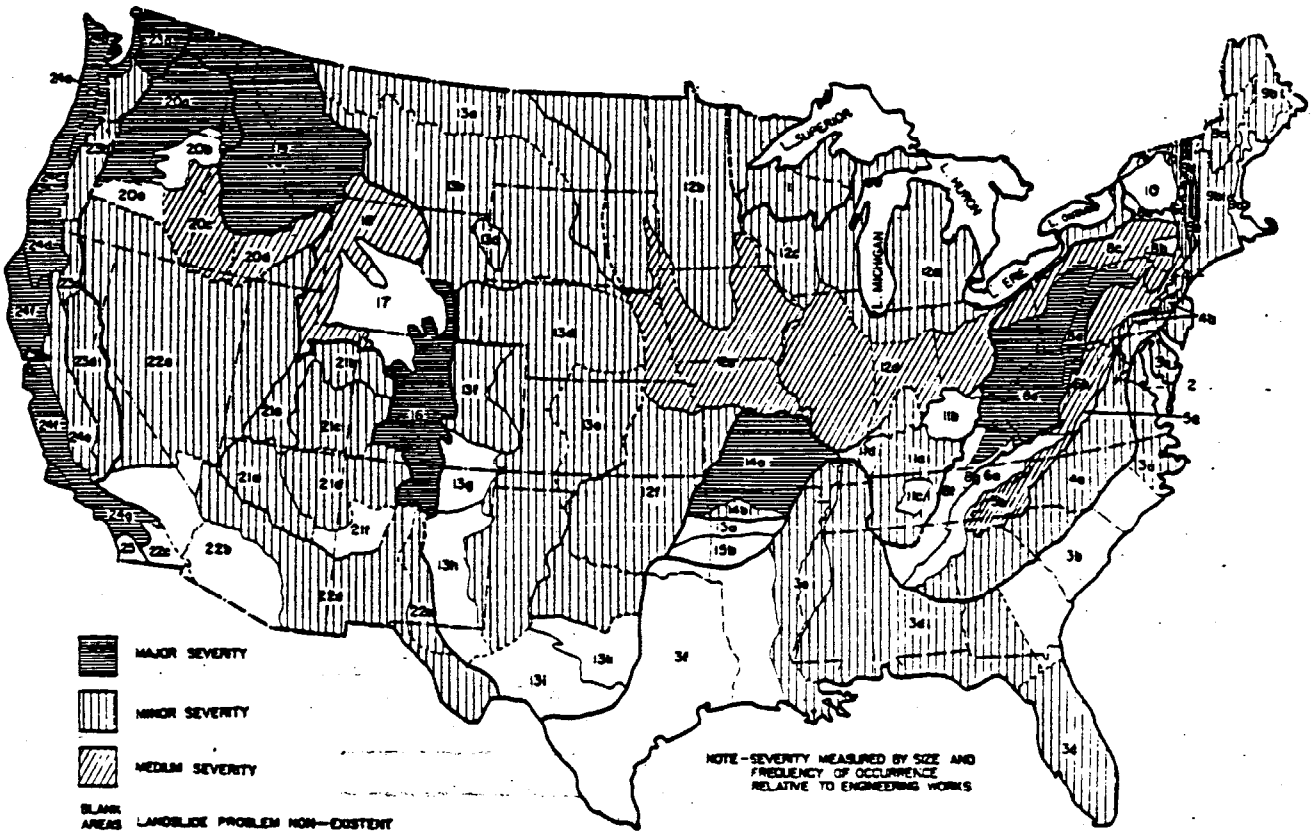
Well Construction, Operation, and Siting

Since special drainage wells have specific functions and features, the construction, operation, and siting for each of these well types is discussed under separate subheadings.

Water Tank Overflow Drainage Wells. The State of Idaho reported use of seven special drainage wells that inject water from two sources: water tank overflow systems and municipal pump check valve systems. Potable water from these sources is drained to the subsurface periodically (mostly due to emergency overflow or bypass) at depths ranging from less than 18 ft up to 100 to 667 ft below the surface.

The three deep wells, with depths ranging from 100 to 667 ft, are used to drain pump control valve discharges and water tank overflows at municipal water supply pump stations. The deep well in Shoshone injects above the underlying aquifer, while the wells in Kimberly and Moscow inject directly into drinking water sources. The rates of injection are reported to approach 800 gpm for short periods of time.

The four shallow wells, with depths less than or equal to 18 feet, are used to drain pump control valve discharges. The wells inject above the underlying aquifer. Two wells inject less than



LANDSLIDE SEVERITY OF THE UNITED STATES

(Courtesy of Highway Research Board)

Figure 4- 7

TABLE 4-8 RATING OF LANDSLIDE SEVERITY

I. *Major severity*
- 8d. Allegheny Mountain Section
- 8e. Kanawha Section
- 14a. Springfield-Salem Plateaus
- 16. Southern Rocky Mountains
- 19. Northern Rocky Mountains
- 20a. Walla Walla Plateau
- 23a. Northern Cascade Mountains
- 24a. Puget Trough
- 24b. Olympic Mountains
- 24c. Oregon Coast Range
- 24d. Klamath Mountains
- 24f. California Coast Ranges
- 24g. Los Angeles Ranges

II. *Medium severity*
- 5b. Southern section of the Blue Ridge Province
- 6b. Middle section of Valley and Ridge Province
- 8c. Southern New York Section
- 11b. Lexington Plain
- 12d. Till Plains of the Central Lowland Province
- 12e. Dissected Till Plains of the Central Lowland Province
- 18. Middle Rocky Mountains
- 20c. Payette Section
- 20d. Snake River Plain

III. *Minor severity*
- 1. Superior Upland
- 3a. Embayed Section
- 3c. Floridian Section
- 3d. East Gulf Coastal Plain
- 3e. Mississippi Alluvial Plain
- 4a. Piedmont Upland
- 4b. Piedmont Lowlands
- 6c. Hudson Valley
- 7a. Champlain Section
- 9b. New England Upland Section
- 9c. White Mountain Section
- 9d. Green Mountain Section
- 9e. Taconic Section
- 11a. Highland Rim Section
- 12a. Eastern Lake Section
- 12b. Western Lake Section
- 12c. Wisconsin Driftless Section
- 12f. Osage Plains
- 13a. Glaciated Missouri Plateau
- 13b. Unglaciated Missouri Plateau
- 13c. Black Hills
- 13d. High Plains
- 13e. Plains Border
- 13f. Colorado Piedmont
- 14b. Boston "Mountains"
- 21a. High Plateaus of Utah
- 21b. Uinta Basin
- 21c. Canyon Lands
- 21d. Navajo Section
- 21e. Grand Canyon Section
- 22a. Great Basin
- 22d. Mexican Highland
- 22e. Sacramento Section
- 23b. Middle Cascade Mountains
- 23c. Southern Cascade Mountains
- 23d. Sierra Nevada
- 24e. California Trough

IV. *Nonexistent problem*
- 2. Continental Shelf
- 3b. Sea Island Section
- 3f. West Gulf Coast Plain
- 5a. Northern Section of the Blue Ridge Province
- 6a. Tennessee Section
- 7b. Northern Section of the St. Lawrence Valley Province
- 8a. Mohawk Section
- 8b. Catskill Section
- 8f. Cumberland Plateau
- 8g. Cumberland Mountains
- 9a. Seaboard Lowland Section
- 10. Adirondack Province
- 11c. Nashville Basin
- 11d. Western Section of the Interior Low Plateaus
- 13g. Raton Section
- 13h. Pecos Valley
- 13i. Edwards Plateau
- 13k. Central Texas Section
- 15a. Arkansas Valley
- 15b. Ouachita Mountains
- 17. Wyoming Basin
- 20b. Blue Mountain
- 20e. Harney Section
- 21f. Datil Section
- 22b. Sonoran Desert
- 22c. Salton Trough
- 25. Lower California Province

SOURCE: Based upon Highway Research Board questionnaires and partial literature search.

TABLE 4-9 STRATIGRAPHIC UNITS SUSCEPTABLE TO LANDSLIDES

Region and state	Geologic series or formation	Description
Northeast:	Glauconite beds in Cretaceous sediments	
Vermont		Pervious material beneath clay or soil
Maine		Soft clays
Middle East:		
New Jersey	Upper Cretaceous clays such as Merchantville and Woodbury	Sand or gravel overlying clay strata
Delaware	Talbot/Wicomico; Wissahickon	
West Virginia	Conemaugh; Monongahela; Dunkard	
Ohio	Ordovician shales and limestones	Fire clays
	Conemaugh; Monongahela; Dunkard	
Illinois		Shales
Pennsylvania	Conemaugh; Monongahela; Catskill; Wissahickon	
Southeast:		
North Carolina	Blue Ridge Province	Jointed surfaces filled with manganese
Florida	Miocene-Hawthorne	Fuller's-earth-type clay
North Central:		
Iowa	Des Moines series (Pennsylvanian)	
	Maquoketa (Ordovician)	
Kansas	Pierre shale, Graneros shale, Dakota formation	
South Central:		
Texas	Tertiary lava, tuffs, and agglomerates, and miscellaneous sediments	
Mountain:	Pierre shale; Bearpaw shale; Graneros shale; top Dakota sandstone	
Montana	Precambrian Belt sediments	Clay shales, bentonite, serpentine
Idaho	Payette; Triassic sediments	
Colorado	Fort Union; Denver, Arapahoe	Glacial till; ground moraine
New Mexico	Dakota on Morrison	
Pacific:		
California	Franciscan; Pico; Rincon	Serpentine; clay shale, Quaternary alluvium
Oregon	Eagle Creek volcanic breccia	Basalt talus resting on breccia
Washington	Neopelcin silts, Astoria siltstone; Eocene shales	

(from Woods, Berry and Goetz, 1960)

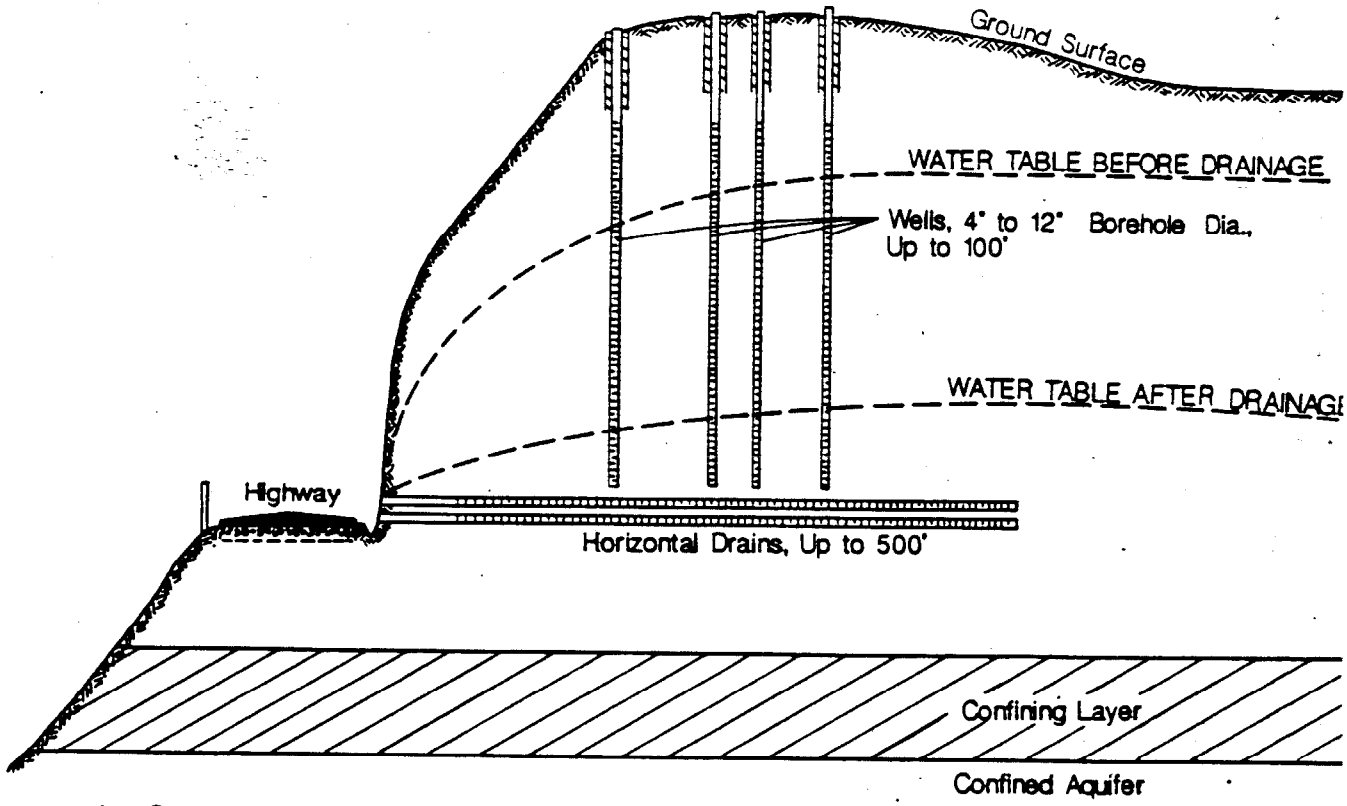
40 gallons/week while the discharge rate for the other two wells is unknown.

Landslide Control Drainage Wells. The presence of ground water in the subsurface increases the weight of the sediment debris and decreases resistance to shearing. This phenomenon stimulates, or continues, sediment movement in landslide-prone areas. Special drainage wells are employed to dewater these areas by removing ground water that also acts as a "lubricant." This countermeasure helps to reduce continued or potential landsliding in active slide areas.

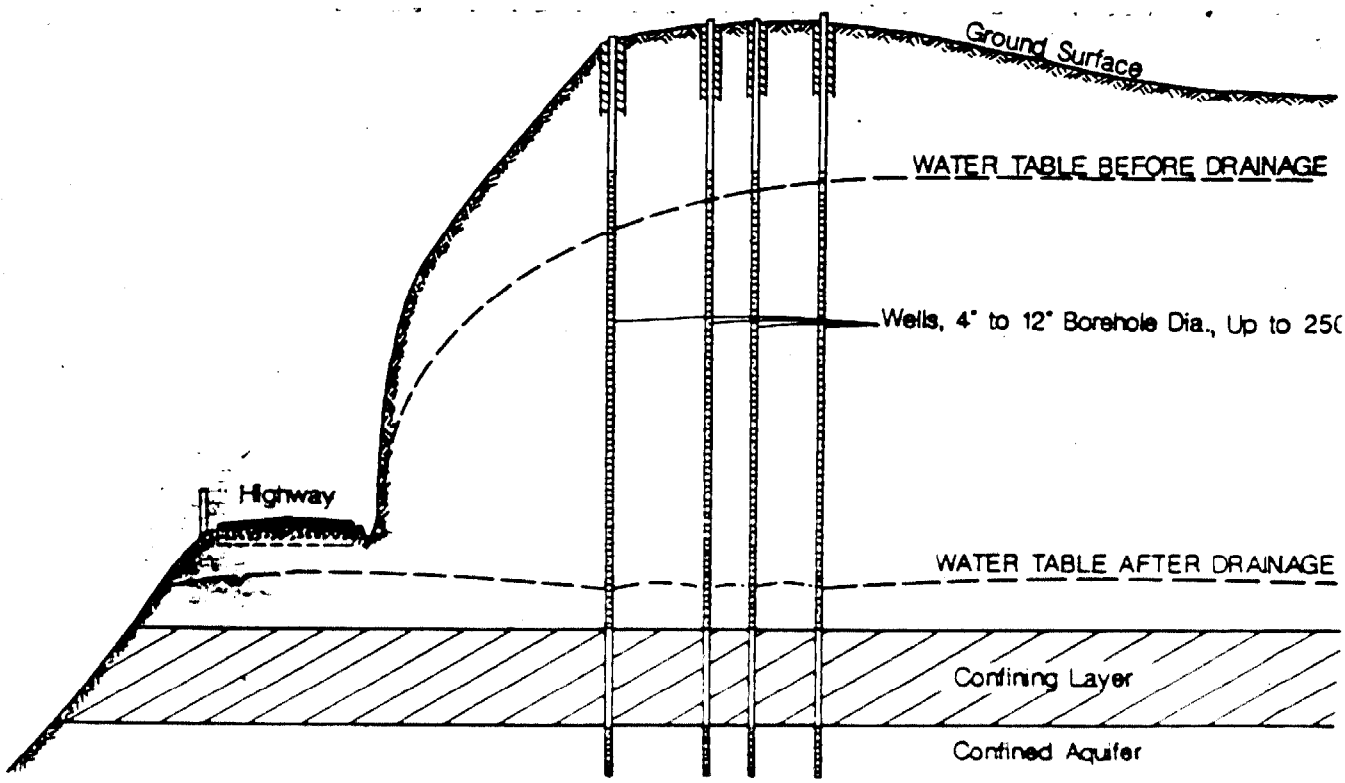
Two kinds of vertical drainage systems are employed to dewater slide areas. One method involves installation of a combination of vertical drainage wells and horizontal/subhorizontal drains. At the Craig and Lewistown sites, vertical drainage galleries, consisting of clusters of wells, are installed in the center of the general area that is landslide-prone. These wells have borehole diameters varying from 4 to 12 inches and borehole depths of up to 100 feet. Tiles, steel, or PVC casing are installed in these boreholes to various depths as the situation warrants. The annular space of the wells above the drainage area is grouted with cement or bentonite, and the tops are closed to prevent any surface water inflow. Surface runoff is primarily directed to surface drains on the perimeter of the landslide area. Horizontal/subhorizontal drains up to 500 feet in length are then installed through stable ground (downgradient of the landslide) to intersect the vertical drainage wells near the base of the unstable area, resulting in an "L" configuration as shown in Figure 4-8. Proper installation of the system is confirmed by monitoring the water level in the vertical drainage wells. A sudden drop in water level indicates that the system is hydraulically connected. Often, several boreholes may have to be drilled for successful installation.

Another type of drainage system (installed south of Dillon) drains shallow ground water from the Pipe Organ Landslide and flows by gravity into a vuggy limestone unit in the underlying Madison Formation. These wells are 200 to 250 ft. deep and penetrate approximately 150 ft. into the Madison Formation. The wells are constructed much like the vertical drainage wells discussed above with an open borehole in the bottom of the well.

Swimming Pool Water Drainage Wells. General construction features of the swimming pool drainage wells vary depending on the geographic location and type of pool (i.e., private or public). Small diameter wells (2 in. and 4 in.) are typically constructed with PVC well casings, while steel casings are used for large (5 in. - 18 in.) diameter wells. Figure 4-9 is an illustration of a typical swimming pool drainage well with con-



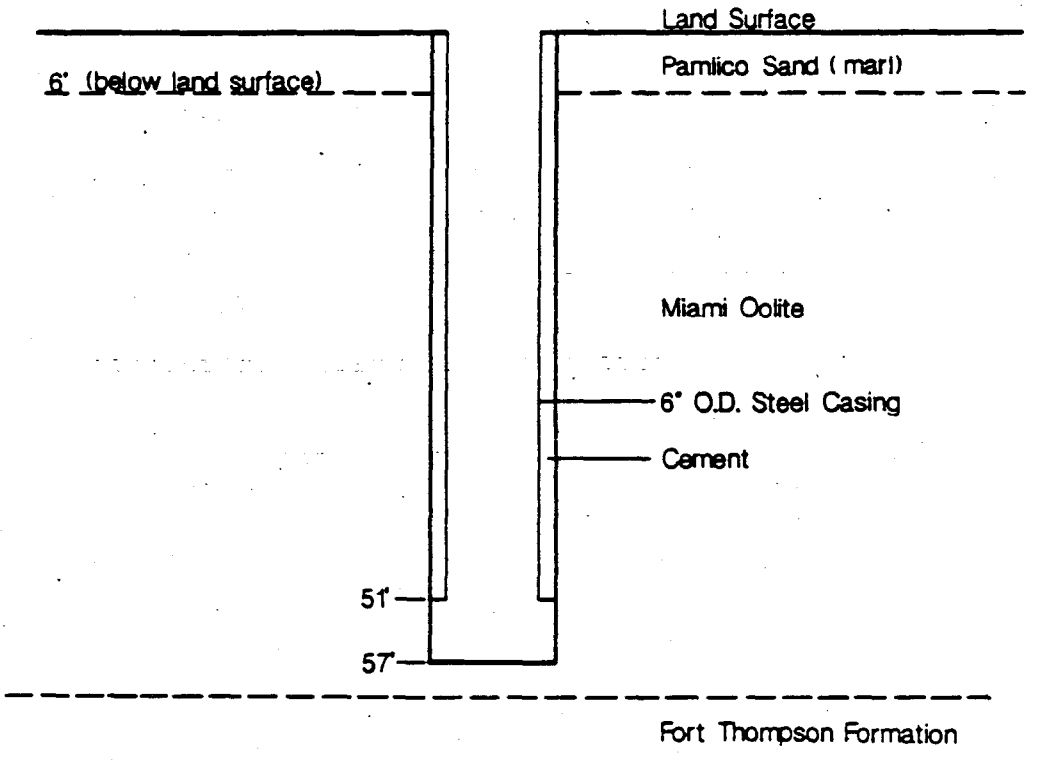
A. Combination of Vertical and Horizontal Drainage (employed in Lewiston & Craig, Montana)



B. Vertical Drainage (employed in Dillon, Montana)

METHODS EMPLOYED TO DEWATER LANDSLIDE PRONE AREAS

Figure 4-



CONSTRUCTION DETAILS OF A TYPICAL SWIMMING POOL DRAINAGE WELL IN SOUTH DADE COUNTY

(from FDER files, 1986)

Figure 4-9

struction details. Typically, private pools contain between 10,000 - 20,000 gallons of water and the public pools contain several hundred thousand gallons of water.

The drainage wells are usually located in the deeper part of the pool and periodically drain up to several thousand gallons of pool water. Public pools usually drain annually while private pools drain every couple of years, or when repairs are needed. Drainage is accomplished by gravity flow to the subsurface.

Injected Fluids and Injection Zone Interactions

According to the State of Idaho, the inventoried deep drainage wells inject drinking water quality fluids originating from pump control valves and water tank overflow systems. The inventoried shallow wells inject drinking water quality fluids resulting from municipal pump check valve systems.

The landslide control drainage wells inject ground water from the shallow subsurface to deeper zones. The report from the State of Montana has mentioned no source of contamination that might affect the natural water quality in this shallow zone.

Swimming pool drainage fluid may include constituents such as lithium hypochlorite, calcium hypochlorite, sodium bicarbonate, chlorine, bromine, iodine, cyanuric acid, aluminum sulfate, algaecides, fungicides, muriatic acid, and other physical, chemical, and biological contaminants. Some of these chemicals may be used to maintain pH, or for disinfection of the pool water. Other contaminants may result from the activities in the swimming pool. Some of the free chlorine available in the drainage fluid may degrade into trihalomethanes. These contaminants are drained into the subsurface without any kind of pretreatment. Thus, swimming pool effluent may contain many constituents in excess of the National Primary and Secondary Drinking Water Regulations.

The nature of injected fluids and injection zone interactions for the other three types of special drainage wells is unknown at the present time.

Hydrogeology and Water Usage

Due to a lack of detail in the state reports, hydrogeologic aspects for three of the five special drainage well types are not discussed in this report. These three special drainage well types are potable water tank overflow drainage wells, drainage of water associated with municipal dewatering, and the special drainage wells reported by Louisiana. Discussions of

hydrogeology and water usage are presented under separate subheadings for landslide control and swimming pool drainage wells.

Landslide Control Drainage Wells. The normal annual precipitation in the areas of Montana where these well types are located is approximately 16 inches. Infiltration of rainfall is one of the main sources of recharge to the underlying aquifers. Due to the presence of the underlying fresh water aquifers at Craig and Lewiston (Todd, 1983), a combination of vertical and horizontal drainage wells is employed at these sites as opposed to the direct vertical drainage employed at Dillon.

Due to lack of information in the State report, it is difficult to discuss hydrogeology and water usage in these areas. Nevertheless, draining of water from an upper zone to a deeper aquifer may cause potential problems. In the event that the shallow zone becomes contaminated, the contaminants may migrate into the vicinity of these drainage wells. Once the contaminants enter the area of influence, migration to the underlying aquifer will occur quickly, thereby contaminating the deeper aquifer. This could occur because the drainage wells act as conduits, hydrogeologically connecting the shallow zone to the deeper aquifer. Eventually, any drinking water wells completed in these zones may become contaminated.

Swimming Pool Drainage Wells. All of the swimming pool drainage wells inventoried inject wastewater into the unconfined Biscayne Aquifer. This aquifer serves as a major source of drinking water for southeast Florida. Owing to its high permeability, some large diameter public supply wells in Dade County produce as much as 7,000 gpm with very little drawdown. The majority of swimming pool drainage wells (1,334 verified wells) are located in this county. Hence, all injection activities that take place in this area may contribute contaminants which may eventually enter public or private water supply wells.

Contamination Potential

Based on the rating system described in Section 4.1, special drainage wells are assessed to pose a moderate to low potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance may or may not allow fluid injection or migration into unintended zones. Injection fluids sometimes have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. However, sometimes the fluids are of equivalent or better quality

(relative to standards of the National Primary or Secondary Drinking Water Standards and RCRA Regulations) than the fluids within any USDW in connection with the injection zone. Based on injectate characteristics and possibilities for attenuation and dilution, injection typically does not occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in groundwater, or endanger human health or the environment beyond the facility perimeter or in a region studied on a group/ area basis.

Based on the report from the State of Idaho, water tank overflow drainage wells are not expected to cause any degradation to the underground drinking water sources. However since most of these wells inject into or above USDW it is necessary to monitor the characteristics of the fluid to detect any accidental discharge of contaminated water resulting from contaminant leaks into the flow systems.

Properly designed and constructed landslide control drainage wells in Montana may have a low contamination potential owing to their use in relatively uncontaminated shallow aquifers. Yet these wells may act as conduits that can transfer large amounts of contaminants immediately into the lower aquifers in the event of accidental spills or leaks of chemicals at the surface.

Similarly, swimming pool drainage wells drain pool water to the subsurface. Such untreated pool water may contain toxic chemical constituents such as trihalomethanes and microbial contaminants. In addition, some microbial contamination may be contributed by the people who use the swimming pool. Depending on the concentration levels, these contaminants may eventually reach a drinking water well and degrade water quality.

The contamination potential of other types of special drainage wells is unknown at the present time.

Current Regulatory Approach

Special drainage wells are authorized by rule under the Federally-administered UIC programs (see Section 1). Almost all types of special drainage wells also are regulated by the respective States by permit and/or by rule. For instance landslide control drainage wells in Montana are permitted by the State of Montana Department of Highways. The district offices of the Florida Department of Environmental Regulation (FDER) permit the swimming pool drainage wells in Florida. A permit is required in Florida to construct, plug, or abandon the wells, but there are no requirements for operation. Also, monitoring is optional, and

reporting is not required. Permitting of potable water tank overflow drainage wells, drainage wells employed for dewatering, and other special drainage wells is currently unknown.

Recommendations

All special drainage well types are necessary to perform various functions in different regions. But improperly managed wells, or well sites, can present a threat to human health and the environment. Few of the State reports included recommendations concerning special drainage wells.

In the event that contamination problems develop in the water tank overflow drainage wells, the State of Idaho suggests some alternatives to dispose the fluids. Possible alternatives include ponding with evaporation or seepage, disposal into suitable surface waters, or transport to municipal sewer treatment facilities.

Florida suggests the need to characterize swimming pool wastewater for possible contaminants before injection/drainage. This can be achieved by obtaining random samples representative of the pool wastewater. Those pools that have contaminant levels in excess of the water quality standards will need treatment of fluids before injection.

States noted that regardless of the well type, all special drainage wells that are improperly plugged or abandoned after their useful lifetime will act as a hydraulic connection between the shallow aquifers and the deeper ones. Therefore, States recommended that good record keeping of all active and inactive wells, monitoring activities, and accidental leaks or spills would provide useful information if corrective actions need to be implemented.

4.2.2 GEOTHERMAL WELLS

4.2.2.1 Electric Power and Direct Heat Reinjection Wells (5A5, 5A6)

Well Purpose

Geothermal waters are high-temperature fluids used as an energy source. Following extraction of the heat energy, injection wells are used to dispose of spent geothermal fluids. Such disposal serves to recharge geothermal reservoirs and to avoid degrading other water sources. If geothermal reservoirs are not recharged, water pressure, and therefore production capacities, are lowered. At present, recharge of geothermal reservoirs has not been a major concern except at some reservoirs used to generate electric power. The cooled geothermal fluids, termed "heat spent," are still warmer than non-thermal waters and may cause temperature pollution. Also, geothermal fluids

generally have at least one constituent exceeding the National Primary Drinking Water Regulations and usually have a greater concentration of dissolved solids than non-thermal waters. Because of these characteristics it is usually not prudent to dispose of spent geothermal fluids by discharging into seepage-evaporation ponds or surface water bodies, or by injecting into non-thermal groundwater.

Inventory and Location

Geothermal reservoirs currently utilized fall into three categories: dry steam, hot water with temperatures above 150°C, and warm water with temperatures from 50° to 150°C. The only dry steam field in the United States is the Geysers in California. The steam is piped directly from production wells and used to turn turbine generators. Hot water reservoirs are being used to generate electricity in southern California, eastern California and Nevada.

Where hot water systems have a connection to shallow aquifers, heat transfer from or mixing of hot geothermal fluids and cooler waters has created low temperature geothermal systems. These systems are being utilized in California, Nevada, Oregon, Idaho, Colorado, New Mexico, and Texas for direct space heating. One or more electric power generation facilities may be operational in Oregon, utilizing low temperature (50-150° C) geothermal resources (Forcella, 1984). However, no mention of such a facility occurs in the Oregon report.

The best available data indicate there are currently 21 direct heat reinjection wells (5A6) and 89 electric power reinjection wells (5A5). The majority of these wells are located in USEPA Regions IX and X. The numbers and distribution of wells are shown on Tables 4-10 and 4-11. The California inventory of electric power reinjection wells (5A5) is significant with respect to total volumes of heat spent geothermal fluid injected. An electric power reinjection well will typically inject a volume 10 to 100 times that of a direct heat reinjection well. Most (89 percent) of these large volume injection facilities are located in California.

A few minor inventory problems were detected in State reports and FURS. The most common errors were the differentiation of direct heat reinjection wells (5A6) from heat pump/air conditioning return flow wells (5A7). Therefore, the well count is suspect for direct heat reinjection wells. Also, low volume injection facilities may not be required to register, be reviewed, or obtain permits. Limits for what is considered low volume vary among the States. Oregon considers less than 5,000 gallons/day as low volume, while Nevada permits any geothermal injection well with injection rates greater than 1,800 gallons/day (Oregon, 1986; Nevada, 1987).

TABLE 4-10: SYNOPSIS OF STATE REPORTS FOR GEOTHERMAL ELECTRIC POWER RE-INJECTION WELLS(5A5)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	YES	PERMIT	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	65 WELLS	PERMIT	YES	LOW
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	16 WELLS	PERMIT	YES	LOW - HIGH
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	4 WELLS	N/A	NO	MODERATE
Idaho	X	4 WELLS	PERMIT	YES	12TH HIGHEST/14TYPES
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

TABLE 4-11: SYNOPSIS OF STATE REPORTS FOR GEOTHERMAL DIRECT HEAT RE-INJECTION WELLS(5A6)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	YES	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	2 WELLS	PERMIT	NO	LOW
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	1 WELL	PERMIT	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE/PERMIT	NO	N/A
Colorado	VIII	2 WELLS	N/A	NO	LOW
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	1 WELL	PERMIT	NO	5 (7=HIGHEST)
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	1 WELL	PERMIT	YES	LOW
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	6 WELLS	PERMIT	YES	LOW
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	2 WELLS	PERMIT	YES	5TH HIGHEST/14 TYPES
Oregon	X	6 WELLS	PERMIT>5K GPD	NO	LOW
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

Siting, Construction, and Operation

Siting. General considerations in siting these wells are choosing the injection zone and deciding where (laterally and vertically in the injection zone) to complete the well. Typically the injection zone is a geothermal reservoir or some other thermally altered reservoir. Several approaches are taken by regulators in choosing the injection zone and determining the areal distribution of injection wells. All of them attempt to prevent the lateral and vertical spread of thermally altered water. In cases where the geothermal reservoir is confined at depth, injection back into the reservoir is required (California, 1987; Nevada, 1987). When the geothermally altered zone extends to the surface, injection into shallow, unconfined aquifers can occur. In these cases ground-water monitoring may be required to demonstrate that injected fluids do not migrate laterally into non-thermal waters (Nevada, 1987).

Operators also must decide if recharging the reservoir is necessary. If it is not, then injection wells may be located at some convenient place away from producing geothermal wells to eliminate problems of reservoir cooling due to reinjection. If recharge to the geothermal reservoir is critical, spent geothermal fluids are typically injected back into the reservoir. Wells will be sited so as to best enhance this strategy. Factors of importance to this strategy are vertical and lateral permeability to flow, reservoir pressures, and injection volumes. In general, the operator will use knowledge of the flow pattern in the reservoir to locate wells. The injection wells may be positioned as close to the production wells as possible without excessively cooling that portion of the reservoir.

Another geologic control with regard to siting is the ability of the formation to accept the desired volume of injectate. Injection wells associated with electric power production are characterized by large volumes of injectate. If the geothermal reservoir is the injection zone, the siting of injection wells must be at a point where the reservoir is most capable of receiving the fluid. This, in virtually all cases, will be in an area where the reservoir exhibits high fracture permeability associated with major structural features. The goal of the injection program is to inject with little to no injection pressure.

Injection wells associated with direct space heating are subject to similar siting controls. The geothermal reservoir typically is the injection formation. For these facilities to be operated economically, the production (and injection) zone must be a relatively shallow geothermal resource. Ease of injection may be controlled by fractures associated with major faults. These features represent conduits to the surface for geothermal fluids as well as conduits for injection.

Construction. Plans for injection well construction must address two criteria. The first is the protection of shallow ground water. This is accomplished using conductor and surface casing strings, cemented in place. Although materials may vary, there is little variation in design between deep and shallow geothermal wells. The second criteria is assurance that injection will be into the intended zone. Injection control is accomplished by a wide variety of techniques, dependent upon well depth and geologic nature of the injection zone.

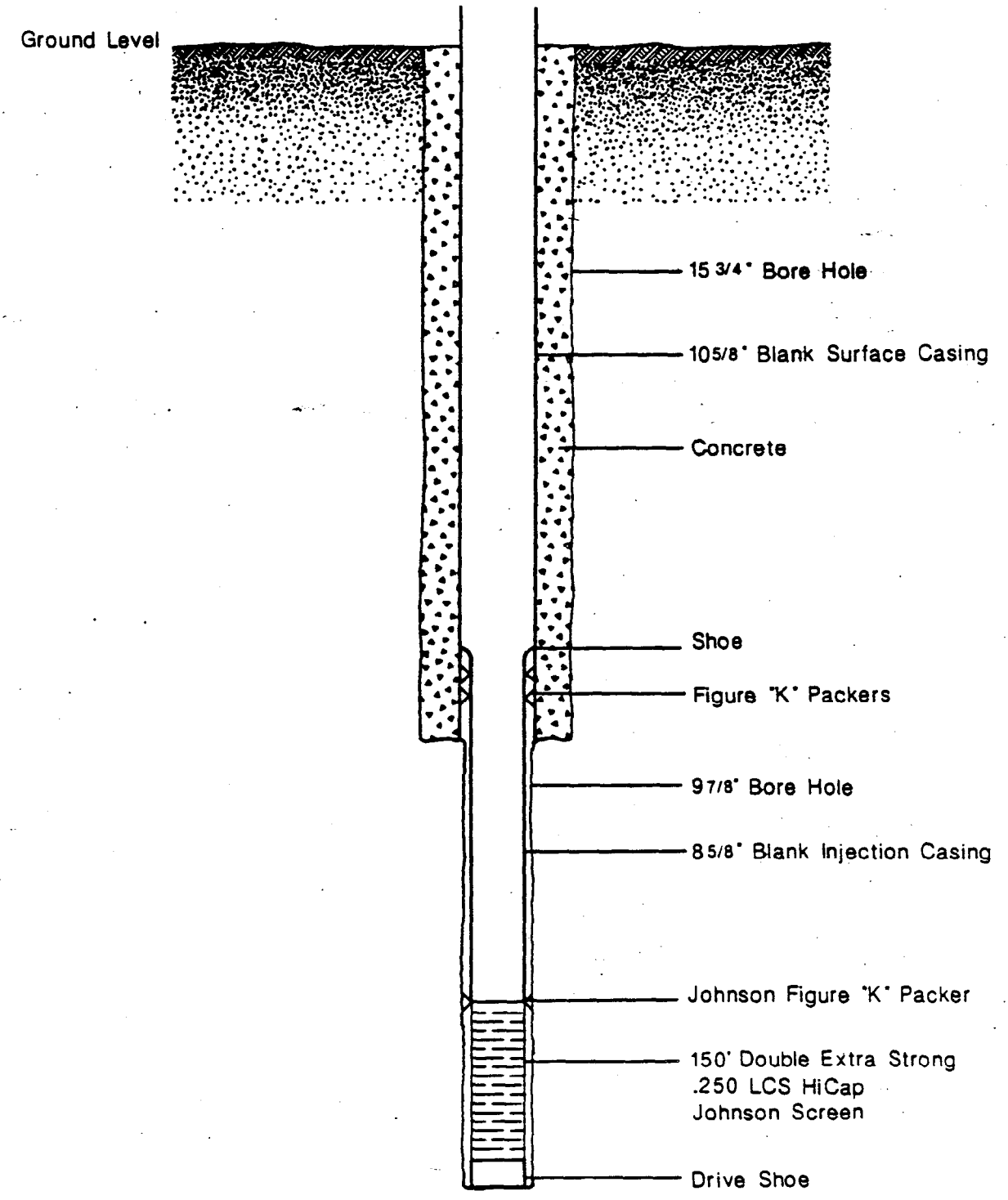
Direct Space Heating

Injection wells associated with direct space heating facilities are usually shallow (500-1,500 feet). A typical design for an injection well of this type is presented in Figure 4-10. The largest diameter casing, referred to as surface casing, is hung from the surface and typically penetrates a few hundred feet into the borehole. The entire void space between the surface casing and borehole wall is filled with cement. This procedure is designed to prevent any commingling of injection fluid with shallow ground water. While variations in diameter and depth of surface casing exist from well to well, the basic design and goal is consistent in all of geothermal injection wells.

Inside the surface casing, a string of smaller diameter casing is suspended using a "shoe." This string may or may not be cemented into place, depending upon the borehole diameter and the nature of the formation opposite the casing. The purpose of the cement program is to protect zones from injection fluid and to hold the casing in place. If a zone is impermeable to the injection fluid and the borehole diameter is sufficiently small for the casing to fit snugly, cement may not be used. Figure 4-10 is an example of such a well. In this case, a packer is used at the top of the injection casing to prevent leakage between casing strings. Likewise, a packer is used between the injection casing and well screen. This packer, pressed against the wellbore, is designed to create a seal and prevent injectate from going anywhere but into the intended zone.

Opposite the injection zone, a variety of mechanical configurations are possible. The example well in Figure 4-10 has a well screen designed to allow injection without clogging by particulate matter. Another design makes use of a slotted liner. Both designs are used for formations that readily accept injection fluids.

Where the injection formation is less permeable, or several separate zones within the wellbore are to be used, a perforation program may be employed. In this method, the injection zone is cemented off and a "perf gun" is lowered to the proper depth and discharged. This procedure is repeated in each zone of a



CONSTRUCTION DESIGN FOR A TYPICAL DOMESTIC DIRECT SPACE HEATING GEOTHERMAL INJECTION WELL

(provided by Sierra Geothermal, Reno, NV)

Figure 4-10

multiple-zone completion. The charge used is sufficient to perforate the casing, cement, and formation. Fluid to be injected will exit the casing through these perforations.

Wellhead assemblies vary for different facilities, but a typical design for domestic direct space heating systems is presented in Figure 4-11. The wellhead is an interface between the flowline from the facility and the downhole equipment. Injection pressure, if needed, is established at injection pumps located downstream of the facility. Pressures and flow rates are typically monitored at the wellhead via a system of gauges. The pressure gauge usually is removable to facilitate adapting the wellhead for use as a sample port.

Fluid flow to the wellbore can be regulated by valve systems at the wellhead. Ball valves operated using a pipe wrench, and gate valves manipulated by rotating "wheels", are typical restrictors on this type of geothermal injection well. These valves are "on or off" systems and are not designed to allow partial flow. If partial restriction of flow is required during normal operation, it is usually controlled by adjustable valves at the injection pumps.

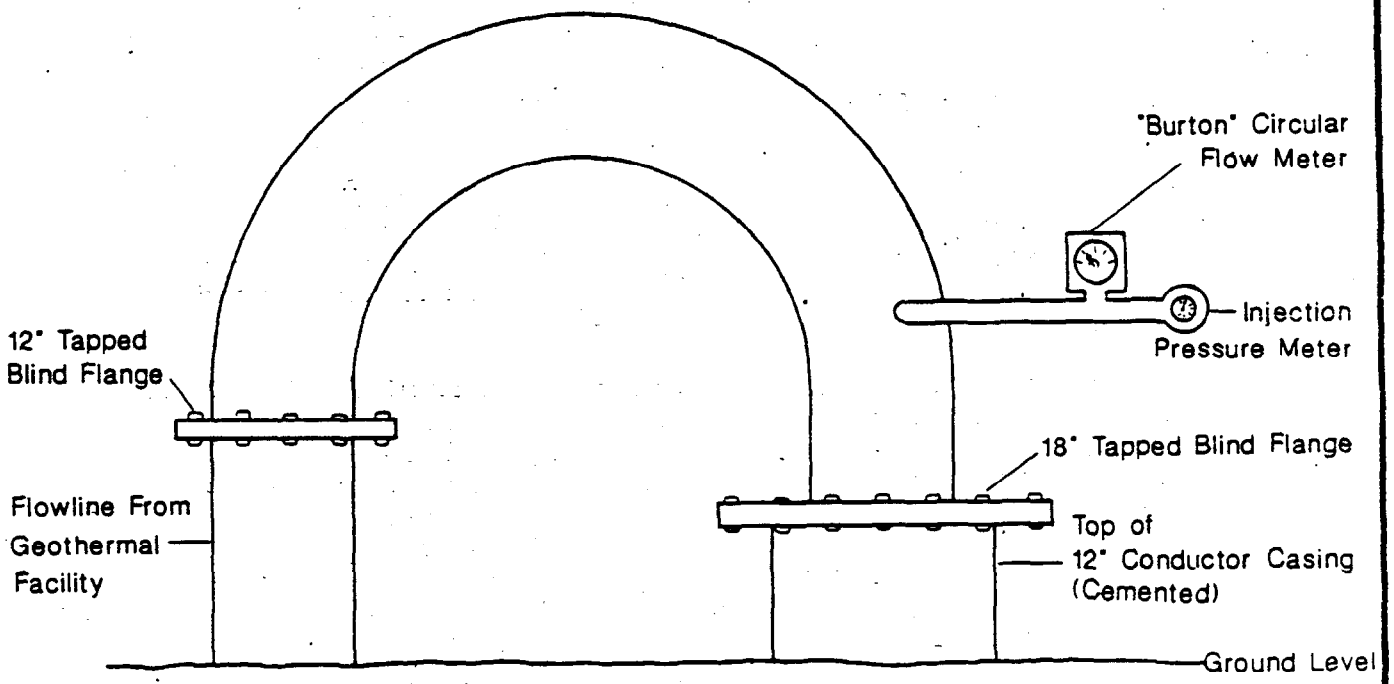
Present construction designs for these wells must address corrosive problems associated with cooled geothermal fluids. Casing made of low carbon steel with minimum .25 inch sidewall thickness is optimum. The casing should be cemented with a slurry consisting of approximately twenty percent bentonite clay (Nork and Bantz, 1983).

Electric Power Generation

Injection wells associated with electric power generation facilities typically dispose of larger volumes of spent fluid, and are deeper than those wells associated with direct space heating. As a result, construction designs for downhole and wellhead assemblies are more complex and display more variation. Again, specific details for design are dictated by the size of the operation and local geologic factors.

A typical design for an injection well at an electric power generation facility is presented in Figure 4-12. Current practice for injection wells of this type is to construct all casing strings of low to moderate strength steel to resist corrosion and work hardening (Snyder, 1979). Work hardening is the process by which a material becomes more brittle in response to continued stress. With respect to casing in geothermal injection wells, this stress is the result of thermal expansion and contraction.

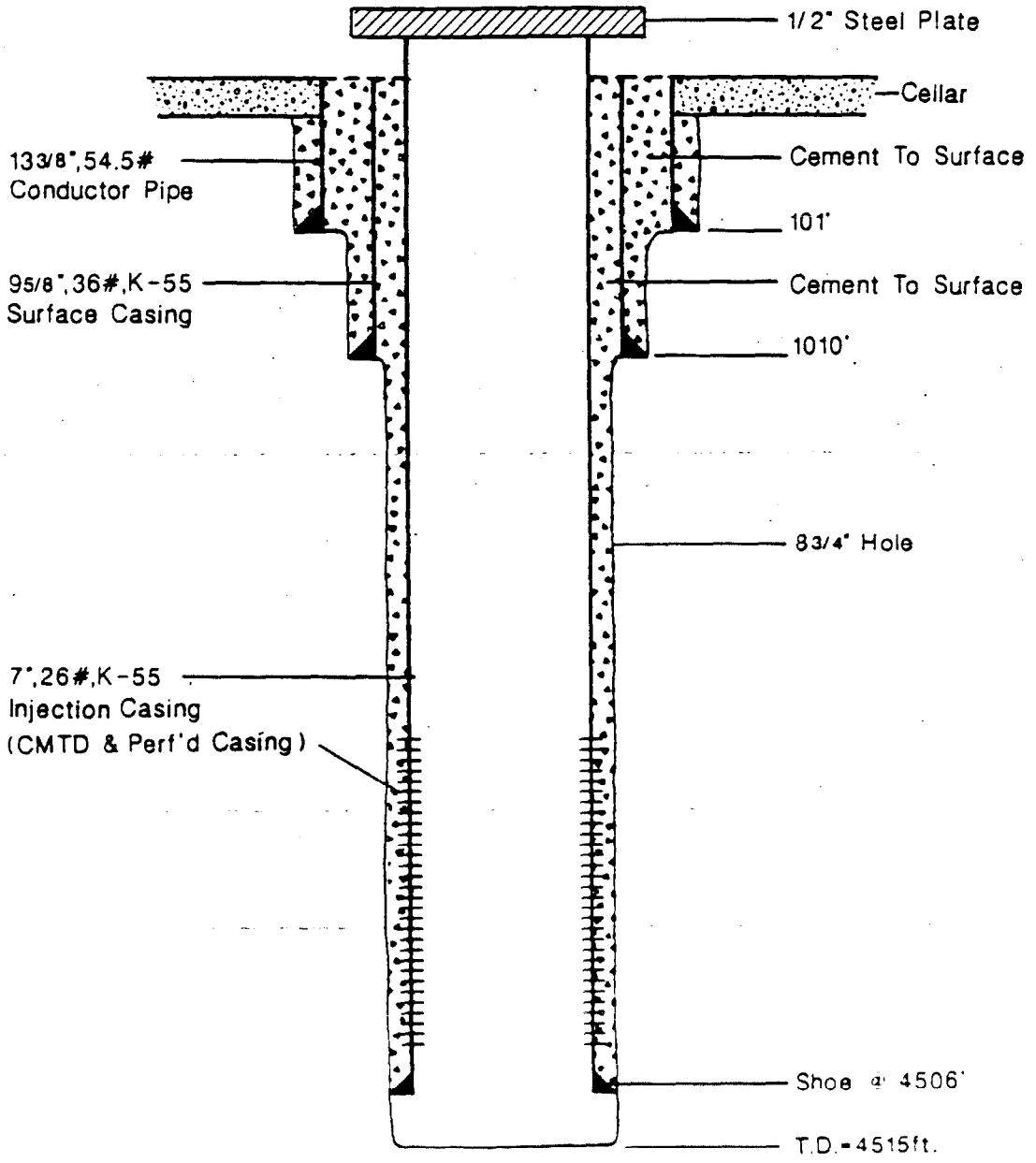
The design in Figure 4-12 features conductor casing that typically is not found with direct space heating facilities. The purpose of the conductor casing is to prevent shallow unconsolidated sediments from collapsing into the wellbore during



TYPICAL DOMESTIC SPACE HEATING
INJECTION WELLHEAD

(after Warren Estates Geothermal, Reno, NV)

Figure 4-11



TYPICAL SCHEMATIC FOR
GEOTHERMAL INJECTION WELL ASSOCIATED
WITH ELECTRICAL POWER GENERATION

(provided by Chevron Geothermal)

Figure 4-1

drilling operations. This string is cemented back to the surface.

Inside the conductor casing, hung from the surface, is the surface casing. Again, the purpose of this string is to protect shallow ground water from drilling fluids and from injected fluids after the well is completed. This string is cemented back to surface prior to continued drilling. Depth of surface casing is dictated by local hydrogeology, and ultimate determination is the responsibility of State drilling engineers and hydrogeologists. It is also common to find that injection casing extends only to the top of the injection zone. In such cases the bottom portion of the well may be left as an open hole, or a slotted liner may be hung from the injection casing. Liners are hung near the bottom of the injection casing. Open hole or slotted liner completions do not involve placing any cement across the injection zone.

Inside the surface casing, also hung from the surface, is the injection casing. The example in Figure 4-12 displays a single string of injection casing, perforated through the injection interval. Depending upon the depth and pressures associated with injection, additional strings of casing may be used. Diameter of the casing will decrease with increased depth.

Cementing the casing strings in a geothermal injection well is an integral part of well design. Casing failure in geothermal wells generally is attributed to the inability to consistently and reliably cement casing strings solidly from bottom to top. Gallus and others (1979) had the following recommendations concerning cements:

1. Cements with a compressive strength of less than 1,000 psi or a water permeability higher than 1 millidarcy (md) are not adequate for geothermal well use.

2. API Class G cement with 40-80% silica flour, a thickening time of at least 1 hour at 250°F, and no free water will achieve satisfactory results.

Class G cement without silica can disintegrate when exposed to the geothermal well environment. The silica and water react to recrystalize xonotlite to truscottite with an increase in volume and decrease in permeability (Gallus et. al., 1979). Coarse silica particles react more slowly than fine silica but can develop higher compressive strengths and lower permeabilities (Gallus et. al., 1979).

Wellhead assemblies for these injectors are essentially the same as those discussed for space heating facility injectors. Injection pressure can be monitored at the wellhead, and valves for manual shut-off are present. Variations in injection pressure are controlled at the injection pumps.

Operation. Geothermal injection well operation is addressed separately for direct heat and electric power reinjection wells.

Domestic Direct Space Heating

Facilities of this type use low temperature (50-150°C) geothermal fluids. The fluid is piped to heat exchangers located at central facilities or individual homes where municipal water is heated for use in homes. Heat exchangers are "closed loop" systems, and no commingling of geothermal and municipal fluids occurs. The geothermal fluid is untreated, and the only physical change is a reduction in temperature prior to injection.

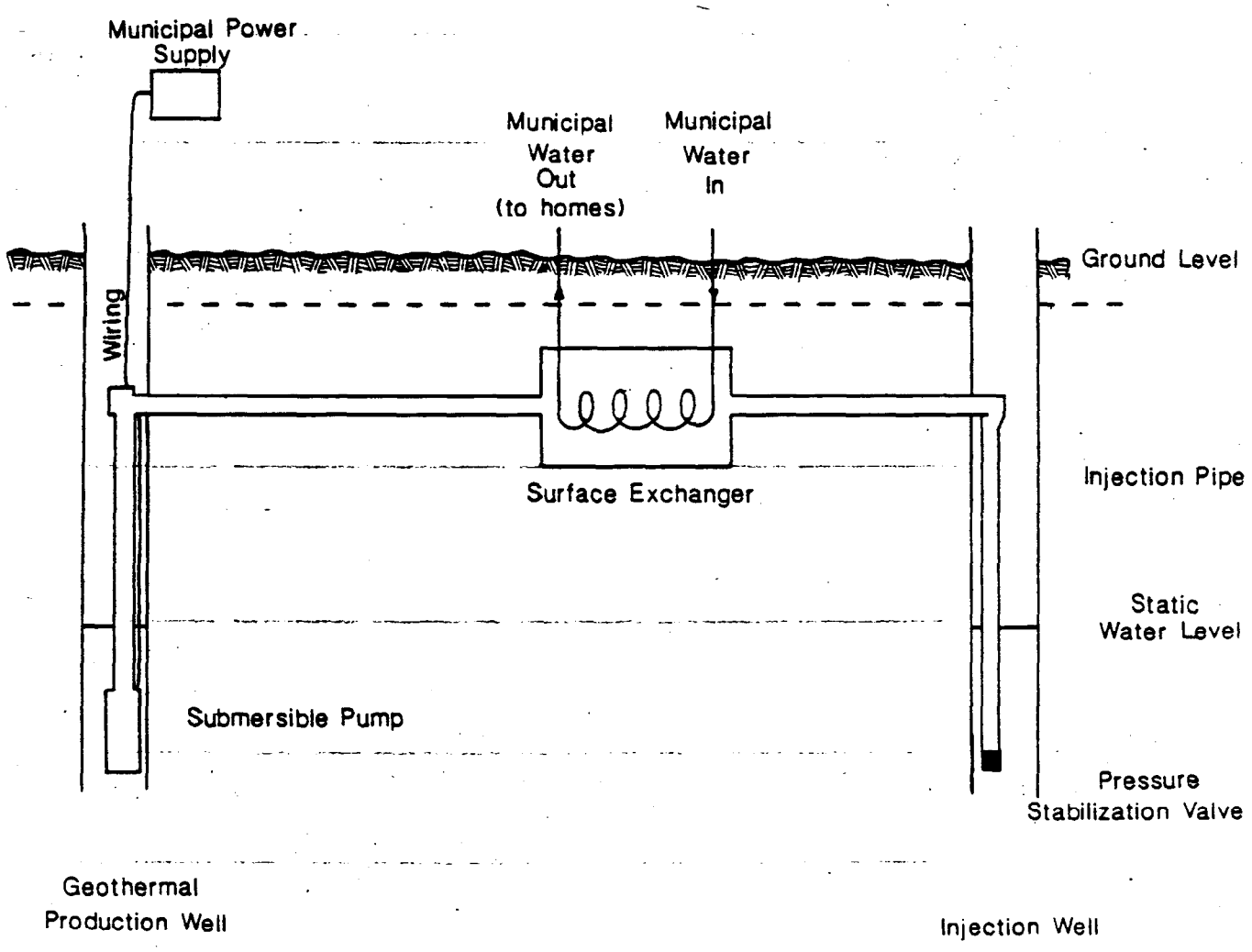
Both downhole and surface heat exchangers are used for direct space heating. Warren Estates, a new housing subdivision in Reno, Nevada, employs a centralized surface heat exchanger. This system is schematically presented in Figure 4-13. This system is ideal when a single, high volume production well is used in conjunction with the municipal water supply. Hot, municipal water is dispersed to individual homes, eliminating the need for individual heat exchangers. Because surface exchangers can be large, facilitating a larger surface area for heat exchange, this system is the most efficient available for this type of geothermal resource.

Some geothermal injectors of this type make use of slotted liners rather than a perforation program at the injection interval. This is less expensive in that the liner (light-weight casing) can be placed into the wellbore with the other strings. This method is actually preferable where the injection formation is very permeable.

Where several production wells are available, each serving only two or three homes, a downhole exchanger is the system of choice. The system employed at Sierra Geothermal in Reno is considerably less efficient than surface exchange due to borehole size constraints but is also less expensive. This system operates by piping municipal water through a "trombone" loop inside a geothermal production well. As the fresh water is heated and pumped to homes, geothermal fluid around the loop is cooled. Downhole convection cells and pumps are used to remove this brine from the wellbore and transfer it via pipeline to the injection well. One injection well is typically capable of disposing the spent brine for an average-sized subdivision.

Electric Power Generation

Three different systems are used for electric power generation depending on the nature of the geothermal resource. Dry steam systems are the most efficient of the power generation facilities (McLaughlin and Donnelly - Nolan, 1981). Reservoir temperatures and pressures are such that there is virtually no



SCHEMATIC DIAGRAM OF A SURFACE HEAT EXCHANGE SYSTEM ASSOCIATED WITH DOMESTIC GEOTHERMAL SPACE HEATING

(after Nork & Bantz, 1983)

Figure 4-13

liquid phase to the geothermal resource. No separators or "flash" systems are necessary. Produced steam is piped directly to the generator turbines. At this point, the resource is condensed in cooling towers, where approximately eighty percent is evaporated to the atmosphere. The remaining condensate is collected in settling ponds and ultimately pumped to the injection systems. Figure 4-14 is a schematic of a typical dry steam facility.

Because settling ponds are used at dry steam facilities, the systems are not totally "closed." Some interaction may occur between the heat-spent fluids and the atmosphere. No treatment procedures are conducted on the spent fluid at any time. The assumption is made that no significant chemical alteration occurs within the fluid prior to its reinjection into the geothermal reservoir.

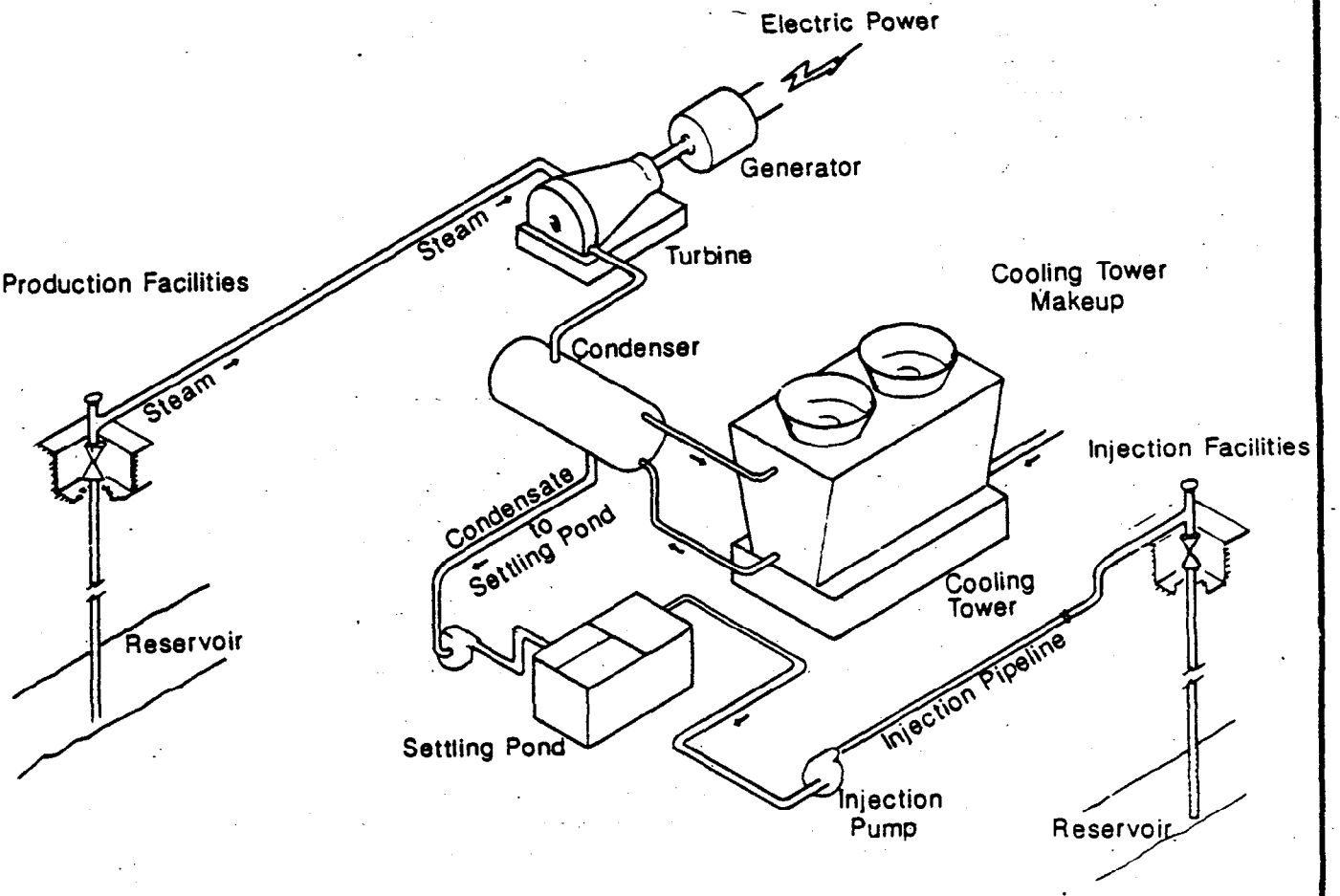
Dual phase systems are being used in California and Nevada. This system, diagrammatically represented in Figure 4-15, makes use of geothermal resources comprised partly of steam and partially of hot water (300 - 400°F).

In a dual phase system, the first step is separation of the steam and liquid fractions. The steam is not totally "dry" and must be demisted to remove liquid molecules. The steam leaving the demister is used to drive the system turbines. The steam is then condensed in cooling towers where up to eighty percent is lost to evaporation. The remaining condensate is pumped to the injection system.

The liquid fraction of the geothermal resource is piped into a lower pressure vessel following separation from steam. This pressure reduction causes the fluid to "flash" into steam. This steam is demisted and used to drive turbines as described above. After condensation in the cooling system, the spent fluid is sent to the injection system.

Some dual flash facilities use settling ponds to reduce particulates from corrosion and mineral precipitation. Significant temperature reduction and aeration due to atmospheric exposure occur. Some facilities add oxygen scavenger compounds, for example sodium bi-sulfite, to inhibit corrosion in surface and down-hole equipment. Effects to injection zone water quality resulting from these practices is discussed further under Injection Zone Interactions.

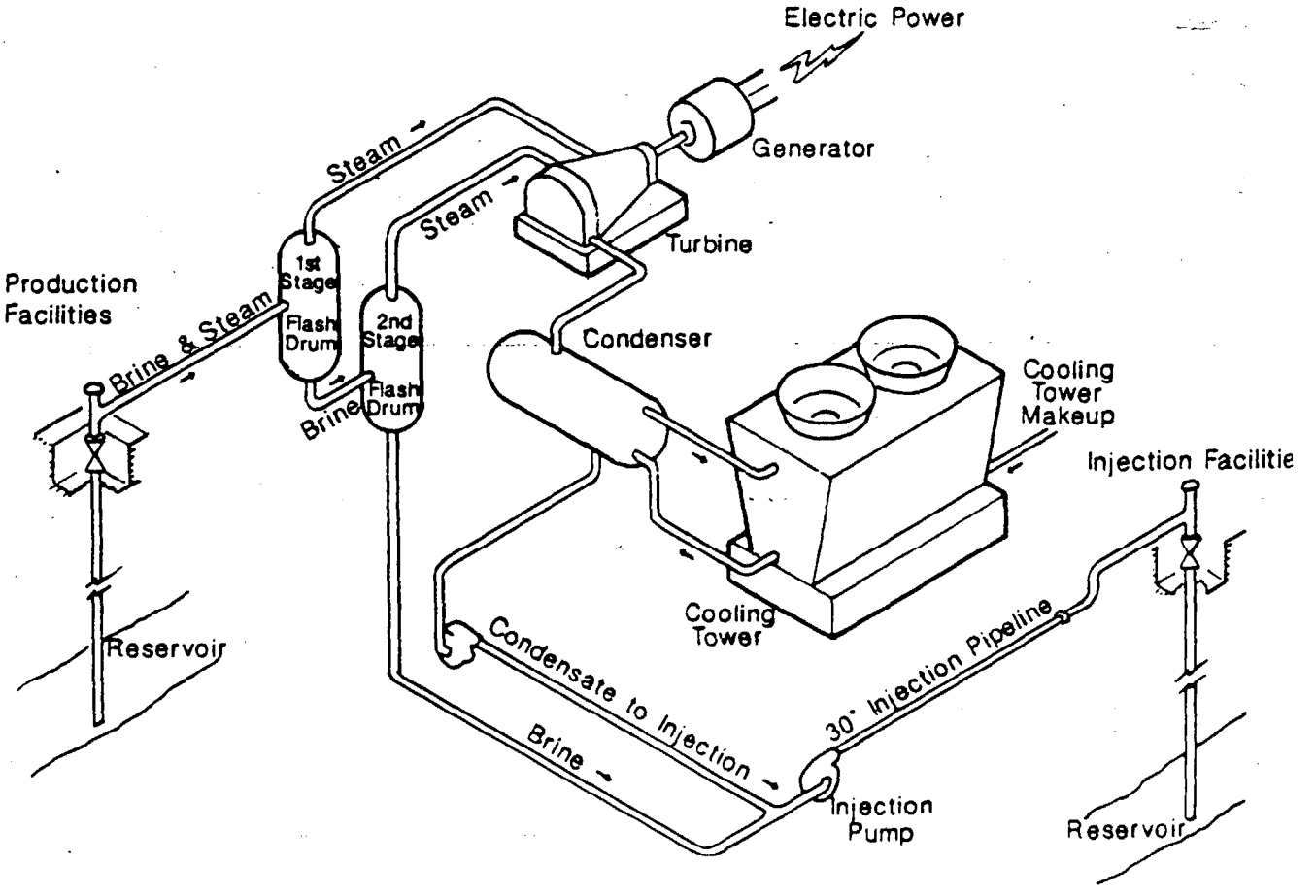
Several facilities using the Binary Method of electric power generation also are located in California and Nevada. A binary facility schematic is presented in Figure 4-16. This type of system is truly "closed." It is designed so that one hundred percent of the produced fluid is reinjected into the geothermal reservoir.



TYPICAL DRY STEAM ELECTRICAL POWER GENERATION FACILITY

(after a figure provided by Chevron Geothermal)

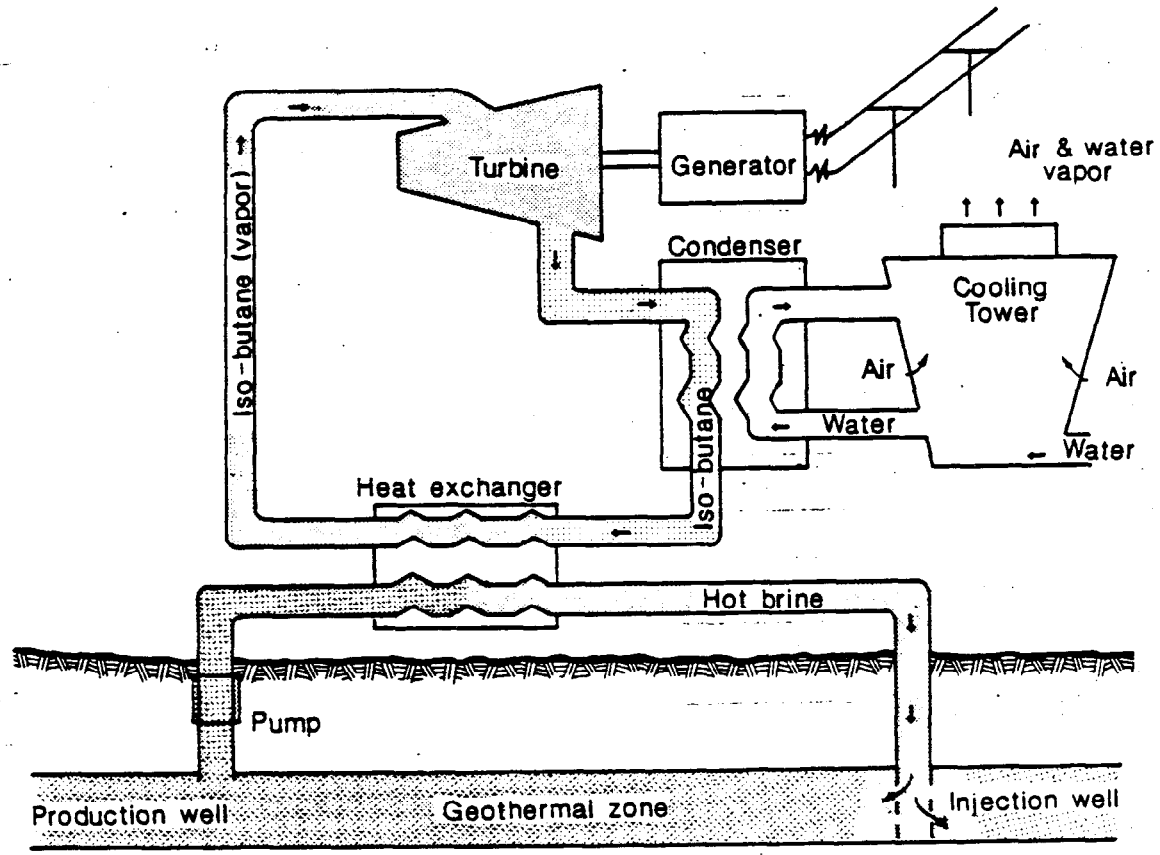
Figure 4-14



TYPICAL DUAL FLASH GEOTHERMAL ELECTRIC POWER GENERATION FACILITY

(provided by Chevron Geothermal)

Figure 4-15



SCHEMATIC OF BINARY GEOTHERMAL ELECTRIC POWER GENERATION FACILITY

Figure 4-16

In a binary system, fluid from the production wells is pumped into tubular heat exchangers where a light hydrocarbon such as isobutane is vaporized. The vapor drives the generator turbines, and then is condensed via cooling towers prior to being reintroduced to the heat exchange system. The cooled fluid is pumped to the injection system. No commingling between isobutane and fluid occurs, and the fluid is not held in settling ponds.

Injected Fluids

The following discussion groups geothermal injection fluids into three categories: low temperature (50 - 150°C) water used for space heating, hot water resources used for electric power generation (including hot dry rock reservoirs), and vapor dominated resources used for electric power generation. In order to evaluate the hazards of geothermal injection fluids, data in published literature and from geothermal injection well operators were compared to several parameters of the Primary and Secondary Drinking Water Regulations (Table 4-12). Available data at best covers the inorganic constituents plus pH and Total Dissolved Solids (TDS). The data from various resource areas are presented in Tables 4-13 to 4-16.

Low Temperature Resources. Only one facility utilizing an injection well with a low temperature space heating system has been inventoried in California. Susanville Geothermal is located in the Honey Lake Valley, one of several low temperature geothermal resource areas identified in northern California (Hannah, 1975). The potential certainly exists for increased use of these resources along with utilization of injection wells to dispose of spent fluid.

Currently, six geothermal space heating facilities utilizing injection wells to dispose of spent fluid have been inventoried in Nevada. Two are multi-home space heating systems which tap the Moana Geothermal System in Reno, Nevada. Future development of these types of facilities is expected in the Moana area and in another area known as Steamboat Hot Springs about twelve miles to the south. Relatively inexpensive, shallow wells can encounter geothermal fluids with temperatures of 100°C (Flynn and Ghusn, 1984; Bateman and Scheibach, 1975) in these areas.

Several other States indicated Class V injection wells were utilized in low temperature geothermal resources areas usually as part of direct space heating projects. However, little or no data on the geochemistry of those geothermal fluids was given. A limited amount of data was available in the literature for the Raft River Geothermal Site, in Idaho. This is represented in Table 4-16. The Oregon State report mentions TDS of geothermal reservoirs around Klamath Falls is less than 1,000 mg/l.

TABLE 4-12

NATIONAL PRIMARY DRINKING WATER REGULATIONS

Inorganic Constituents	Max. Permissible Concentration (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr^{+6})	0.05
Fluoride (F)	4.0*
Lead (Pb)	0.05
Mercury (Hg)	0.002
Nitrate (NO_3^-)	45.0
Selenium (Se)	0.01
Silver (Ag)	0.05

NATIONAL SECONDARY DRINKING WATER REGULATIONS

Inorganic Constituents	Recommended + Conc. Limit (mg/l)
Chloride (Cl-)	250
Copper (Cu)	1.0
Fluoride (F)	2.0*
Iron (Fe)	0.3
Manganese (Mn)	1.0
pH	6.5-8.5 pH units
Sulfate (SO_4^{2-})	250
Total Dissolved Solids (TDS)	500
Zinc (Zn)	5.0

\+ Recommended limits are mainly to provide acceptable esthetic and taste characteristics

* Revised by 51 FR 11410, Apr. 2, 1986

Source: U.S. EPA 1976 and 1977

TABLE 4-13
COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
*HONEY LAKE VALLEY - LOW TEMPERATURE
(2 SPRINGS)

CALIFORNIA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	ND				0.05
Barium	ND				1.0
Cadmium	2		<0.01	0	0.01
Chromium	ND				0.05
Fluoride	2	4.2	4.1-4.4	100	4.00
Lead	2		<0.1		0.05
Mercury	ND				0.002
Nitrate	ND				45.00
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride	2	175	160-190	0	250
Copper	2		<0.02	0	1
Fluoride	2	4.2	4.1-4.4	100	2
Iron	2		<0.06	0	0.3
Manganese	2		<0.01	0	0.05
Sulfate	2	330	300-360	100	250
Dis. Solids	2	960	879-1,040	100	500
Zinc	ND				5
pH	2		8.4	0	6.5 to 8.5
other					Criteria
Boron	2	4.8	4.0-5.5	100	2.0 [1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980.
* = Data from Reed (1975)
n = Number of samples
x = Sample average
ND = No data

TABLE 4-14

COMPARISON TO STANDARDS SET BY PRIMARY AND SECONDARY DRINKING WATER REGULATIONS
*STEAMBOAT GEOTHERMAL AREA - LOW TEMPERATURE

NEVADA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	2	2.5	1.8 - 3.2	100	0.05
Barium	2	0.06	0.05 - 0.06	0	1.0
Cadmium	ND				0.01
Chromium	ND				0.05
Fluoride	2	2.6	2.5 - 2.6	0	4.0
Lead	ND				0.05
Mercury	ND				0.002
Nitrate	2	2.3	0 - 4.6	0	45.0
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride	2	850	770 - 930	100	250
Copper	ND				1
Fluoride	2	2.6	2.5 - 2.6	100	2
Iron	2		0.01-<0.05	0	0.3
Manganese	2		<0.01	0	0.05
Sulfate	2	126	102 - 151	0	250
TDS	2	2300	2200 - 2370	100	500
Zinc	ND				5
pH	2		7.4	0	6.5 to 8.5
other					Criteria
Boron	2	61	60 - 62	100	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980.
* = Data from Flynn and Ghusn (1984)
n = Number of samples
x = Sample average
ND = No data

TABLE 4-15

COMPARISON TO STANDARDS SET BY PRIMARY AND SECONDARY DRINKING WATER REGULATIONS *MOANA GEOTHERMAL AREA - LOW TEMPERATURE

NEVADA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic**	13	.09	0.01 - .20	69	0.05
Barium	10		<0.02-0.036	0	1.0
Cadmium	ND				0.01
Chromium	1		<0.02	0	0.05
Fluoride	10	4.4	1.0 - 5.6	77	4.0
Lead	1		<0.05	0	0.05
Mercury	1		<0.0005	0	0.002
Nitrate	ND				45.00
Selenium	1		<0.005	0	0.01
Silver	1		<0.01	0	0.05
secondary					
Chloride	10	33	10 - 51	0	250
Copper	1		<0.02	0	1
Fluoride	10	4.4	1.0 - 5.6	90	2
Iron	10		<0.01-0.01	0	0.3
Manganese	10		<0.01-0.02	0	0.05
Sulfate	10	365	74 - 460	70	250
TDS	10	797	2197 - 1010	80	500
Zinc	1		<0.01	0	5
pH	10		7.5 - 8.5	0	6.5 to 8.5
other					Criteria
Boron	10	2.0	0.30-2.62	80	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980.
* = Data supplied by an operator of geothermal injection wells and from Flynn and Ghusn (1984)
n = Number of samples
x = Sample average
ND = No data
** = Compiled from data for 13 wells encountering thermal waters in T 19N/R19E Section 24, 25, 26 in Bateman and Scheibach (1975). Data for arsenic and lithium in Flynn and Ghusn (1984) were reported by them to be suspect (p. 50).

TABLE 4-16

COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
RAFT RIVER GEOTHERMAL SITE, LOW TEMPERATURE (<150°C)

IDAHO

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	ND				0.05
Barium	ND				1.0
Cadmium	ND				0.01
Chromium	ND				0.05
Fluoride	3	6.2	4.3 - 8.6	100	4.0
Lead	ND				0.05
Mercury	ND				0.002
Nitrate	ND				45.00
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride	3	1130	682 - 2000	100	250
Copper	ND				1
Fluoride	3	6.2	4.3 - 8.6	100	2
Iron	ND				0.3
Manganese	ND				0.05
Sulfate	3	49	32 - 61	0	250
TDS	3	2080	1300 - 3580	100	500
Zinc	ND				5
pH	ND				6.5 to 8.5
other					Criteria
Boron	ND				2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980.
2 = Data are the average values for three geothermal wells at the Raft River Geothermal Site, Malta, Idaho from Allen et. al., 1978.
n = Number of samples
x = Sample average
ND = No data

Water quality data for most parameters of the Primary Drinking Water Regulations were not available. Arsenic concentrations are above the standard in the Steamboat Springs - Moana area of Nevada. No other data on arsenic concentrations are available.

Fluoride concentrations commonly exceed the Maximum Concentration Limit of 4.0 mg/l set in the National Primary Drinking Water Regulations. This standard has been set to prevent the occurrence of crippling skeletal fluorosis. Fluoride also is a parameter of the National Secondary Drinking Water Regulations, for which the Recommended Concentration Limit is 2.0 mg/l. This standard has been set to protect against dental fluorosis (mottling of the teeth).

Among parameters of the Secondary Drinking Water Regulations, TDS and flouride are consistently above standards in geothermal fluids. Chloride and sulfate concentrations also commonly exceed standards. The boron criteria was exceeded in each case reported.

High Temperature. Three hot water dominated geothermal resource areas utilizing Class V injection wells as part of electric power generating facilities are located in California and Nevada. One experimental hot dry rock geothermal system also produces high temperature fluid (200°C). The Los Alamos hot dry rock experiment involves two deep wells (10,000 feet). A granitic rock unit was hydrofractured establishing a hydraulic connection between the two wells. Water is injected in one well and is pumped from the recovery well 10 hours later at 200°C (Tester et. al., 1978).

The data presented in Tables 4-17 to 4-22 show that much remains to be learned about the concentrations of most elements covered by the National Primary Drinking Water Regulations. In general, one or more parameters were above the standards at each facility.

Among parameters of the Secondary Drinking Water Regulations, several were well above standards at each facility, notably TDS, chloride, and fluoride. In addition, the boron criteria was greatly exceeded at each area.

Vapor Dominated Resources. The only resource area of this nature is the Geysers, Sonoma and Lake Counties, California. Five injectate analyses were available from operators in this area (Table 4-23). Unfortunately, detection limits varied among the different analytical laboratories for most parameters of the Primary Drinking Water Regulations and were often above the regulation standard. The detection limit is the lower limit for resolution of an analytical procedure. When the detection limit is above the standard, it cannot be determined whether the sample

TABLE 4-17
COMPARISON TO STANDARDS SET BY PRIMARY AND SECONDARY DRINKING WATER REGULATIONS
***MONO-LONG VALLEY - HOT WATER DOMINATED**
(2 INJECTION WELLS)

CALIFORNIA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	2	1.23	0.95 - 1.5	100	0.05
Barium	ND				1.0
Cadmium	2		<0.02		0.01
Chromium	ND				0.05
Fluoride	2	14	11-16	100	4.00
Lead	2		<0.12		0.05
Mercury	2	0.097	0.003-0.19	100	0.002
Nitrates	2	1.0	0 - 2.0	0	45.00
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride	2	215	170-260	50	250
Copper	ND				1
Fluoride	2	14	11-16	100	2
Iron	2	0.31	0.27-0.35	50	0.3
Manganese	2		<0.04	0	0.05
Sulfate	2	145	140-150	0	250
Dis. Solids	2	1600	1600	100	500
Zinc	ND				5
pH	2		8.9-9.2	100	6.5 to 8.5
other					Criteria
Boron	2	10	8.6-12	100	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980.
* = Data supplied by geothermal injection well operator (August, 1986)
n = Number of samples
x = Sample average
ND = No data

TABLE 4-18
COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
*IMPERIAL VALLEY - HOT WATER DOMINATED
(13 INJECTION WELLS)

CALIFORNIA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	13		<0.05	0	0.05
Barium	13	0.92	0.23-1.83	46	1.0
Cadmium	ND				0.01
Chromium	13	0.47	0.10-0.92	100	0.05
Fluoride	13	0.60	0.40-0.75	0	4.00
Lead	13	0.84	0.22-3.39	100	0.05
Mercury	13	0.003	.001-0.011	46	0.002
Nitrates	ND				45.00
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride	13	8,880	6900-9000	100	250
Copper	12	0.24	0.04-0.71	0	1
Fluoride	13	0.60	0.40-0.75	0	2
Iron	13	15.1	4.0-30.9	100	0.3
Manganese	13	1.02	0.41-1.76	100	0.05
Sulfate	13	54.3	41-68	0	250
Dis. Solids	13	10,700	8,840-12,360	100	500
Zinc	13	0.36	0.11-1.38	0	5
pH	13		7.1-8.0	0	6.5 to 8.5
other					Criteria
Boron	13	50.9	32.9-70.2	100	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980
* = Data supplied by a geothermal injection well operator (August, 198
n = Number of samples
x = Sample average
ND = No data

TABLE 4-19
COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
*COSO HOT SPRINGS AREA - HOT WATER DOMINATED

CALIFORNIA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	1		8.2	100	0.05
Barium	ND				1.0
Cadmium	ND				0.01
Chromium	ND				0.05
Fluoride	1		3	0	4.00
Lead	ND				0.05
Mercury	1		<0.0005	0	0.002
Nitrate	1		<0.03	0	45.00
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride	1		3600	100	250
Copper	1		<0.005	0	1
Fluoride	1		3	100	2
Iron	1		0.08	0	0.3
Manganese	1		<0.01	0	0.05
Sulfate	1		100	0	250
Dis. Solids	1		9700	100	500
Zinc	1		<0.02	0	5
pH	ND				6.5 to 8.5
other					Criteria
Boron	1		79	100	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980
* = Data supplied by a geothermal injection well operator (August, 1986)
n = Number of samples
x = Sample average
ND = No data

TABLE 4-20
COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
*SALTON SEA GEOTHERMAL AREA - HOT WATER DOMINATED

CALIFORNIA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/
primary					
Arsenic	5	11.4	10 - 15	100	0.05
Barium	6	483	200 - 1100	100	1.0
Cadmium	1		<0.005	0	0.01
Chromium	1		<4		0.05
Fluoride	5	10.8	2 - 18	80	4.00
Lead	7	95	50 - 200	100	0.05
Nitrate[2]	2	20	5 - 35	50	45.00
Mercury	3		0.006-<0.2		0.002
Selenium					0.01
Silver	6	0.70	0 - 1.4	66	0.05
secondary					
Chloride	9	162, 600	93,650-210,700	100	250
Copper	7	4.0	0 - 10	29	1
Fluoride	5	10.8	2 - 18	80	2
Iron	8	2,050	1,150-3,420	100	0.3
Manganese	9	1,340	410-1,300	100	0.05
Sulfate	7	34.7	0 - 75	0	250
Dis. Solids	8	278,000	184,000-388,000	100	500
Zinc	4	715	500-970	100	5
pH	6		3.9-5.3	100	6.5 to 8.5
other					Criteria
Boron	7		149-745	100	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980
* = Data summarized from Cal. Dept. Water Resources (1970) and represents one to four samples from four different wells.
n = Number of samples
x = Sample average
ND = No data
2 = Data indicate very high levels of ammonia nitrogen [(NH_3 and NH_4+)] ranging from 340-570 mg/l. In an oxidizing environment some would convert to nitrate. Additionally, ammonia nitrogen in small amounts (Criteria for fresh water is 0.02 mg/l, EPA (1977)) is toxic to fish in fresh water.

TABLE 4-21
COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
LOS ALAMOS, NEW MEXICO
HOT DRY ROCK EXPERIMENT (200°C)

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/l)
primary					
Arsenic	ND				0.05
Barium	ND				1.0
Cadmium	ND				0.01
Chromium	ND				0.05
Fluoride			12 - 14	100	4.00
Lead	ND				0.05
Mercury	ND				0.002
Nitrate[2]	ND				45.00
Selenium	ND				0.01
Silver	ND				0.05
secondary					
Chloride			400-600	100	250
Copper	ND				1
Fluoride			12-14	100	2
Iron			2-3	100	0.3
Manganese			0.01	0	0.05
Sulfate	ND				250
Dis. Solids			1470-2390	100	500
Zinc	ND				5
pH			6.8-7.0	0	6.5 to 8.5
other					Criteria
Boron	ND				2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980
2 = Data from Tester et. al. in EPA, 1978.

TABLE 4-22

COMPARISON OF GEOTHERMAL FLUIDS ASSOCIATED WITH HOT WATER DOMINATED RESOURCES IN NEVADA TO NATIONAL PRIMARY DRINKING WATER REGULATIONS

Resource Area	Arsenic (mg/l)	Barium (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Fluoride (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nitrate (mg/l)	Selenium (mg/l)	Silver (mg/l)
Chevron[a] Beowawe										
n	5	5	ND	ND	5	5	ND	ND	ND	5
x	0.05	0.10			15	0.005				0.01
range	ND	ND			ND	ND				ND
Chevron[b] Des. Peak										
n	2	2	2	2	2	2	ND	ND	ND	2
x					6.2					
range	<0.61	<0.6	<0.06	<0.05	6.0 - 6.5	<0.24				<0.05
GDA[c] Steamboat										
n	1	1	ND	ND	1	ND	1	1	ND	ND
x	3.2	0.08			2.4	0.002		0.5		
range										
Standard	0.5	1.0	0.01	0.05	2	0.05	0.002	10	0.01	0.05

a - average of 5 samples from flow test - data supplied by operator (Rossi 21-19)
b - data from 2 production wells supplied by operator
c - data from permit information in files of the Nevada, Department of Environmental Protection

n = number of samples
x = sample average
ND = no data

TABLE 4-22, continued

COMPARISON OF GEOTHERMAL FLUIDS ASSOCIATED WITH HOT WATER DOMINATED RESOURCES IN NEVADA TO NATIONAL SECONDARY DRINKING WATER REGULATIONS

Resource Area	Chloride (mg/l)	Copper (mg/l)	Fluoride (mg/l)	Iron (mg/l)	Manganese (mg/l)	Sulfate (mg/l)	TDS (mg/l)	Zinc (mg/l)	pH (mg/l)	Boron (mg/l)
Chevron[a] Beowawe										
n	5	5	5	5	5	5	5	5	5	5
x	110	0.01	15	3.3	0.05	440	1580	0.7	9.4	2.0
range	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron[b] Des. Peak										
n	2	2	2	2	2	2	2	2	ND	2
x	1700		6.2			110	5070			12.2
range	1635-1775	<0.6	6.0-6.5	<0.02-0.03	<0.24	106-115	4880-5260	<0.12		11.6-12.9
GDA[c] Steamboat										
n	1	1	1	1	1	1	1	1	1	1
x	950	0.01	2.4	0.17	0. 01	126	2440	0.02	8.6	49
range										
Standard Criteria	**250**	**1**	**2**	**0.3**	**0.05**	**250**	**500**	**5**	**6.5 to 8.5**	**0.05** 2.0[1]

a - average of 5 samples from flow test - data supplied by operator (Rossi 21-19)
b - data from 2 production wells supplied by operator
c - data from permit information in Nevada, Department of Environmental Protection

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980
n = number of samples
x = sample average
ND = no data

TABLE 4-23
COMPARISON TO STANDARDS SET BY PRIMARY
AND SECONDARY DRINKING WATER REGULATIONS
*THE GEYSERS - VAPOR DOMINATED
(3 INJECTION WELLS, 2 CONDENSATE PONDS)

CALIFORNIA

Parameter	n	x (mg/l)	Range (mg/l)	% Exceedance	Standard (mg/
primary					
Arsenic	5	0.87	<0.01-3.2	80	0.05
Barium	5		<0.5	0	1.0
Cadmium	5		<0.1		0.01
Chromium	5		<0.05-<0.1		0.05
Fluoride	4	0.12	<0.1-0.27	0	4.00
Lead	5		<0.05-<0.1		0.05
Mercury	5		<0.001-<0.01	20	0.002
Nitrate[2]	2		1 - < 5	0	45.00
Selenium	5		<0.01-<0.1		0.01
Silver	5		<0.02-0.10	at least 20	0.05
secondary					
Chloride	4	26	0-100	0	250
Copper	4		<1.0	0	1
Fluoride	4	0.12	<0.1-0.27	0	2
Iron	5	7.1	<0.1-29	60	0.3
Manganese	2		<0.03-0.06	50	0.05
Sulfate	5	180	8-440	40	250
Dis. Solids	5	436	98-1,095	40	500
Zinc	2		0.06-0.11	0	5
pH	4		6.6-7.51	0	6.5 to 8.5
other					Criteria
Boron	5	94	62-190	100	2.0[1]

1 = American Society of Agricultural Engineers, Monograph No. 3, 1980
* = Data supplied by two operators of geothermal injection wells (August, 1986).
n = Number of samples
x = Sample average
ND = No data
2 = Data indicate high levels of ammonia nitrogen (NH_3 and NH_4^+) are present ranging from 6.7 to 13.2 mg/l. In an oxidizing environment some would convert to nitrate. Additionally, small amounts of ammonia nitrogen in fresh water is toxic to fish (Criteria for freshwater is 0.02 mg/l, EPA (1977)).

contains constituents in concentrations above or below the standard. In general, arsenic was the only parameter commonly above the standard. Data for cadmium and selenium were inconclusive except to indicate that an occasional sample could contain these constituents in concentrations up to ten times the standard. Concentrations of mercury and silver were each over the standard in one sample.

Among the Secondary Regulations only iron was found to have at least a 50% exceedance rate. Sulfate and TDS also could be minor problems and occasionally exceeded twice the standard. The boron criteria was greatly exceeded for each sample.

Injection Zone Interactions

General. Two important considerations for the Underground Injection Control Program are:

1. how injection practices will affect the ability of the rock media to accept fluids at the desired rates and pressures; and

2. how the injection fluid will change the water quality naturally present in the injection zone.

The first point is important in deciding the type and frequency of operational monitoring and mechanical integrity testing which should be employed. Undesirable connections between the injection zone and other USDW because of packer failures, formation fracturing, and other casing or tubing failures could occur due to a decrease in the accepting formation's ability to receive fluids. Point number two directly addresses pollution of the injection zone by the geothermal fluid effluent.

Effects on Injectivity. Negative impacts upon injectivity occur due to two main phenomena: high suspended solids in the injectate causing filter cake buildup at the borehole and pore plugging due to precipitation of solids as the injectate moves through the rock media. Precipitation of dissolved solids occurs due to changes in temperature and pressure as the geothermal brine is taken out of the reservoir and moved through the various surface equipment necessary to extract the heat energy. Solids can also precipitate if ion concentrations increase due to loss of water during flashing or if significant evaporation occurs as spent brine is temporarily held in ponds or tanks before injection. Suspended solids are commonly amorphous silica, carbonate minerals (example - $CaCO_3$, $MnCO_3$) and gypsum ($CaSO_4$) (Arnold, 1984; Summers et. al., 1980; Michels, 1983; Vetter and Kandarpa, 1982; Hill and Otto, 1977). A worst case example of plugging due to formation of a low permeability filter cake at the well bore is described by Owen et. al., (1978). The injection well was disposing of a high TDS fluid from the Salton Sea Geothermal

Field in California. Spinner survey information indicated that a 458-foot slotted liner was plugged every where except for a 4-foot interval. This occurred over a one-week period. The interval through which injection fluids were still moving was believed to correspond with a zone of fracture permeability.

Precipitation of solids also may occur within the rock media of the injection zone at some distance away from the wellbore. For instance, if the concentration of sulfate anion ($SO_4^{=}$) or calcium cation (Ca^{++}) increases during loss of water from flashing or evaporation, solid calcium sulfate ($CaSO_4$) may precipitate in the injection zone. This would occur as the injectate is heated by mixing with hotter fluid in the injection zone and from heat given up by the rock itself. $CaSO_4$ is less soluble at high temperatures (Nancollas and Gill, 1978; Vetter and Kandarpa, 1982). A host of such reactions causing solids to precipitate in the injection zone can occur depending upon variables such as temperature, pH, and ion concentration. These are extremely difficult to predict based on theory because of the numerous variables involved. Pilot scale injectivity testing or experiments with core samples allow the best predictions (Michels, 1983; Owens et. al., 1978; Arnold, 1984).

Effects on Injection Zone Water Quality. This is the second injection zone consideration. It will be discussed in two parts dealing with major ion composition and minor (or trace) element composition.

Major Ion Composition

This consideration ~~deals with the~~ potential degradation of injection zone water quality by introducing the geothermal brine effluent. Based on information from literature review, UIC Facility Inspection Reports, and UIC File Investigation Reports, typical industry practice is to utilize the geothermal reservoir as the injection zone. If this is the case, only minor changes to the overall injection zone water quality would occur. Major ion composition is expected to be negligibly influenced by fluid-fluid and rock-fluid interactions. Hence, TDS can be considered as a non-reactive parameter for pollution studies (Freeze and Cherry, 1979; Summers et. al., 1980).

Changes in major ion concentration may occur due to the concentrating effects of evaporation/vaporization. A facility like the Geysers loses 80% of produced fluid (steam) to the atmosphere. Cooling towers condense 20% to liquid which is then injected. The majority of dissolved solids will be concentrated in those fluids. If essentially all the dissolved solids remain in the liquid fraction there will be a four fold increase in concentration. Dual flash systems lose about 15 to 20 percent of the original fluid volume. Assuming the lost steam is essentially pure, a concentration factor of 1.15 to 1.20 results.

Successive concentration of TDS by recycling of injected brine to production wells could be a serious problem to injection zone water quality and to equipment operations.

Minor or Trace Constituents

Minor or trace elements for which there are Primary or Secondary Drinking Water Standards include: Silver (Ag), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Fluorine (F), Iron (Fe), Mercury (Hg), Manganese (Mn), Lead (Pb), Selenium (Se), and Zinc (Zn). Fluid-fluid or rock-fluid interactions could be grouped into six types: adsorption-desorption, acid-base, solution-precipitation, oxidation-reduction, ion pairing-complexation, and microbial cell synthesis (Driscoll, 1986). In general, thermodynamic principles and chemical equilibria can be applied to dilute solutions at near-earth surface conditions to estimate ion concentrations due to the above interactions. This does not hold for microbial cell synthesis. The chemistry of high temperature, high pressure, and high ionic strength (high TDS) solutions is extremely complex. Estimates of interactions in geothermal reservoirs might be attainable on a case-by-case basis where thermodynamic data on an element and its possible solid, ion pair or complex species are available. The same concentrating effects of evaporation/vaporization could increase minor or trace element concentrations in geothermal reservoirs.

Pre-Treatment

A variety of treatments are in use to ensure efficient functioning of equipment such as pipelines, cooling towers, pumps, and wells. Three general types of problems, namely corrosion, scaling, and suspended solids, are discussed below, with possible treatment methods:

1. Corrosion - rusting due to dissolved oxygen in the effluent; treat by adding oxygen scavengers such as ammonium bisulfite or sodium sulfite.

2. Scaling - Precipitation of minerals onto metal surfaces; treat with scale inhibitors such as organic phosphonate derivatives and polyacrylic acids.

3. Suspended Solids - partially composed of eroded rust or scale but also minerals precipitated from solution; treat by filtering, sedimentation, or acidification.

Among facilities actually inspected, oxygen scavengers, filtering, and sedimentation are methods observed in use. Michels (1983) reported the unpredictable results of injecting a flashed

brine combined with an unidentified $CaCO_3$ scale inhibitor. $CaCO_3$ was deposited within the injection zone after injection was halted, and native fluids moved back toward the well bore in one experiment. This did not occur in another experiment where the same fluid was injected into an area of slightly different geothermal fluid chemistry. The oxygen scavengers noted do not pose a threat to injection zone water quality. They may reduce concentration of various metal ions in solution by helping to maintain a reducing environment in the injection zone. Additional information on industry pre-treatment practices needs to be gathered and evaluated with respect to injection zone water quality.

Summary. Qualitatively, closed systems (direct heat or binary method for electric power generation) should experience the least change of water quality in the injection zone. Vapor dominated and flash systems would be injecting fluids more out of equilibrium with the reservoir. Small shifts in trace or minor constituent concentrations could result in waters potentially harmful to human health or the environment. Injection testing on a pilot scale or studies with reservoir cores should be used to estimate long-term injectivity as well as effects to minor trace element concentrations when injection is into a good-quality or currently used ground-water resource.

Beneficial uses of most non-thermal waters with TDS <1,000 mg/l could be seriously altered if heat spent geothermal fluids from high temperature reservoirs were injected. Non-thermal waters could be adversely affected by injection of spent geothermal fluids from low temperature resources if water qualities are not carefully compared. Most drinking water quality aquifers in the western United States would be negatively impacted by such a practice. However, Idaho recommends allowing injection into non-thermal reservoirs if the thermal injection fluids meet drinking water standards or if the receiving fluids are of equal or lesser quality.

Hydrogeology and Water Use

Geothermal systems in most cases have a natural discharge of thermal water into shallow aquifers. Faults are usually the conduits along which geothermal fluids rise although other geologic discontinuities can allow geothermal fluids to discharge from the reservoir. For instance, confining layers may thin and disappear allowing discharge. In some cases the discharge is seen at the surface as fumaroles, mud pots, or geysers.

The areal distribution of thermally altered waters in USDW represent a quasi-steady state before the development of the resource. Injection wells, should they develop casing leaks or inject into non-thermal waters, may change the areal or vertical distribution of thermally altered water. Such changes could affect current or potential beneficial uses of USDW.

The California, Nevada, and Oregon State reports show that the vast majority of heat spent geothermal fluids are injected into the geothermal reservoirs. The geothermal reservoirs themselves usually meet the definition of an USDW. As was shown in the previous section, the geothermal reservoirs frequently have a high concentration (several thousand mg/l) of dissolved solids. Aquifers of better water quality are usually penetrated by the Class V injection wells disposing of geothermal fluids.

Current use of ground water in areas near geothermal resources is usually low. The majority of geothermal facilities are in sparsely populated, remote areas. In some instances natural mixing of thermal and non-thermal waters has limited current use by creating poor water quality up to the surface. Exceptions to this are the Truckee Meadows (metropolitan Reno and Steamboat) area of Nevada, Klamath Falls area of Oregon, and the Raft River Geothermal Area of Idaho. Shallow valley-fill or volcanic rock aquifers supply important municipal, domestic, and irrigation water needs in these locations.

Two geothermal resource areas in the Truckee Meadows are being developed, Steamboat Hot Springs and Moana. Moana is a low temperature (<150°C) resource where Class V injection wells are utilized in space heating applications. Multi-home systems, churches, motels, and apartment complexes are finding geothermal energy affordable and convenient. The Steamboat Hot Springs area is being developed primarily for electric power production at present. One company has recently put a binary system utilizing two Class V injection wells on line. Another company is drilling wells for a planned binary facility. Case studies with material on the contamination potential of three facilities in the Truckee Meadows are listed in Appendix E. The Class V injection wells at these facilities penetrate the valley-fill aquifer which supplies the 200,000 people of metropolitan Reno with about 20 percent of the municipal water (Van Denburgh, et al., 1973).

Contamination Potential

Based on the rating system described in Section 4.1, electric power and direct heat reinjection wells are assessed to pose a moderate potential to contaminate USDW. These facilities typically inject below Class I and Class II aquifers but <u>into</u> some USDW. Typical well construction, operation, and maintenance would not allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of National Primary or Secondary Drinking Water Regulation

parameters in ground water, or endanger human health or the environment beyond the facility perimeter.

Several States have rated the contamination potential of both 5A5 and 5A6 wells as low. Several case studies of Class V wells associated with both 5A5 and 5A6 are presented in the California and Nevada State reports. The reports state that assurance of mechanical integrity is assumed in the contamination potential rating. The rating system used in this report does not give as much weight to proper construction, operation, and maintenance as the State reports.

Current Regulatory Approach

Electric power and direct heat reinjection wells are authorized by rule under Federally-administered UIC programs (see Section 1). Based on data from the Texas, California, Oregon, and Nevada reports, various State regulatory agencies are at least reviewing applications to install and operate geothermal injection wells. The Oil and Gas Division of the Railroad Commission of Texas runs a permit program for oil, gas, and geothermal injection wells. It is not known whether comments on proposed projects are solicited from other State agencies in Texas.

In California, the Geothermal Office of the California Division of Oil and Gas (CDOG) has primary responsibility for permitting the drilling and completion of geothermal injection wells. Monthly reports on the operational status of the well(s) is required along with injection volume and rate information. The Geothermal Office also requires a yearly mechanical integrity test and periodic analyses of injectate. The California Regional Water Quality Control Board is also actively involved in regulating geothermal injection. The authority exercised by the Water Board stems from the California Administrative Code and the Porter-Cologne Water Quality Control Act. The Water Board issues waste discharge permits regulating the choice of the injection zone and limiting the maximum injection pressure.

Three agencies in Oregon are responsible for oversight of geothermal injection. The Water Resources Department (WRD) regulates geothermal projects involving thermal fluids of less than 250°F (120°C). These fluids are considered ground-water resources and are the property of the public trust. Thermal fluids 250°C or hotter are considered a portion of the surface or mineral estate of the property and are regulated by the Department of Geology and Mineral Industries (DOGAMI). Each agency has procedures for drilling and standards for well construction. Chemical analyses of the water from the production zone, the injectate, and the injection zone are required. If an operator plans to inject into a different aquifer than the producing aquifer or if chemicals are added to the effluent, a second permit is required. This is a Water Pollution Control

Facilities Permit (WPCF) which is issued by the Department of Environmental Quality.

Regulatory oversight of the drilling and operation of geothermal injection wells in Nevada is shared by three agencies. Two of them, the Division of Environmental Protection (DEP) and the Division of Water Resources (DWR) are branches of the Department of Conservation and Natural Resources. The Department of Minerals (DOM) is the third agency. The DWR has broad jurisdiction over appropriation of water. The DEP administers and enforces the Nevada Pollution Control Law. This includes evaluating the potential to pollute waters of the State by waste disposal operations. The DOM share jurisdiction because it administers the Geothermal Resources Law under the Nevada Revised Statutes (NRS), Chapter 534A. The DOM and DEP are most directly involved and their responsibilities are discussed in the next few paragraphs.

Pursuant to NRS 534A a permit must be obtained through DOM to drill or operate a geothermal injection well. The DOM regulations address bonding to ensure proper plugging of abandoned wells. Other regulations cover minimum casing, cementing, safety, and control requirements. Before a permit can be issued DOM is required to consult with DWR, DEP, and the Department of Wildlife. The minimum requirements mentioned above vary depending on whether the geothermal facility is classified as domestic, commercial, or industrial. One area not regulated by this agency is periodic mechanical integrity testing.

The Division of Environmental Protection also has a permit program for geothermal injection wells. It is directed toward demonstrating the mechanical integrity of injection wells and that the heat spent fluids are injected into a zone of similar chemical quality within the geothermal reservoir. Baseline hydrogeological studies and analyses of both injection fluid and injection zone formation water may be required to obtain a permit. The DEP evaluates the need for a permit and permit requirements on an individual project basis where geology, hydrogeology, flow rates, and potential impacts are considered.

Geothermal injection on Federal lands may involve obtaining State and Federal permits. On a Federal level, the Bureau of Land Management has regulatory jurisdiction over geothermal injection operations at several facilities in California. They review the injection plans and approve well construction. No requirements for periodic, mechanical integrity tests, or injectate analyses are made by BLM. The CDOG does not extend its authority to include these facilities on Federal land. In Nevada, DEP would require all appropriate State permits be obtained in addition to Federal permits (Mr. Daniel Gross, DEP, 1986). How other States interface with Federal agencies to regulate geothermal injection on Federal lands is not known.

Some aspects of geothermal injection are regulated on a local level in Oregon. Subjects addressed are spacing requirements between production and injection wells and pump test requirements (Forcella, 1984). To date this is the only reported State having local ordinances or codes.

Recommendations

In general, these types of geothermal wells are sited, constructed and operated in such a way as to protect USDW. Two areas needing improvement have been identified by States which use geothermal wells. These are mechanical integrity testing and initial chemical analyses of injectate, and injection zone waters, followed by annual analyses of injectate.

Geothermal injection would have a high contamination potential if mechanical integrity could not be assured. Nevada strongly recommends that USEPA fund a detailed study on the types of MIT available for geothermal systems and the resolution of each method. The Bureau of Land Management does not require periodic mechanical integrity tests at any of the facilities under their jurisdiction in California. Annual MIT also are not required by DEP in Nevada. Another aspect of this problem is that there are many types of MIT. Many of these are based on well designs and reservoir conditions typical to the oil industry.

According to the California and Nevada reports, initial analyses of injectate and injection zone water quality are needed to establish baseline reservoir conditions. Annual injectate analyses will indicate any changing conditions possibly dictating new construction, siting, or operating conditions at a facility. Parameters included in the analyses, as recommended in the California and Nevada reports, should be temperature, inorganic constituents of the National Primary and Secondary Drinking Water Regulations, plus alkalinity, hardness, silica (SiO_2), boron, and ammonia nitrogen (NH_3 and NH_4+), gross alpha, and beta.

4.2.2.2 Heat Pump/Air Conditioning Return Flow Wells (5A7)

Well Purpose

With the recent rise in costs of residential heating oil and natural gas, many Americans have begun to realize the need for conservation of energy. The use of ground-water heat pumps has become increasingly common for residential space heating or cooling needs. Ground-water heat pumps are particularly efficient in areas where ground water is readily available and where there is extreme variation in seasonal temperatures.

The operation of a ground-water heat pump involves taking thermal energy (heat) from ground water and transferring it to

the space being heated. The process is reversed when cooling is required as heat pumps remove excess heat from a building and put it into the ground water. Ground-water heat pumps do not consume any water in the heat exchange process. Whatever volumes of water are supplied to the system must be returned to the environment; therefore, owner/operators are faced with finding a method to discharge the spent water.

There are several options available for disposal of heat pump/air conditioning effluent including return to the source aquifer, injection into an alternative aquifer, discharge for secondary use (e.g. irrigation), discharge to surface, etc. The most commonly recommended method of discharge is the return of water to the aquifer from which it was extracted. Subsurface injection of spent water qualifies heat pump/air conditioning return flow wells as Class V injection wells per 40 CFR 146.5(e)(1).

Inventory and Location

The compilation of a national inventory of heat pump/air conditioning return flow wells has been complicated by insufficient delineation of the type 5A subclasses within the Federal Underground Injection Control Reporting System (FURS) and State reports. Another complicating factor is errant classification of heat pump/air conditioning return flow wells as cooling water return flow wells, and vice versa. There are 10,017 heat pump/air conditioning return flow wells inventoried to date, and their distribution throughout the United States is presented in Table 4-24.

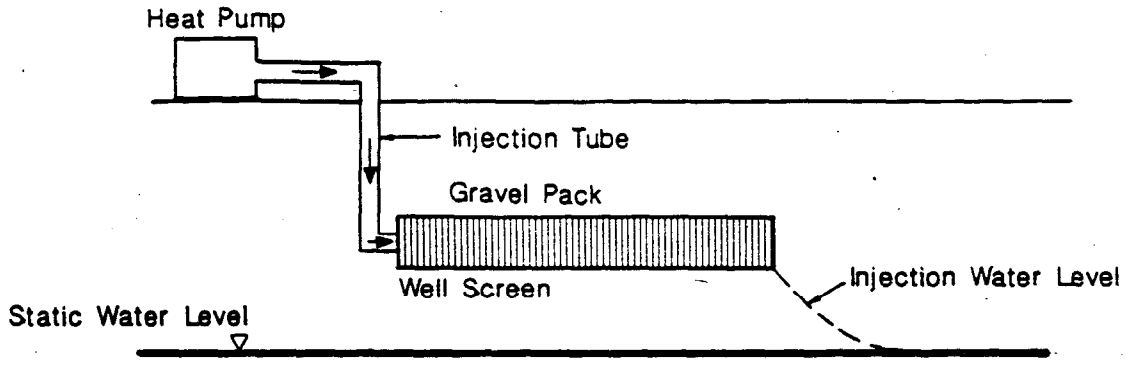
Well Construction, Operation, and Siting

Construction. Heat pump/air conditioning return flow wells are constructed in a variety of ways throughout the United States. Typically, waters are returned to the surface through shallow, large diameter wells and horizontal wells (Figure 4-17), small diameter wells (Figure 4-18), or in some instances, drainfields. Information from State reports show that the average depth of heat pump/air conditioning return flow wells in the conterminous United States is approximately 190 feet, with well depths ranging from 19 to 930 feet. Return flow wells that are completed in sand and/or gravel facilitate water movement. Heat pump/air conditioning return flow wells must be constructed as well as, if not better, than the ground-water supply wells. Iowa suggests that the well should be cased from the surface through the top of the injection zone. Casing aids in supporting the walls of the well (borehole) and helps keep out possible surface contaminants. Three States (Iowa, Kansas, and Nebraska) recommend that when boreholes are drilled oversize, the annular space (empty space between the casing and the borehole) should be

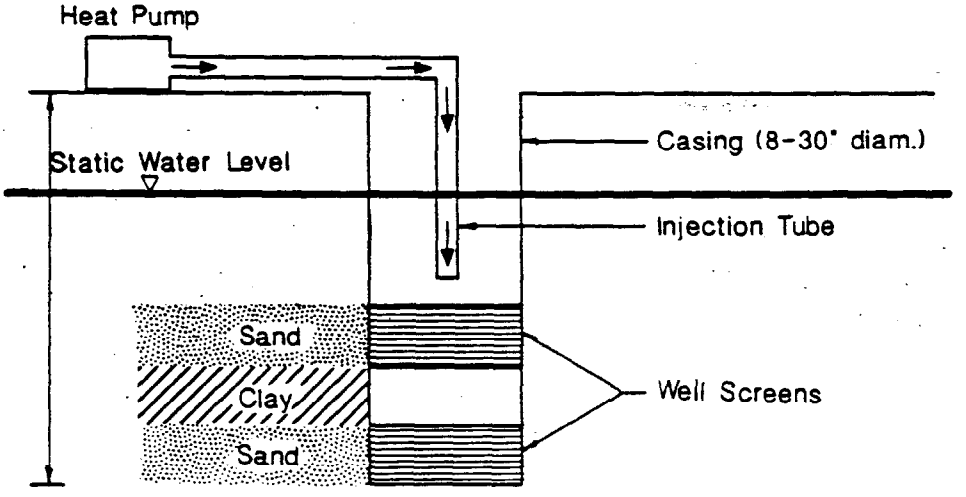
TABLE 4-24: SYNOPSIS OF STATE REPORTS FOR HEAT PUMP/AIR CONDITIONING RETURN FLOW WELLS(5A7)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	12 WELLS	PERMIT	YES	NONE
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	10 WELLS	PERMIT>15K GPD	YES	LOW
New Hampshire	I	2 WELLS	N/A	YES	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	181 WELLS	RULE/PERMIT	YES	N/A
New York	II	YES	PERMIT	NO	LOW
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	164 WELLS	PERMIT	NO	LOW
Maryland	III	368 WELLS	PERMIT	NO	LOWEST/3 TYPES
Pennsylvania	III	24 WELLS	N/A	NO	LOWEST/6 TYPES
Virginia	III	1,735 WELLS	N/A	YES	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	2,671 WELLS	PERMIT	NO	7TH HIGHEST/8 TYPES
Georgia	IV	111 WELLS	BANNED	NO	LOW
Kentucky	IV	YES	N/A	NO	N/A
Mississippi	IV	7 WELLS	N/A	NO	N/A
North Carolina	IV	79 WELLS	PERMIT	NO	LOW
South Carolina	IV	60 WELLS	RULE	YES	2ND HIGHEST/3 TYPES
Tennessee	IV	70 WELLS	N/A	NO	LOW
Illinois	V	57 WELLS	RULE	NO	N/A
Indiana	V	236 WELLS	N/A	NO	N/A
Michigan	V	760 WELLS	N/A	NO	N/A
Minnesota	V	34 WELLS	PERMIT	NO	N/A
Ohio	V	73 WELLS	N/A	NO	LOW
Wisconsin	V	4 WELLS	RULE	YES	LOW
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	5 WELLS	PERMIT	NO	LOW
New Mexico	VI	27 WELLS	REGISTRATION	NO	LOW
Oklahoma	VI	>100 WELLS	RULE	NO	LOW
Texas	VI	1,014 WELLS	RULE	YES	LOW
Iowa	VII	17 WELLS	N/A	NO	LOW
Kansas	VII	394 WELLS	N/A	NO	LOW
Missouri	VII	741 WELLS	REGISTRATION	NO	LOW
Nebraska	VII	650 WELLS	RULE	NO	LOW
Colorado	VIII	2 WELLS	N/A	NO	LOW
Montana	VIII	20 WELLS	NONE	NO	LOW
North Dakota	VIII	135 WELLS	RULE	NO	LOW
South Dakota	VIII	48 WELLS	N/A	NO	N/A
Utah	VIII	7 WELLS	PERMIT	NO	4 (7=HIGHEST)
Wyoming	VIII	7 WELLS	PERMIT	NO	8TH HIGHEST/10 TYPES
Arizona	IX	YES	NONE	NO	LOW
California	IX	53 WELLS	PERMIT	NO	LOW
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	YES	N/A	NO	LOW
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	7 WELLS	PERMIT	NO	MODERATE
Idaho	X	20 WELLS	PERMIT	NO	12TH HIGHEST/14TYPES
Oregon	X	13 WELLS	PERMIT>5K GPD	NO	N/A
Washington	X	110 WELLS	PERMIT	NO	LOW

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



A.



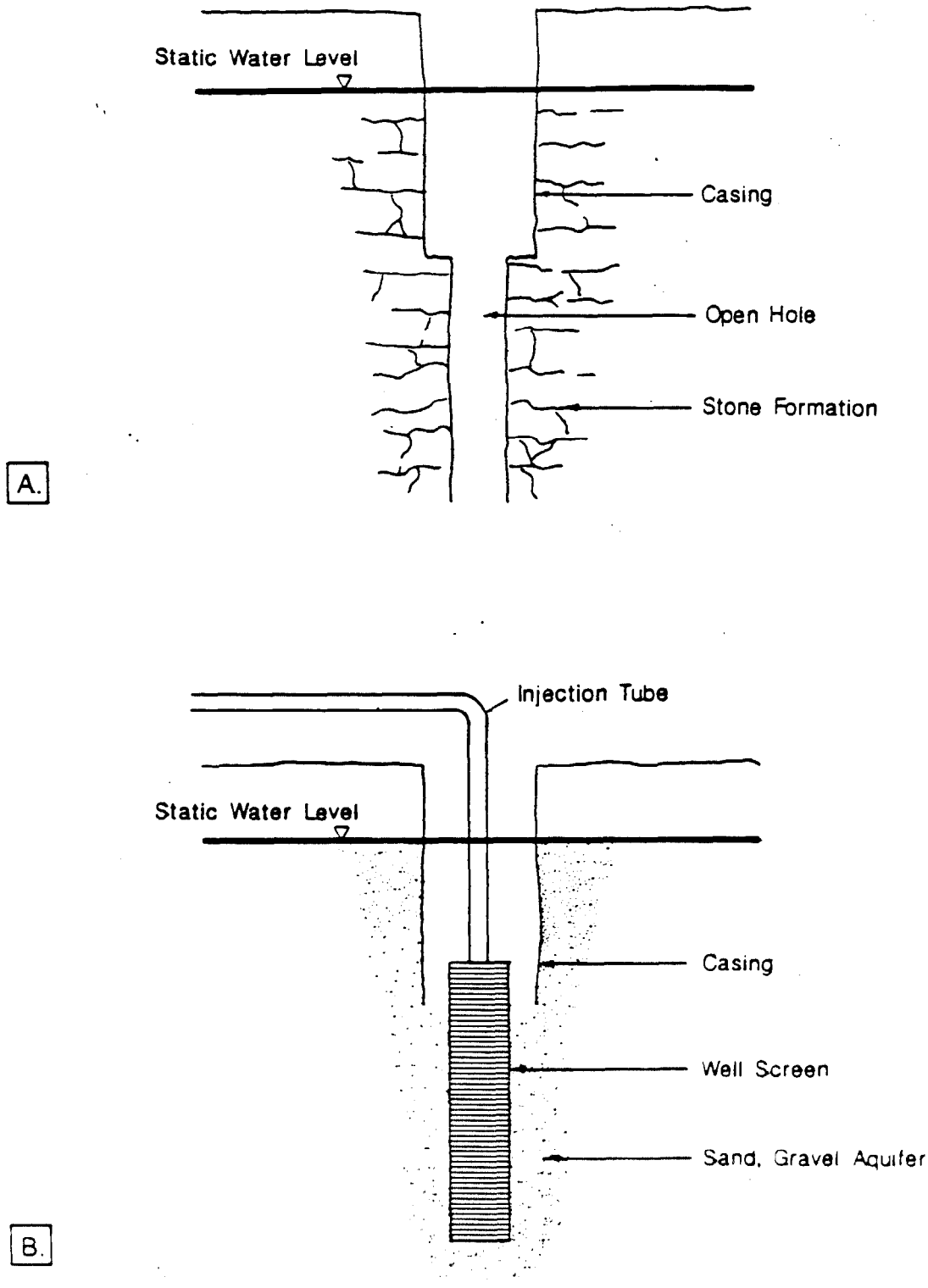
B.

SHALLOW WELLS

A. HORIZONTAL
B. LARGE DIAMETER

(From McCray Ed. 1983 NWWA Publication)

Figure 4-17



DEEPER SMALL DIAMETER WELLS

A. COMPLETED IN STONE
B. COMPLETED IN SAND

Figure 4-1

filled with cement or clay grout to prevent introduction of contaminants from the surface. (See Figure 4-19.)

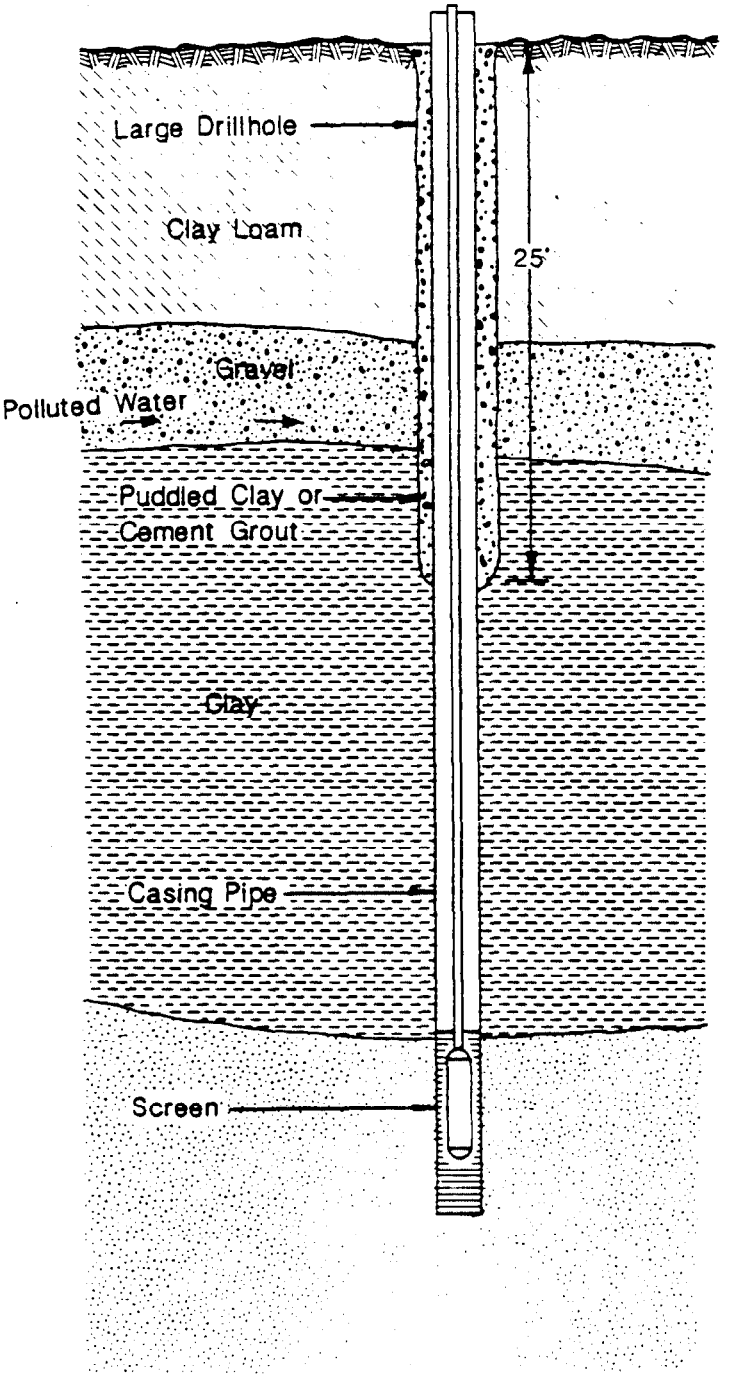
Operation. Although the most common operation of heat pump/air conditioning return flow wells is through gravity flow, this is not always possible. In aquifers with low permeabilities, return flow waters may need to be pressurized to produce sufficient infiltration rates. Also, most aquifers will not accept 100% of their yields. An aquifer which yields 10 gallons per minute (gpm) will readily accept only 7.8 gpm of the return flow, potentially allowing the remaining 2.2 gpm to run out on the ground. These problems are alleviated by the use of pumps to pressurize return flows or by the storage of water to slow return flow rates enough to allow total return.

Siting. Siting is a very important factor in the use of heat pump/air conditioning return flow wells. The National Water Well Association recommends the return of heat pump/air conditioning return flow effluent to the production aquifer, providing the water remains in a closed system. There are several methods for returning water to its source, including the use of a single well for both supply and return; the use of two wells which alternate between supply and return, depending on the season; and the use of two wells, one a permanent supply, one a permanent return. The most efficient well system is the two well alternating system, but it is also the most costly and it is used on a limited basis in the United States. Discharge to aquifers other than the production aquifer also occurs on a limited basis. However, this method is not widely accepted unless the supply and return aquifers are chemically compatible.

Injected Fluids and Injection Zone Interactions

Nature of Injected Fluids. Generally heat pump/air conditioning return flow wells dispose or return supply water which has been only thermally altered. Even in cases where poor quality ground water is supplied to the heat pump, additives generally are not used. Water with high concentrations of metals and salts, high or low pH, or even water that is not of drinking water quality is readily utilized in these systems by simply using fixtures and components which resist scaling, incrustation, and corrosion of the plumbing and piping.

Water flow requirements for heat pump/air conditioning systems depend on several factors: 1) System size and design (varies widely with application), 2) water flow per BTU/hour of heating (varies among systems), and 3) temperature of groundwater source (should provide 50,000 BTU/hour of output -- typical requirements for an average modern home). A heat pump/air conditioning system typically consumes between 7,500 and 21,600 gallons per day (gpd), depending on the system's design. The use of heat pumps to heat water for household use in addition to space heating or large commercial systems may require much more



PROPER GROUTING OR CEMENTATION
OF ANNULAR SPACE

(From McCray Ed. 1983 NWWA Publication)

Figure 4-19

water. Information from the national inventory suggests that flow rates throughout the United States vary from 2,500 gpd for small residential applications to 1,000,000 gpd at a shopping mall.

Injection Zone Interactions. The most significant interactions which occur when returning spent heat pump/air conditioning return flow to the source aquifer involve thermal alteration of the aquifer water. Generally, thermal alteration of an aquifer can alter water chemistry and viscosity, aquifer permeability and porosity, and the physical characteristics of the water. However, little is known about the specific effects of thermal alteration on aquifers.

Chemical equilibria in an aquifer is a very fragile balance, and in certain cases, it may require only slight temperature changes to precipitate certain salts or solids or to take more into solution. Furthermore, hydrolysis of certain metals may be achieved with only slight temperature changes. Temperature also affects the ambient pressure within an aquifer and may stimulate or retard bacterial growth.

There are several factors which influence the rate of thermal impact within an aquifer. They include flow rates, volumes, and temperature disparities between injected and receiving waters. Heat is transported through an aquifer by combinations of convection and conduction. The movement of thermal fronts within an aquifer is influenced primarily by parameters which control the flow of water. Temperature fronts advance faster in aquifers which have smaller values of the porosity-thickness product. The minimum distance to which injected water fronts travel is inversely proportional to the square root of the product of porosity and thickness. Aquifers with high hydrodynamic dispersivity increase the movement and speed of thermal fronts. In addition, the heat capacities of the specific water and rock in an aquifer control the quantities of heat stored.

Well siting also plays a major role in thermal front advancement. Temperatures in aquifers change more rapidly when production wells are located downgradient from injection wells. In addition, partial penetration or completion has nearly the same effect (increasing the movement and speed of the thermal front) as reducing the total aquifer thickness to the length of the completed interval.

Well spacing plays one of the most significant roles in temperature change within an aquifer. The temperature difference between inlet and outlet ends of a heat pump is fixed for a given heat pump; therefore, the temperature of the injected water changes directly with the temperature of the produced water. When the thermal front arrives at the production well, water begins to recycle between the wells leading to greater temperature changes within the aquifer in shorter times. This effect could be

multiplied if heat pumps with supply and injection wells were installed on adjacent properties.

The most serious interaction occurs when waters are returned to aquifers other than the source. In addition to thermal impacts resulting from injection, if receiving waters are not chemically compatible with injected waters, then chemical interactions resulting from thermal impacts may be more severe.

Hydrogeology and Water Use

Most heat pump/air conditioning return flow wells inject spent waters directly into USDW. The majority of these groundwater heat pump systems are installed at residences, and domestic supply wells are often the source for heat pump systems in residential applications. Because returning the spent water to its source is the most common method of disposal for heat pump effluent, we can see that injection to USDW is prevalent. The expense of drilling usually mandates return to the shallowest formations. Since shallower aquifers often are of higher quality, this is a major concern. Private or public supply wells completed in the vicinity of the injection zone consequently are subject to any thermal and/or chemical changes which may occur in the aquifer. The degree to which they may be vulnerable depends on a number of items, including distance (horizontal and vertical) from injection operations, volumes of injected fluids, hydraulics of the aquifer, amount of water drawn in the supply well, etc. Domestic supply wells and heat pump/air conditioning return flow wells often are completed in formations less than 200 feet deep.

While it does not occur often, heat pump/air conditioning return flow is sometimes injected into formations other than the supply aquifer. Usually, these are shallower formations, and the practice is implemented to minimize installation costs (drilling costs are less). Receiving waters in these formations are subject to the same changes as the original aquifer but with higher chances of chemical alteration. If the receiving formation is an USDW which supplies public or private facilities, those supply wells are subject to alterations. The same factors previously discussed would affect the degree of alteration. Water use and hydrogeology should be key points in determining proper siting and location of heat pump/air conditioning return flow wells.

Contamination Potential

Based on the rating system described in Section 4.1, heat pump/air conditioning return flow wells are assessed to pose a low potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would not allow fluid

injection or migration into unintended zones. Injection fluids typically are of equivalent quality (relative to standards of the National Primary or Secondary Drinking Water Standards and RCRA Regulations) than the fluids within any USDW in connection with the injection zone. Based on injectate characteristics and possibilities for attenuation and dilution, injection does not occur in sufficient volumes or at sufficient rates to cause an increase in concentrations (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeters or in a region studied on a group/area basis.

One of the most serious threats to USDW through the use of heat pump/air conditioning return flow wells is thermal degradation of an aquifer. Thermal change resulting from injection of heat pump effluent occurs in all aquifers, at least temporarily. The degree to which it occurs depends on several factors.

A study conducted by the NWWA in 1979 used a computer model to determine thermal impacts that might be expected as a result of heat pump discharge into a water supply aquifer. To limit the variables, the model kept the aquifer characteristics, well design, and well spacing constant. It was determined that measurable changes in aquifer temperatures can be expected to occur if ground water used by a heat pump is returned to the subsurface.

While the changes are measurable, and the migration of a thermal front from the injection well may be anticipated, it should be noted that aquifer characteristics (a constant in the study) play a very important role. For example, an aquifer one-half the thickness used in the simulation will expand the thermal front at twice the rate. The hydraulics of an aquifer also play an important role in expanding thermal fronts.

The possibility also exists for chemical alteration as a result of temperature changes within an aquifer. Solids present in an aquifer are at equilibrium, which is to say that all those solids that will dissolve under the present conditions have done so. Changing physical conditions (i.e. changing the temperature) will alter the equilibrium within the aquifer. Usually, a temperature increase will bring more solids into solution and result in increased total dissolved solids (TDS). Increased TDS in turn, may result in degradation of the water so that drinking water standards are threatened, or it may result in altered ground-water flow. Conversely, lowering ambient aquifer temperature may result in precipitation of certain salts and metals which can lead to formation plugging and subsequent flow changes. In addition, thermal changes may result in the hydrolysis of certain metals within an aquifer and an increase or decrease in biological activity.

Furthermore, thermal interference may occur within an aquifer between heat pump supply wells and injection wells. While

this is a threat to supply waters, it is probably not permanent and can be easily alleviated by discontinuing injection.

The practice of injecting poor quality waters into high quality USDW presents a potential threat of direct contamination of ground water. Fortunately, this practice is not common. It is believed to be happening on such a small scale that the threat is not serious. Such operations actively degrade the waters into which they are injecting.

Possibly the most serious threat to USDW resulting from use of heat pump/air conditioning systems is the practice of surface discharge. In certain areas of the country ground-water supplies are being rapidly depleted through the use of heat pump/air conditioning systems discharging to the surface.

Current Regulatory Approach

Heat pump/air conditioning return flow wells are authorized by rule under the Federally-administered UIC programs. Based on data compiled in 1983, most states chose to regulate heat pump/air conditioning return flow wells as a part of their UIC programs (Table 4-25). However, the data in Table 4-25 are not entirely consistent with the information compiled in the State report.

To date, 16 States in the conterminous United States require permits for the injection of heat pump/air conditioning discharge waters. These requirements are administered by a variety of State agencies. For example, most States with regulatory policies promote the return of spent waters to the production aquifer. While some aspects of the regulatory policies differ widely, common factors include prohibited injection of either waters used in contact systems or chemically altered waters, mandated separations between injection and supply wells ranging from 50 to 500 feet, and required submittal of maps or sketches showing injection well location in relation to supply wells, streams, ponds, lakes, water courses, buildings, etc. Most States, in accordance with USEPA administered UIC programs, require the reporting of these systems for inventory purposes. Local governments generally are not attempting to regulate heat pump air conditioning return wells at the present time.

Recommendations

Because aquifer characteristics play an important role in the degree of thermal degradation and, therefore, chemical alteration, some States recommended that each well location be examined on the basis of its own characteristics. Several States

TABLE 4-25

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Alabama	No permit needed to use water for H-P under domestic category	Simple permit required by Water Improvement Commission. Well regulated as Class V well under Underground Injection Control Program (UIC)	Theoretically covered by NPDES-however this system usually not equipped to consider small domestic use so in most cases could just discharge without a permit	Not a problem if discharge to land owned by H-P user	A loophole in regulations-this type of discharge is allowed-if tank is big enough and far enough from well	Would probably be allowed almost anywhere—although in many areas would be cost-prohibitive
Alaska	No problem to obtain water rights	No mechanism to require a permit or to prevent this type of injection well				
Arizona	No problem to obtain water use—falls into domestic category--no permit needed	Will be regulated by rule as Class V well under UIC when the state obtains primacy				
Arkansas	No permit needed for water use of this type	Permit required by Dept. of Pollution Control and Ecology as Class V well under UIC				
California	32 counties out of 58 total require permits for all wells	At present, there are no regulations. In the future, may be regulated by the regional water quality control boards and through UIC				
Colorado	No permit needed for a well that has a yield less than 15 gpm	Permit required by state engineer				
Connecticut	Diversion permit required for use of more than 50,000 gpd	Permitted as Class V well under UIC				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama
**Small-scale domestic heat pump utilization only

TABLE 4-25, Continued

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Delaware	No problem to use water-would be classified as a domestic well-no permit required	State policy is to encourage reinjection. Permitted through UIC as Class V well				
Florida	A permit would be required for this volume of water use	Permit required by Dept. of Environmental Regulation as Class V well under UIC				
Georgia	No permit needed for use less than 100,000 gpd	Reinjection of cooling water is allowed in state. No permit is required for this				
Hawaii	Classified as a domestic well-so no problem to obtain water use	A regulation exists that requires permission for disposal wells and wastewater disposal-however not enforced at present				
Idaho	No permit needed for domestic use—except in critical ground water area--need a permit for any use more than 13,000 gpd	Permit will be granted if water quality remains the same	No problem except in critical ground water areas where recharge back to the aquifers would be required			
Illinois	Domestic use classification--no permit needed	Heat pump return wells are unregulated. The state EPA has the jurisdiction to permit them but has chosen not to do so at the present time				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama
**Small-scale domestic heat pump utilization only

TABLE 4-25, Continued

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Indiana	Domestic use--no permit needed	Conventional and cooling water recharge wells not regulated--though Stream Control Board has theoretical authority. Permitting regulations currently being considered	Board of Health permit--no special problem to obtain			
Iowa	No permit needed for domestic use	The state is not administering the UIC. Heat pump wells must be registered with U.S. EPA. Users are encouraged to consult with Iowa Geological Survey before construction				
Kansas	A water appropriation permit would be needed	No regulations at present but will probably require a permit as Class V well of UIC				
Kentucky	Private use--no permit required	Will probably be regulated as Class V well under UIC				
Louisiana	No permit required	Permit required as Class V well of UIC				
Maine	No permit needed for this type of water use	Permit required by Water Bureau of Dept. of Environmental Protection				
Maryland	A permit would be needed for use of this type	Permit required at county level. One county has banned heat pumps				
Massachusetts	No permit needed for this type of water use	Registration will be required with the Division of Water Pollution Control as Class V well under UIC				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama
**Small-scale domestic heat pump utilization only

TABLE 4-25, Continued

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Michigan	No permit needed for this type of water use	No permit required by Water Resources Commission as long as heat pump has a heat exchange rate less than 120,000 Btu/hour or has no chemical additives				
Minnesota	No permit required	Permit required by Dept. of Health. Drinking water well may not be used as supply well. Water must be reinjected to same aquifer in a closed system. No other type of disposal allowed				
Mississippi	No permit required	Permit required as Class V well of UIC				
Missouri	No permit needed	Permit required by Dept. of Natural Resources unless heat pump is limited to single family residence or is limited to eight or fewer single family residences with a combined injection/withdrawal rate of 600,000 Btu/hour				
Montana	Certificate of water right is needed-no serious problem to obtain	Class V well of UIC				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama
**Small-scale domestic heat pump utilization only

TABLE 4-25, Continued

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Nebraska	No permit needed	Permit required as Class V well of UIC. New regulations possible in summer of 1983				
Nevada	Permit would be required	Not regulated at this time but probably will be in the future				
New Hampshire	No permit needed	Notification required. Wells regulated as Class V wells of UIC				
New Jersey	No permit needed	Permit requires wells 5 feet apart and water returned to same aquifer				
New Mexico	Permit needed for use of this magnitude	Regulated under New Mexico's existing ground water regulations on a case-by-case basis				
New York	No permit needed	Dealt with on an ad hoc basis by Division of Water Dept. of Environmental Conservation. May require a discharge permit if a unit presents a possible thermal pollution problem				
North Carolina	No permit required	Recharge well requires a permit as a Class-V-A well under the state's UIC				
North Dakota	Standard appropriation permit needed	Registration required as Class V well of UIC				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama

**Small-scale domestic heat pump utilization only

TABLE 4-25, Continued

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Ohio	No permit needed for domestic use	No permit required. The state EPA has recommended construction and operation procedures				
Oklahoma	No permit needed for domestic use	Will be treated as Class V well of UIC for permitting purposes				
Oregon	Less than 15,000 gpd--no permit required	Permit and report required by Water Resources Dept. as low temperature geothermal well				
Pennsylvania	No permit needed	No regulations. The state is not adopting the UIC program. Bureau of Water Quality Management suggests returning water to its original source				
Rhode Island	No permit needed	Approval will be required as Class V well of UIC	RIPDES may require a simple permit			
South Carolina	No permit needed	Pending legislation will designate heat pump wells as Class V-B wells. Wells will not need permits but will be reported. Construction standards are being considered.				
South Dakota	No permit needed	Will be regulated as Class V well under UIC				
Tennessee	No permit needed for water use less than 50,000 gpd	Heat pumps will be regulated by UIC. Proposed rules exclude domestic heat pumps from permit requirements. Commercial and industrial heat pumps will be permitted by rule as Class V well of UIC				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama
**Small-scale domestic heat pump utilization only

TABLE 4-25, Continued

Summary of Groundwater Heat Pump Use and Effluent Disposal Regulations by State** (Source: McCray, 1983)

State	Water Use	To Recharge Well	To Surface Water*	To Land*	To Septic Tank*	To Sewer*
Texas	No permit needed for water use	Authorized by rule as Class V well of UIC				
Utah	Permit needed for use of any type	Class V well of UIC				
Vermont	No permit needed	Probably will be regulated as Class V well under UIC				
Virginia	No permit needed	Currently considering regulations that would require a general national pollutant discharge elimination system permit for small heat pumps and a specific NPDES permit for large units.				
Washington	Permit needed for use of more than 5,000 gpd	Discharge permit not required on single family residence. Anything larger requires permit from Dept. of Ecology				
West Virginia	No permit needed	Return wells are Class V wells under UIC. However, there are no plans to require permits at this time				
Wisconsin	No permit needed	Reinjection of water allowed only by permit through experimental program running through 1984				
Wyoming	No permit needed	Permit required to recharge water				

* If no information is provided in this column, regulations pertaining to this type of discharge are similar to those in Alabama
**Small-scale domestic heat pump utilization only

recommended that guidelines for construction, siting, and operation be developed. Some of these guidelines included the following:

1. Return wells should be cased through the top of the injection formation (IA);

2. Annular spaces should be cemented or grouted (IA, KS, NE, TN);

3. Return should be in to or above the supply aquifer (LA, IA, KS, SC);

4. Closed loop systems should be required (TN, UT);

5. Discharge should be to the surface rather than to an injection well (LA);

6. Adequate spacing should be provided between injection wells and supply wells (KS, NE, SC);

7. Authorization by rule is appropriate for properly spaced and operated systems (SC).

8. Volumes and temperatures of injected fluids should be monitored (NC);

9. Records should be maintained by counties and periodically uploaded to the State water rights data management center in order to monitor well density (WA);

10. Analyses of receiving waters should be carried out periodically to monitor changes in aquifer temperature and chemistry (KS, WA);

11. Permits for development of a commercial system should include requirements for water quality characterizations of both source and receiving water (WA).

12. More research is needed on the theoretical environmental effects of heat pumps (MO, SC, AZ);

13. New regulatory systems should be directed at large-scale systems rather than at systems for single family dwellings (LA, OK, TX);

14. The state permitting agency should set construction standards and ensure that wells are constructed and operated properly (FL, KS, MO, NE, SC, WA);

15. The waste product should include no additives or only approved additives (LA, KS, NE);

16. A licensed water well contractor should be employed to install, rework, and plug/seal the well (LA, IL); and

17. A policy of prohibiting new well installation in known or suspected contaminated aquifers should be developed and implemented by states. This policy would be administered by local government (WA).

4.2.2.3 Aquaculture Return Flow Wells (5A8)

Well Purpose

Aquaculture is the active cultivation of marine and fresh water animals and plants. When raised in environments in which temperature, food rations, and other factors can be regulated, fish and shellfish can undergo rapid growth through high efficiency of feed conversion to useable protein (McNeil, 1978). Geothermal aquaculture utilizes relatively warm water from the earth. Primarily, low-grade geothermal ground water is used for this purpose, though steam and hot water reservoir supplies also may be used. Warm water aquaculture also can derive the necessary heat from a variety of sources such as reuse of waste heat from thermal power generation sources or industrial processes. Aquaculture is not limited to warm water resources, and certain facilities use cold marine water to cultivate sea life.

Injection generally is an acceptable technique for disposal of liquid and semi-solid wastes associated with aquaculture. Disposal by injection has the advantage of replenishing the ground-water resource, often requiring no pumping, and being technically feasible. These injection wells are recognized as Class V wells according to 40 CFR 146.5(e)(12). Because of the variety of water sources for aquaculture, only some aquaculture wastewater disposal wells are actually return flow wells.

Inventory and Location

At present, the only documented aquaculture waste disposal wells inventoried are located in the State of Hawaii (Table 4-26). These facilities are on the islands of Oahu and Hawaii and include seven active, three standby, and fifteen proposed injection wells. This data is summarized by facility and presented in Table 4-27.

TABLE 4-26: SYNOPSIS OF STATE REPORTS FOR GROUNDWATER AQUACULTURE RETURN FLOW WELLS(5A8)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	25 WELLS	PERMIT	YES	LOW-HIGH
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	PERMIT>5K GPD	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

TABLE 4-27

AQUACULTURE WASTEWATER DISPOSAL
FACILITIES IN HAWAII

FACILITY	LOCATION	# OF WELLS	STATUS	PERMIT #
Sea Life Park	Makapuu Point, Waimanalo, Oahu	5	Active	UO1219
Marine Culture Enterprises	Kahuku, Oahu	3	Standby	UO1315
Oceanic Institute	Waimanalo, Oahu	2	Active	UO1325
Hawaiian Abalone Farms	Kailua-Kona, Hawaii	15	Under Construction (August, 1986)	UH1384

Sea Life Park, of Waimanalo, Oahu, has five active disposal wells that inject untreated aquaculture wastewater. Small amounts of secondary treated sewage, generated on site, are also injected. Marine Culture Enterprises, Kahuku, Oahu, is an aquaculture operation producing marine shrimp for resale. Three injection wells are permitted for disposal of salt water and untreated aquaculture wastewater used in the operation. These wells are currently inoperative due to severe clogging problems, and the facility utilizes canal discharge to the ocean under a National Pollutant Discharge Elimination System (NPDES) surface water outfall permit. Oceanic Institute of Waimanalo, Oahu has two active injection wells used for disposing aquaculture wastewater which serve the secondary purpose of sanitary wastewater disposal, originating from a small on-site septic system. Finally, Hawaiian Abalone Farms, Kailua-Kona, Hawaii, has proposed 15 injection wells to be used for disposal of untreated aquaculture wastewater. At the time of the last inventory update (August, 1986), these wells were still under construction.

Construction, Siting, and Operation

Construction. Injection wells associated with disposal of untreated aquaculture wastewater typically are simple in design. Total depths vary, depending upon depths to injection aquifers. For the inventoried wells, total depths range from 50 to 200 feet below land surface. Wells typically display two different wellbore diameters. The upper portion of the wellbore is larger in diameter and is often cased with lightweight steel or PVC. If steel is used, thinner wall thicknesses (3/16") may be used, as compared to thicker-walled PVC (1/2"). The injection zone is usually below the larger wellbore into a smaller-diameter uncased wellbore. Perforated or slotted liners may be present opposite the injection zone. The diameter of the lower wellbore (when present) usually is equal to or smaller than the diameter of the smallest casing used at the surface. This serves two purposes: 1) providing a ledge to seat the casing, and 2) isolating the annulus to facilitate gravel packing and cement grouting.

Injection may be facilitated by using a gravel pack when slotted or perforated casing is used. The thickness of gravel packing used varies but typically extends more than twenty feet above the uppermost perforations or slots in the casing. Cement grout may be pumped into the annulus atop the gravel packing and returned to the surface to provide a seal. Surface projections (wellheads) for these injection wells typically are not elaborate. The facility where a site inspection was conducted (Marine Culture Enterprises) was characterized by open-ended PVC tubing for injection wellheads. This PVC connection can be hooked up to various waste stream sources by PVC lines or hoses. This construction design is such that almost any substance could

be introduced into the wellbore. Other facilities reporting construction designs display similar simplicity for wellhead constructions. A schematic diagram representative of the construction features for inventoried wells at one facility is presented in Figure 4-20.

Siting. All data acquired to date in the investigation indicate that no specific strategy exists for siting these injection wells with respect to ground-water quality. Most facilities of this type in Hawaii are located along the coast, and the geology of the shallow aquifers in these areas is relatively homogeneous. It is concluded, then, that siting is conducted with primary emphasis upon proximity to the aquaculture facility.

Operation. The three inventoried facilities with active or standby wells use saline ocean water or brackish ground water for aquaculture operations. The facility on the island of Hawaii which has proposed 15 new injection wells will use cool marine water taken directly from the Pacific Ocean. The injection wells generally are designed for large disposal volumes, and variations from 60,000 to 10 million gallons per day have been reported.

Because the water used for marine aquaculture must support abundant life, water must be continually circulated to maintain marine conditions within the holding tanks. As such, volumes of effluent from the operations tend to remain relatively constant. While injectate volumes may be constant, the composition of effluent can vary greatly with time. This is discussed in the following sub-section.

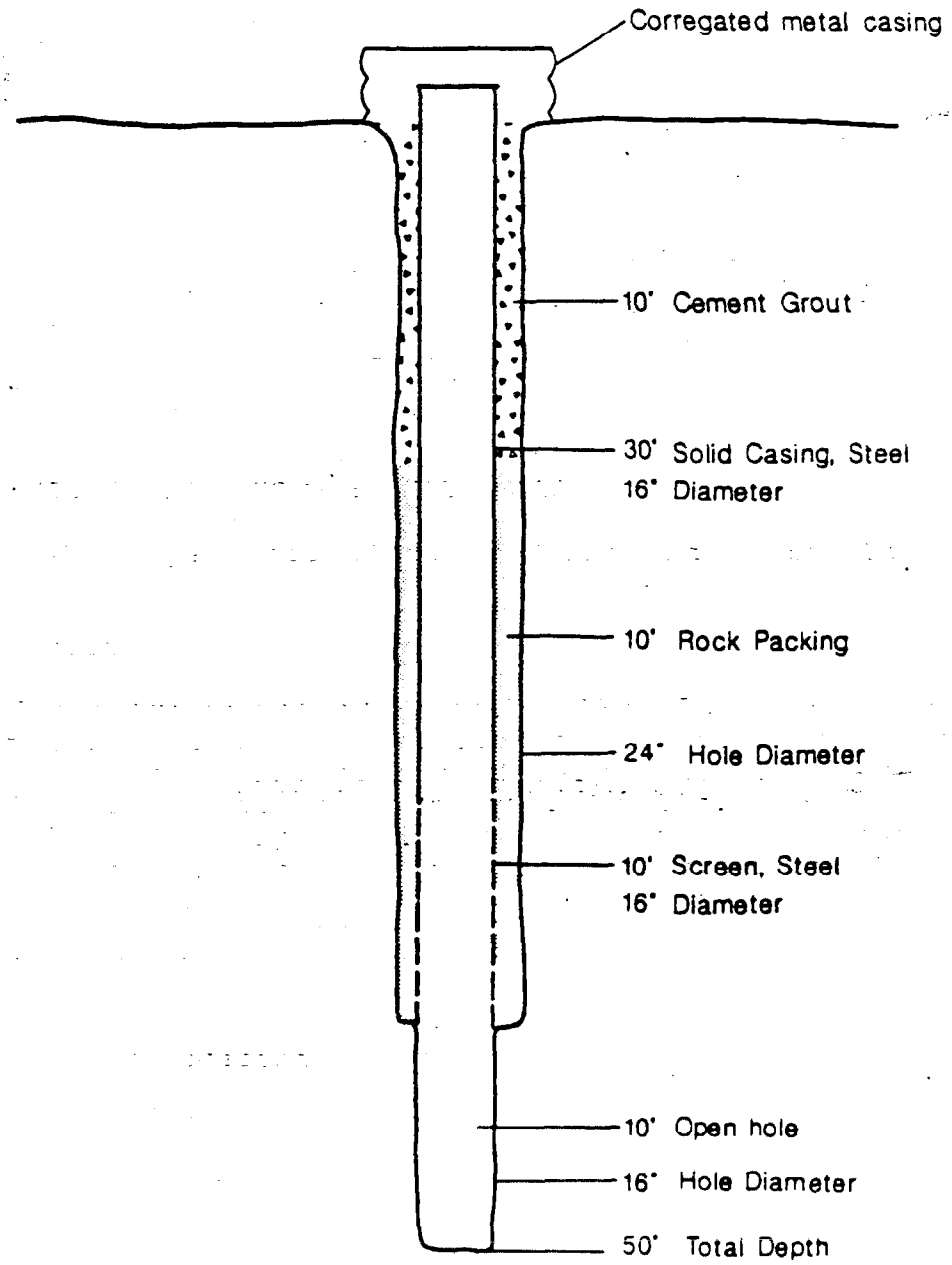
Some problems associated with reinjection of aquaculture wastewater include:

1. The volume of water required by some operations may represent too large a volume to be reinjected.

2. Well plugging, primarily at the injection zone perforations, may occur if the water is used directly in raising aquatic animals and is not pretreated or filtered prior to injection.

3. Depending upon the location and quality of the geothermal water source, discharge of the used fluids into aquifers other than the source can introduce traces of heavy metals, organic matter, and higher concentrations of dissolved and suspended solids.

4. Precipitation of dissolved solids within the injection zone, caused by the interaction between fluids of different temperatures.



TYPICAL WELL CONSTRUCTION FOR GROUNDWATER AQUACULTURE RETURN FLOW WELL

Figure 4-

At the present time, maintenance of mechanical integrity within disposal wells is not known to be practiced at these facilities. Because the injection aquifers along coastal areas of Hawaii essentially begin at the surface, protection of certain zones from injection fluids would not appear to be a primary concern. Mechanical integrity should be of immediate concern if, or when, well problems exist to the point that the injectate overflows the wellbore and causes surface problems.

Injected Fluids and Injection Zone Interactions

The facilities inventoried for this investigation typically dispose of very large volumes of wastewater. Annual volumes from 20 million gallons (63 acre-feet) to 3.65 billion gallons (11,200 acre-feet) have been reported. Samples taken from test wells for supply and injection sites at an inspected facility in Kahuku displayed salinity values of 5.4 to 22.1 parts per thousand. Detailed site-specific chemical analyses for waste streams are not available at present, thus characterization of such effluents must be general in nature. The wastewater is essentially salt water with added nutrients, bacteriological growth, perished animals, and animal detritus. The effluent likely contains nitrates, nitrites, ammonia, high biological oxygen demand (BOD), and orthophosphate. If geothermal ground water is used, traces of arsenic, boron, and fluoride also may be present. As discussed, certain of the inventoried facilities also dispose of small volumes of treated sewage generated on-site. Nitrates and pathogens would be constituents of most concern in that portion of the waste stream.

Injection aquifers at these facilities are of two kinds. Volcanic aquifers typically are highly porous, owing to their vesicular development. Permeability usually is high and generally is the result of fracturing associated with magmatic cooling. The other injection aquifer typical of these facilities is a "caprock formation," composed of Pleistocene coral and algal reefs. Rocks of this type generally are characterized by moderate primary porosity and permeability which is the result of the decay of organic material within a calcium carbonate matrix. Permeability may vary widely, as secondary processes can increase or decrease porosity.

Injectivity can be negatively impacted by two phenomena: 1) high concentrations of suspended solids in the injectate causing filter cake buildup or clogging at the wellbore, and 2) pore plugging due to precipitation of solids as the injectate moves through the rock media. An example of the first problem has been documented at one facility on the island of Oahu, where injection of wastewater associated with shrimp farming was being conducted. Injection wells were used between August, 1984 and February, 1985, at which time the wells began to "back up," and continued

injection became impossible. These wells clogged probably as a result of high amounts of animal detritus and other debris found within the untreated, unfiltered wastewater.

Pore plugging as a result of precipitation within the rock media is difficult to predict, and little documentation for in situ occurrence exists. Experimental and field data indicate that certain salts typically present in geothermal fluids, namely calcium carbonate and manganese carbonate, tend to precipitate upon introduction to cooler ground water (Summers et al, 1980; Vetter and Kandarpa, 1982; Arnold, 1984). Because the injection fluid is so organically diverse, a host of potential fluid/rock interactions are possible. Prediction of these reactions is difficult based upon theory because of numerous variables involved. Experimental data from cores of aquifer material are needed to adequately characterize those interactions.

Hydrogeology and Water Use

Because Hawaii is currently the only State in which aquaculture return flow wells are being used (according to the inventory), specific hydrogeologic parameters for that State alone will be discussed. Parameters discussed here are indicative of the hydrogeologic aspects of importance within any State that should utilize these wells in the future.

Ground-water withdrawals comprise about 41% of Hawaii's total fresh water use (USGS, 1985). Oahu, the island on which three of the inventoried facilities exist, is the State's largest user of ground water, accounting for 27% of the total usage. Almost 90% of Oahu's total ground water use is for domestic purposes (USGS, 1985).

Rainfall is the sole source of fresh water in the State of Hawaii, and its quantity and spatial distribution govern volumes and qualities of ground water (USGS, 1985). Mean annual rainfall is 73 inches, and ranges from 20 to 300 inches have been recorded. Ground water recharge is approximately 30% of the rainfall (USGS, 1985). Fresh ground water is present primarily as basal water in unconfined volcanic aquifers or in aquifers confined by coastal caprock under artesian pressure (USGS, 1985). Lesser amounts occur in isolated ground-water bodies resting on impermeable lava beds.

One of the inventoried aquaculture return flow facilities is on the northeast island margin of Oahu. Three wells at this facility injected into Pleistocene Coral/algal reef limestone before clogging ceased injection operations. The other two facilities are on the southeast island margin and inject into Honolulu basalts.

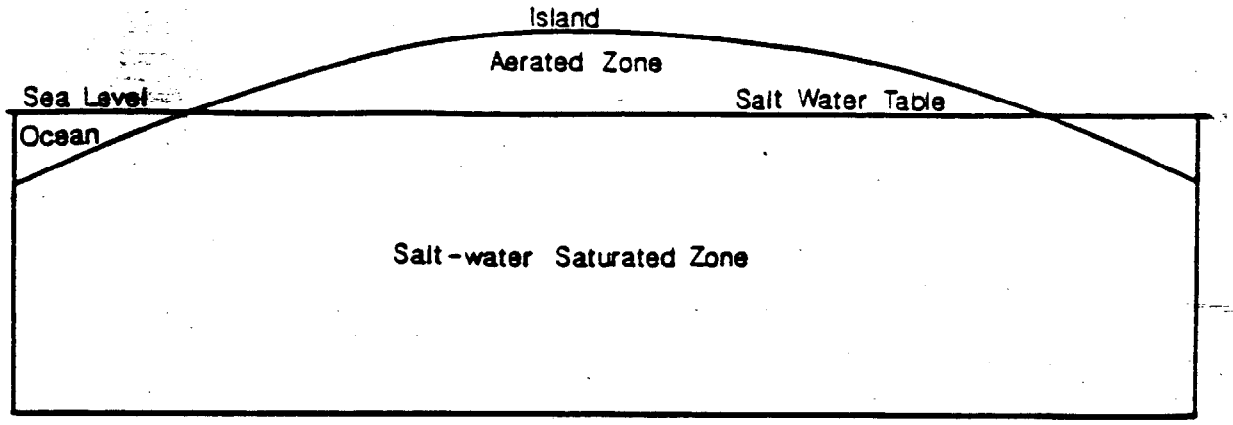
On the island of Hawaii, the proposed injection wells will be located at Keahole Point near Kailua-Kona, along the western island margin. The principal aquifer within this region is an unconfined sequence of basaltic lava flows. In general, the aquifer is highly permeable. This aquifer is the injection zone at the proposed facility in at Keahole Point.

As completed to date, all inventoried injection wells associated with aquaculture return flow dispose of wastes oceanward of the UIC Line. The UIC Line is a general approximation for the limits of 5,000 mg/l total dissolved solids (TDS) content in ground water and generally delineates the extent of sea water intrusion landward within the aquifer. Oceanward of the UIC Line, the aquifer is exempted. The aquifer is protected landward of the Line.

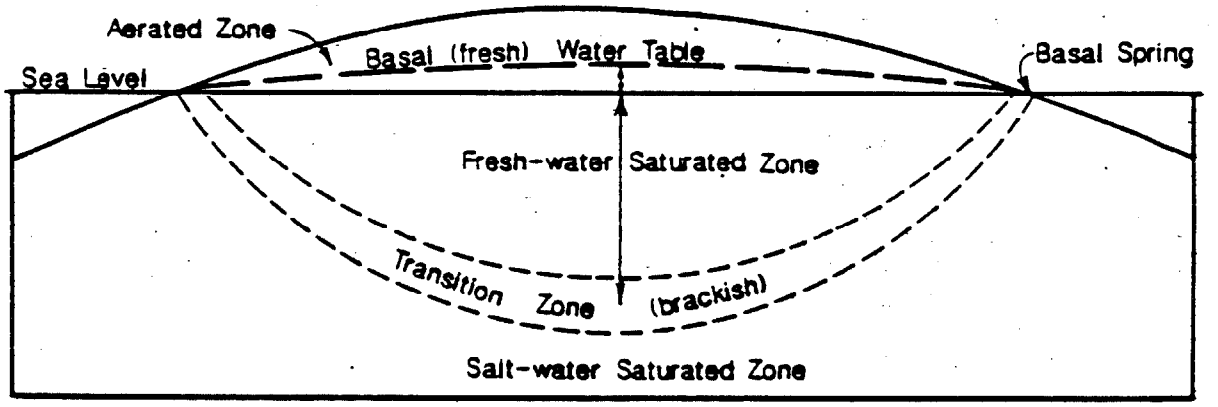
With the exception of rift zones and volcanoes, virtually all of the Hawaiian islands are saturated with sea water below sea level (Macdonald et al, 1983). Fresh ground water occurs in the form of a huge lens floating on sea water (Driscoll, 1986). Fresh basal water floating on salt water presses down the salt water, and the depth to which the salt water is pressed down depends upon the weight (thickness) of the fresh water lens (Macdonald et al, 1983). The principles of fresh ground water flotation on salt water in coastal regions is referred to as the Ghyben-Herzberg principle and is schematically presented in Figure 4-21. Part C of Figure 4-21 best describes the setting for injection operations on Oahu. The presence of a relatively impermeable "caprock," composed of consolidated alluvial deposits and Pleistocene coral and algal reefs, raises the water table inland from it and increases the thickness of the underlying fresh water lens. In these areas, the lens of fresh water is anomalously thick and skewed oceanward, thus facilities oceanward of the UIC Line may be injecting into fresh water. This has not been demonstrated for the inventoried facilities, primarily due to the absence of site-specific hydrogeologic data.

Contamination Potential

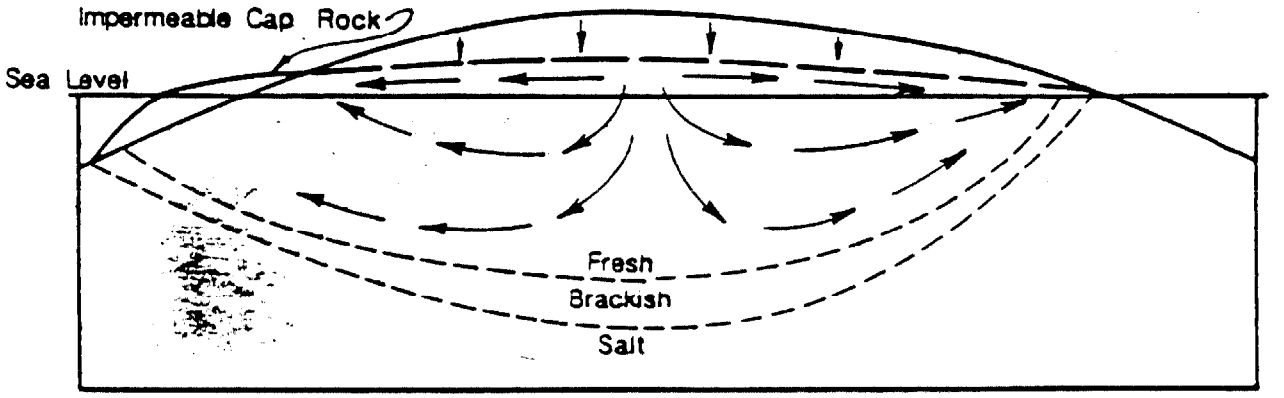
Based on the rating system described in Section 4.1, aquaculture return flow wells are assessed to pose a moderate potential to contaminate USDW. These facilities may or may not inject or above USDW (Class I and/or Class II). Typical well construction, operation, and maintenance would not allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National



A. AN ISLAND WITHOUT RAINFALL, SATURATED UP TO SEA LEVEL WITH SALT OCEAN WATER



B. AN ISLAND IN WHICH WATER THAT FELL AS RAIN ON THE ISLAND SURFACE HAS DESCENDED THROUGH THE ROCKS UNTIL IT ENCOUNTERED SALT WATER



C. AN ISLAND WITH A RELATIVELY IMPERMEABLE CAP ROCK ON ONE SIDE

DIAGRAMS ILLUSTRATING THE DEVELOPMENT OF THE GHYBEN-HERZBERG LENS OF FRESH WATER WITHIN AN OCEANIC ISLAND

Figure 4-

Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter.

All active and proposed aquaculture return flow wells are located on the islands of Oahu and Hawaii in the State of Hawaii. While specific hydrogeologic details about these operations are not readily available, contamination potential can be generically assessed for this well type by making certain broad generalizations.

It has been stated that injection is conducted oceanward of the UIC Line. This Line is often "political" in its positioning, but generally reflects the point at which 5,000 mg/l TDS concentration in ground water begins. This Line is also a rough approximation for the landward extent of groundwater containing in excess of 2,500 mg/l chloride. Because of the Ghyben-Herzberg relationship, significant volumes of USDW quality water may be present oceanward from the UIC Line in the areas under consideration. No hydrologic data which confirm or dispute this claim are presently available for any of the injection facilities. Thus, though it is possible that injection is into or above an USDW, this can not be concluded at this time.

Construction designs for these wells are generally simple. Wells on Oahu are completed in highly permeable basalts or coral and algal caprock of variable permeability. Injection depths are shallow, and the injection aquifers generally are considered to be unconfined. Wellhead designs are equally simple, and the potential for introduction of unpermitted waste streams must be considered to exist. Operational monitoring for these wells is believed minimal, due to the lack of operational and hydrogeologic data.

Water quality of injected fluids has been shown to be generally poor. No specific chemical analyses for waste streams have been provided by operators, but it is known that effluent is essentially salt water with added nutrients, bacteriological growth, perished animals, and animal detritus. These constituents tend to impart high concentrations of nitrates, nitrites, ammonia, BOD, and orthophosphate to the waste stream. Some constituents of the waste stream would exceed Primary and/or Secondary Drinking Water Regulations.

Annual injection volumes at these facilities vary greatly and can exceed 10,000 acre-feet. These are extremely large volumes, and the assumption that they influence ground water beyond facility boundaries is supportable. It must be reiterated that basal groundwater flow in coastal areas is generally seaward and that movement of pollutants likely will be away from fresher water situated inland. It seems safe to conclude, however, that constituents such as nitrates, nitrites, ammonia, and

orthophosphate are not naturally present within ground water. Thus, injection of such large volumes of waste will tend to increase concentrations of such constituents within the ground water.

In summary, injection of aquaculture waste water may be into USDW in Hawaii even though all inventoried wells are seaward of the UIC Line; however, chemical data to confirm this is lacking. General knowledge of waste streams indicates that Secondary Drinking Water Regulations for chlorides are exceeded. Chlorides are definitely above standards (Test data from Inventory Report). Finally, because of large injection volumes, increases of contaminants within ground water beyond facility limits will occur.

Current Regulatory Approach

Class V aquaculture return flow wells are authorized by rule under Federally-administered UIC program (See Section 1). All injection wells in Hawaii are regulated under a permit program administered by the Environmental Permits Branch of the Hawaii Department of Health. Under Chapter 340E, Hawaii Revised Statutes and Chapter 23, Administrative Rules, provisions were set forth requiring owners of both existing wells and proposed wells to submit a permit application. Owners of injection wells existing on or before July 6, 1984 were required to register those wells with the Department of Health. Within 180 days of registration, owners were required to submit the following injection well data:

1. Description of the injection system, including emergency pumps, standby wells, or monitoring wells, if any. Include a copy of the plans.

2. Well log, including:

   a. Lithology of injection interval(s) and confining formation(s);
   b. Physical and structural characteristics of the formations encountered;
   c. Water level, if any;
   d. Tidal fluctuations and efficiency, if any;
   e. Date of construction;
   f. Drilling contractor; and
   g. Ground surface elevation.

3. Complete results of injection testing or a detailed history of operation including dates, volumes and reasons for overflows, modifications and/or redevelopment.

4. Regional water quality (attach data from nearest supply wells, including: chloride, total dissolved solids, coliform, organic chemicals, inorganic chemicals, pH and temperature).

5. Nature and source of formation water, if encountered.

6. Description of operating plans, including:

   a. Identification of legal operator;
   b. Maximum and average rates and volumes of injection fluids;
   c. Nature and source of injection fluids;
   d. Number of hours per day of use; and
   e. Degree and type of treatment.

7. Certification by applicant.

Application for new injection activities to begin on or after July 6, 1984 must be submitted at least 180 days before the date that operations are due to commence. Applications require the following information:

1. Nature of well;
2. Drilling contractor;
3. Facility name and location;
4. Facility owner/operator;
5. Legal contact or authorized representative;
6. Nature and source of injected fluids;
7. Proposed fluid volumes;
8. Injection rates and pressures;
9. Description of injection system, including emergency sumps, standby wells, or monitoring wells, if any;
10. Description of proposed injection testing;
11. Regional water quality (specifically addressed are chloride, TDS, coliform, organic chemicals, inorganic chemicals, pH, and temperature);
12. Well siting details; and
13. Proposed construction details (using cross-section).

Following the review of the application data, an approval to construct or modify must be issued prior to the start of activity. Copies of this approval must be maintained at the construction site. For wells proposing to inject into USDW (as delineated on the UIC map), public notice is required prior to issuance of approval to construct. A public hearing also may be required, depending upon response to public notice. Upon completion of the activity and testing, the applicant must submit a certified engineering report detailing information gathered during con-

struction and testing. The report is to bear the signatures of the engineer and geologist preparing the report and the professional seal of the engineer. The report should be prepared in accordance with the following guidelines:

1. General Information

   a. Brief description of project and location, including:

      (1) Facility name;
      (2) Facility location;
      (3) Site plan with contours and drawn to a scale suitable for the use intended;
      (4) Tax map key number; and

      (5) Location of all existing wells within one-quarter mile of the facility.

   b. Name of owner;
   c. Name and address of legal contact or authorized representative; and
   d. Name of operator.

2. Physical Characteristics of Area

   a. Location;
   b. Climate;
   c. Topography;
   d. Geology and foundation conditions;
   e. Earthquake considerations;
   f. Flood problems including tsunami inundation zones; and
   g. Information confirming adherence with local land-use planning and zoning regulations.

3. Description of System Operation

   a. Nature and source of injected fluids;
   b. Design capacity operating rates, and volumes of injected fluid;
   c. Description of the system, including emergency, standby, or monitoring wells, and system plans;
   [illegible] Number and type of wells actually constructed;
   e. Maximum and average rates and volumes of injected fluids;
   f. Number of hours per day of use; and
   g. Degree and type of treatment.

4. Geohydrologic Considerations

   a. Description of well site:
      (1) Coordinates (latitude, longitude); and
      (2) Land surface elevation;

   b. Well Log, including:
      (1) Lithology of injection interval(s) and confining formation(s);
      (2) Physical and structural characteristics of the formations encountered;
      (3) Initial water level and subsequent water levels, if any; and
      (4) Tidal fluctuations and efficiency, if any.

   c. Nature and source of formation water, including analyses for the parameters specified in the Primary Drinking Water Regulations and regional water quality from the nearest supply wells.

   d. Complete results of injection testing including maximum capacity and hydraulic conductivity.

   e. Description of number and type of injection well(s) constructed including construction materials and procedures.

   f. Elevation section showing final dimensions, elevations, and materials used for each well.

5. Certification by Applicant

Review of applications and activity reports is presently the responsibility of a single staff hydrogeologist with the Department of Health.

Recommendations

The Hawaii report suggests that proper operational procedures should include regular monitoring of injection fluid and ground-water quality. It may not be practical to drill new monitoring wells, but idle or abandoned wells could be converted to monitoring status for determining ground-water quality. Injection fluid analysis, in light of extremely large injection volumes, should be conducted twice annually at a minimum. Constituents specified in permit applications, as discussed previously, would represent minimum reporting requirements. Regularity and type of

mechanical integrity testing should be specified more clearly for operational procedures. It is believed these items are referred to in permit applications, but implementation of requirements was not noted for the facilities studied.

Additional recommendations from the Hawaii report include 1) water to be disposed should be filtered and appropriately treated prior to injection, 2) return waters should be carefully monitored at a point before and after treatment to ensure that the measures being employed are sufficient to allow the water to be injected, 3) injection wells should be sited as close to the coast as possible, and 4) injection of aquaculture return flow fluids should never occur in USDW areas.

4.2.3 DOMESTIC WASTEWATER DISPOSAL WELLS

4.2.3.1 Raw Sewage Waste Disposal Wells and Cesspools (5W9, 5W10)

Well Purpose

Class V raw sewage waste disposal wells (5W9) and cesspools (5W10) primarily are used to receive and dispose of sanitary wastes. Cesspools, which receive solely sanitary wastes and serve over 20 persons per day, are Class V wells. Both types of disposal wells generally are located in areas not served by sanitary sewers. Cesspools and raw sewage disposal wells reportedly have been used by multi-family developments, office complexes, businesses, sewage waste haulers, and hospitals. These wells also may receive additional fluids not commonly characterized as domestic wastes.

Inventory and Location

Raw Sewage Waste Disposal Wells. Reported Class V raw sewage waste disposal wells total 980. These wells were reported to operate in eight States and one protectorate. Reported state totals of 5W9 wells are presented in Table 4-28. The majority of reported wells are located in selected towns within the Great Lakes States. These towns usually are without sanitary sewers and over the abandoned mines. Businesses and multi-family developments reportedly discharge their raw sewage into wells which are conduits to the abandoned mines.

Many unreported raw sewage disposal wells in the Great Lakes Region are suspected to exist. Over 900 raw sewage wells have been reported in Illinois on an Illinois EPA database. These wells, however, have not been reported within the Illinois State Report. In addition, authorities in Ohio and Pennsylvania

TABLE 4-28: SYNOPSIS OF STATE REPORTS FOR UNTREATED SEWAGE WASTE DISPOSAL WELLS(5W9)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	5 WELLS	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	YES	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	916 WELLS	BANNED	YES	N/A
Indiana	V	22 WELLS	N/A	NO	N/A
Michigan	V	11 WELLS	N/A	NO	N/A
Minnesota	V	10 WELLS	N/A	NO	N/A
Ohio	V	NO	N/A	YES	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	10 WELLS	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	BANNED	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	3 WELLS	PERMIT	YES	HIGH
Nevada	IX	NO	BANNED	NO	HIGH
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	3 WELLS	PERMIT OR RULE	NO	HIGH
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	RULE	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

estimate that many unverified "black holes" are used within their States to dispose of raw sewage. Individual homeowners who do not have access to municipal treatment plants or have failing septic systems are suspected to utilize raw sewage disposal wells.

Raw sewage waste disposal wells also have been reported in Puerto Rico, Arkansas, and Hawaii. One well in Honokaa, Hawaii is used by the City's hospital and an unknown number of businesses and residences.

Cesspools Reported Class V cesspools in the United States and its Possession and Territories number over 6,600. The State totals of these wells are presented in Table 4-29. Oregon reports having 6,257 Class V cesspools operating within the State. The vast majority of these wells are located in mid-Multnomah County. Although the State of Oregon has prohibited the construction of cesspools, this method is still the predominant means of sewage disposal in mid-Multnomah County. The total number of cesspools (including non-Class V cesspools) in Multnomah County is approximately 56,000.

Other States reporting cesspools are scattered throughout the country. Most States believe that many unreported cesspools presently are operating within their respective States. These wells are generally located in rural areas not served by municipal treatment plants. This statement is supported in Hawaii, Alaska, and Puerto Rico where Class V cesspools reportedly serve rural communities.

Construction, Siting, and Operation

Raw sewage waste disposal wells are simply constructed. Wells are drilled in limestone or lava flow formations. In the Great Lakes Region, raw sewage waste disposal wells usually consist of surface casing and underlying, uncased boreholes. These wells are drilled until the borehole penetrates an underground cavern or abandoned mine seam. No pressure is used when injecting; the fluids fall to the mine or cavern under the influence of gravity. The reported depths of wells which dispose sewage into abandoned mines range anywhere from 75 to 150 feet deep.

An inspection of a well disposing of raw sewage in Hawaii was conducted in 1985. The well was originally constructed in 1948 as a county-owned cesspool. During excavation, a lava tube (8 feet deep x 10 feet wide) was encountered and subsequently used as a raw sewage disposal well. The vertical and lateral extent of the lava tube from the point of injection is unknown.

TABLE 4-29: SYNOPSIS OF STATE REPORTS FOR CESSPOOLS(5W10)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	1 WELL	NJPDES PERMIT	NO	N/A
New York	II	YES	PERMIT>1x GPD	NO	SIGNIFICANT
Puerto Rico	II	67 WELLS	N/A	YES	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	22 WELLS	N/A	NO	N/A
Michigan	V	18 WELLS	N/A	NO	N/A
Minnesota	V	25 WELLS	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	14 WELLS	BANNED	NO	MODERATE
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	16 WELLS	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	YES	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	BANNED	NO	N/A
Wyoming	VIII	3 WELLS	PERMIT	NO	5TH HIGHEST/10 TYPES
Arizona	IX	17 WELLS	PERMIT	NO	HIGH
California	IX	46 WELLS	BANNED	NO	HIGH
Hawaii	IX	57 WELLS	PERMIT	NO	HIGH
Nevada	IX	NO	BANNED	NO	HIGH
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	>79 WELLS	PERMIT OR RULE	NO	HIGH
Idaho	X	NO	N/A	NO	N/A
Oregon	X	6,257 WELLS	RULE	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

A cesspool is usually a brick lined sump 4 to 6 feet in diameter and 5 to 10 feet deep (Figure 4-22). Raw sewage is generally drained (by gravity) directly to the cesspool from sanitary facilities on site. Larger solids present in the sewage settle to the bottom while the liquid seeps out through the sides.

Injected Fluids and Injection Zone Interactions

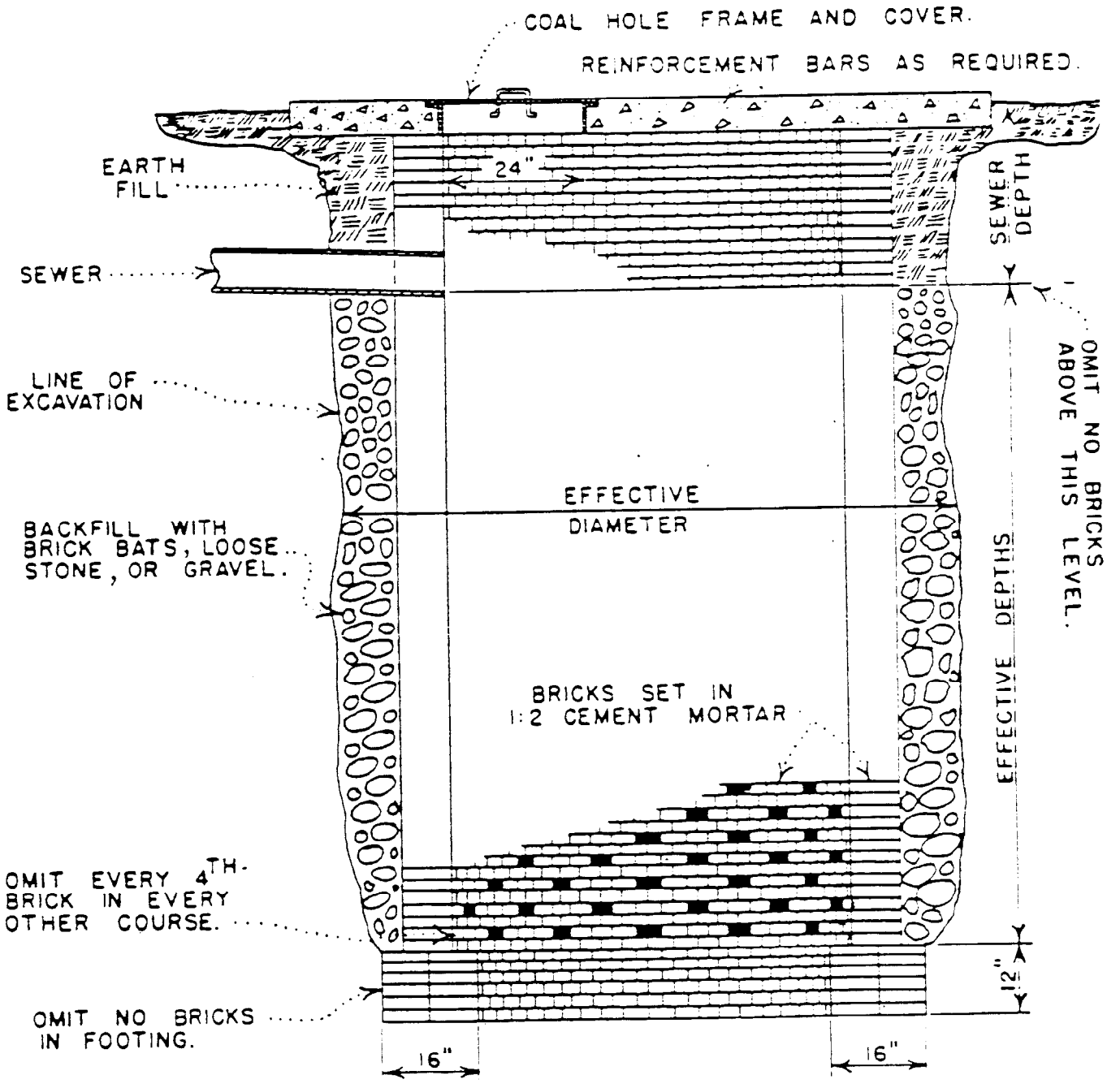
Injected Fluids. The quality of injected wastewaters discharged (by gravity) from Class V cesspools and raw sewage waste disposal wells is poor. These wells receive domestic sewage from individual homes, recreational facilities (i.e. campgrounds) and businesses. Sewage generated from these sources consists of 99.9 percent water by weight and 0.03 percent suspended solids. Table 4-30 presents ranges of constituent concentrations found in domestic sewage. Of these constituents, nitrates, bacteria, and viruses are of most concern.

In addition to domestic wastes, cesspools and raw sewage disposal wells potentially can receive wastes associated with commercial businesses. This is best illustrated in Hawaii, where a raw sewage well was reported to receive untreated sewage, food establishment wastewater, and infectious wastes.

Settleable solids in cesspool influent collect at the bottom of the well. The total solids content of waters injected by cesspools, therefore, is somewhat reduced. The reduction of other contaminants in cesspool effluent or raw sewage disposal well effluent has not been documented. Concentrations of bacteria, viruses, and inorganic and organic compounds in the effluent are therefore assumed to be close to those present in the untreated sewage.

Injection Zone Interactions. Possible injection zones for cesspools and raw sewage disposal wells are the vadose zone and the saturated zone. Cesspools are usually completed in vadose zones comprised of coarse permeable sediments. A clogging layer usually forms several feet below the bottom of a cesspool in permeable sediments. The clogging layer is composed of microorganisms and by-products of decomposition. Contaminants in injected waters are partially removed in this layer by physical filtering as well as by biological and chemical processes. Waste organic compounds in effluent can act as biocides and potentially harm the efficiency of the clogging layer.

Nitrates, the end product of aerobic stabilization of organic nitrogen from ammonia, are formed in the vadose zone in cesspool effluent. Nitrates are not easily attenuated by soils and are fairly mobile in groundwater. Bacteria and viruses in cesspool effluent generally are well attenuated in alluvial



SECTIONAL VIEW OF A CESSPOOL

(Courtesy, Maryland State Dept. of Health)

Figure 4-22

TABLE 4-30

TYPICAL COMPOSITION OF DOMESTIC SEWAGE
(All values except settleable solids are expressed in mg/l.)

Constituent	Concentration		
	Strong	Medium	Weak
Solids, total	1,200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids, (ml/l)	20	10	5
Biochemical Oxygen Demand			
5-day, 20°C (BOD_5 20°)	300	200	100
Total Organic Carbon (TOC)	300	200	100
Chemical Oxygen Demand (COD)	1,000	500	250
Nitrogen, (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrite	0	0	0
Nitrate	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chloride	100	50	30
Alkalinity (as $CaCO_3$)[1]	200	100	50
Grease	100	100	50

[1]Values should be increased by amount in carriage water.

vadose zones. Only in a few documented cases have viruses been shown to migrate significant distances from wastewater disposal facilities.

Interactions occurring in the injection zone utilized by raw sewage disposal wells are minimal. Because these wells generally are completed in consolidated limestones or lava flows, injected waste contaminants are left untreated in this injection zone. A study by Dr. Mallman of Michigan State University (1960's) showed that bacteria traveling in unconfined limestone aquifers were limited only by the extent of water-bearing joints and solution channels in the rock.

Contaminants in effluent discharged from cesspools and raw sewage disposal wells completed below the water table are also untreated. The dilution of these contaminants in ground water is the only mitigating factor.

Hydrogeology and Water Use

Cesspools and raw sewage waste disposal wells reportedly inject wastewater into a variety of geologic formations. Raw sewage waste disposal wells generally are completed in fractured bedrock formations. These formations can be composed of basaltic lava formations, limestone, sandstone, or shales. Disposal wells utilize solution channels, lava tubes, or underground mines to transport sewage away from the surface. The vertical and lateral extent of these cavities often are unknown. Many of the reported raw sewage disposal wells in the Great Lakes States overlie abandoned coal mines. Fill, loess, and other semi-permeable deposits usually are encountered near the surface in these areas. Pennsylvania bedrock with shales, coals, and lesser amounts of siltstone, sandstone, and limestone underlie more permeable strata. Class V raw sewage disposal wells reported in Hawaii inject wastewater into lava tubes present in the near surface basaltic lava (name unknown). These tubes are believed to generally issue outward toward the ocean.

Class V cesspools generally are constructed in alluvial formations which have a high capacity for receiving wastewater. The alluvial layers used to filter cesspool effluent are usually composed of medium- to coarse-grained sands and gravels. Most of the cesspools reported by the responding States (including Oregon) are completed in alluvial deposits. A small percentage of reported cesspools have been completed in fractured basalt or limestone.

Cesspools and raw sewage waste disposal wells inject wastewater above USDW in many cases. States reporting past, present, or potential degradation of USDW due to cesspools and raw sewage disposal wells include: California, Arizona, Oregon,

Illinois, Hawaii, and Ohio. A number of these USDW potentially or presently affected were reported to be used as drinking water sources. Although shallow, domestic supplies appear to be especially threatened, the ground-water contamination of deeper zones may inevitably occur. This currently is being documented in Oregon (Multnomah County) where over 14 million gallons/day of raw sewage is being discharged to the subsurface from cesspools and seepage pits. Elevated concentrations of nitrates and small concentrations of commonly used solvents currently are being detected in deeper waters used for larger sources of drinking water. Aquifers directly threatened by raw sewage disposal wells generally are difficult to isolate. The lateral migration of wastewater in extensive solution channel networks can potentially degrade ground water large distances away from the injection point.

Contamination Potential

Based on the rating system described in Section 4.1, raw sewage waste disposal wells and cesspools are assessed to pose a high potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. The fluids may exhibit characteristics or contain constituents listed as hazardous as stated in the RCRA Regulations. Based on injectate characteristics and possibility for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment in a region studied on a group/area basis.

As discussed in the "Characterization of Injected Fluids" section, domestic sewage typically includes high microbial populations, total solids concentrations, and nitrogen. These contaminants are injected directly into raw sewage disposal wells without pretreatment. Wastewater discharged by cesspools are reduced in total solids content. Harmful nitrates, bacteria and viruses, and soluble constituents, however, are not removed by cesspools. Nitrates, TDS, and coliform bacteria typically can be expected to exceed National Primary and Secondary Drinking Water Regulations in cesspool and raw sewage waste disposal well effluent.

The majority of active cesspools and raw sewage wastewater disposal wells inject wastewaters above USDW of better quality than Class IIB. Over 6,[illegible] Class V cesspools in Oregon inject raw sewage into water-bearing zones currently or potentially [illegible] drinking water [illegible]. Shallow [illegible]

domestic supplies appears to be especially threatened. Aquifers used for municipal drinking water sources usually are deeper and initially are less susceptible to surface discharges. Ground water reportedly has been degraded from cesspool and raw sewage disposal wells in Ohio, Illinois, and Oregon. Ground water degradation was regional in nature and resulted from large numbers of raw sewage disposal wells and cesspools operating in these areas. (Many of the raw sewage wells in Ohio and Illinois were replaced by sewer systems in the late 60's and early 70's.) Fluids injected by Class V cesspools and raw sewage disposal wells are therefore judged to be capable of polluting waters off-site and on a region-wide basis.

The collective contamination potential assessed for Class V cesspools and raw sewage disposal wells is high. The environmental threat posed by cesspools, however, is to some degree site-specific. For example, cesspools injecting into shallow ground water pose a higher contamination potential than those injecting above deep, semi-confined aquifers. The contamination potential of raw sewage disposal wells and cesspools completed in bedrock are categorically high. Attenuation of contaminants disposed through these wells does not occur in the injection zone. One factor which may mitigate the threat of contamination posed by these wells is the injection of higher quality fluids (i.e. storm water runoff) into the same formation(s).

Current Regulatory Approach

Class V raw sewage disposal wells and cesspools are authorized by rule under Federally-administered UIC programs. Regulatory information provided by the States and Territories of the United States concerning cesspools and raw sewage waste disposal wells is limited. From the State reports, seven States have been identified to declare all cesspools and raw sewage disposal wells illegal. These States are: Nevada, California, Arizona, New Mexico, Oregon, Ohio, and Utah. The remaining states reporting cesspools and raw sewage disposal wells apparently regulate these wells under general UIC Class V Well Regulations. State health and environmental departments in these States review waste discharge permits on a case-by-case basis. Permits are granted for discharges judged not to threaten the quality of the states' ground water. In actuality, State permitters in these States may categorically reject permits for new cesspools or raw sewage wells. Written policies regarding these wells, however, were not presented in the State Class V Well Assessment Reports.

Recommendations

Unfortunately, no recommendations concerning cesspools and raw sewage waste disposal wells were provided in the State

reports. However, several States have banned the construction and use of new cesspools and raw sewage disposal wells.

4.2.3.2 Class V Septic Systems (5W11, 5W31, 5W32)

Well Purpose

Class V septic wastewater disposal systems ideally are designed to receive, treat and dispose of sanitary wastes. Often they receive additional wastes. These systems generally are located in areas not served by sanitary sewers.

On-site sewage wastewater disposal systems commonly used are septic tanks coupled with a subsurface disposal method. Drainfields and disposal wells (including seepage pits) are two subsurface disposal systems. On-site systems serve centralized multi-family developments and commercial and industrial properties. Table 4-31 describes the subclasses of Class V septic systems according to their subsurface disposal method.

Inventory and Location

The inventory of Class V septic systems is a complex issue. Tables 4-32 through 4-34 contain the numbers of 5W11, 5W31, and 5W32 wells reported by the States. The 5W11 systems are those about which construction information is lacking. The 5W31 systems use some type of well or "dry well" to dispose of effluent. The 5W32 systems make use of a drain field where further treatment takes place. Unfortunately, in many cases local records do not specify construction and do not distinguish between multi-family, single family, or industrial/commercial sanitary systems. This is illustrated by a letter from the Maricopa County Health Department (Phoenix, Arizona). "We have records covering approximately 30,000 permits with 80-90% of this number meeting your criteria. We estimate it would take at least (one) man year to research the files..."

The 1980 census estimated 22 million septic systems exist serving nearly one-third of the population. Most of these are single family systems, yet potentially they have a great impact upon the proper siting of Class V septic systems. The literature indicates that the major cause of septic system failure is improper spacing, that is, the construction of too many systems too close together. It is true that many systems are found in remote areas where the population is sparse. However, States report the use of systems in fringe areas of rapid growth, where available public transport is limited. In these areas the use can be critical and overloading a real danger, especially when multi-family systems are very quickly designed and installed by developers.

Table 4-31. Class V Septic Wastewater Disposal Systems

New Code	Name of System Type and Description
5W11	Septic Systems (Undifferentiated disposal method) - used to inject the waste or effluent from a multiple dwelling, business establishment, community or regional business establishment septic tank. (Primary treatment).
5W31	Septic Systems (Well Disposal Method) - examples of wells include actual wells, seepage pits, cavitettes, etc. The largest surface dimension is less than or equal to the depth dimension. (Less treatment per square area than 5W32).
5W32	Septic Systems (Drainfield Disposal Method) - examples of drainfields include drain or tile lines, trenches, etc. (More treatment per square area than 5W31)

TABLE 4-32: SYNOPSIS OF STATE REPORTS FOR SEPTIC SYSTEMS(5W11)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	62 WELLS	PERMIT>5K GPD	YES	HIGH
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	27 WELLS	PERMIT>15K GPD	NO	LOW
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	8 WELLS	N/A	YES	LOW
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	143 WELLS	NJPDES PERMIT	NO	N/A
New York	II	YES	PERMIT>1K GPD	NO	SIGNIFICANT
Puerto Rico	II	1,073 WELLS	N/A	NO	N/A
Virgin Islands	II	44 WELLS	N/A	YES	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	6 WELLS	N/A	NO	N/A
West Virginia	III	2 WELLS	N/A	NO	N/A
Alabama	IV	1 WELL	PERMIT	NO	VARIABLE
Florida	IV	19,000 WELLS	PERMIT	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	YES	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	895 WELLS	N/A	NO	N/A
Michigan	V	2,693 WELLS	N/A	NO	N/A
Minnesota	V	588 WELLS	RULE	NO	N/A
Ohio	V	361 WELLS	N/A	NO	HIGH
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	YES	RULE	NO	N/A
New Mexico	VI	10 WELLS	REGISTRATION	NO	MODERATE
Oklahoma	VI	YES	RULE	NO	N/A
Texas	VI	56 WELLS	LOCAL	NO	N/A
Iowa	VII	3 WELLS	N/A	NO	LOW
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	2 WELLS	PERMIT	NO	LOW
Nebraska	VII	YES	RULE	NO	HIGH
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	2 WELLS	PERMIT	NO	HIGH
North Dakota	VIII	NO	RULE	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	YES	PERMIT	NO	N/A
Wyoming	VIII	420 WELLS	PERMIT	NO	5TH HIGHEST/10 TYPES
Arizona	IX	143 WELLS	PERMIT	NO	HIGH
California	IX	1,165 WELLS	N/A	NO	HIGH
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	3 WELLS	PERMIT	NO	MODERATE
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	2 WELLS	NONE	NO	LOW
Alaska	X	8 WELLS	PERMIT OR RULE	NO	HIGH
Idaho	X	52 WELLS	PERMIT 15 FT	NO	5TH HIGHEST/14 TYPES
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	PERMIT/RULE	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

TABLE 4-33: SYNOPSIS OF STATE REPORTS FOR SEPTIC SYSTEMS(5W31)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	YES	PERMIT>1K GPD	NO	N/A
Puerto Rico	II	85 WELLS	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	890 WELLS	PERMIT	NO	2ND HIGHEST/3 TYPES
Pennsylvania	III	13 WELLS	N/A	NO	3RD HIGHEST/6 TYPES
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	736 WELLS	RULE	NO	UNKNOWN
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	105 WELLS	N/A	NO	N/A
Michigan	V	2,511 WELLS	N/A	NO	N/A
Minnesota	V	16 WELLS	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	3 WELLS	RULE	NO	LOW
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	18 WELLS	PERMIT	NO	HIGH
California	IX	48 WELLS	PERMIT	NO	HIGH
Hawaii	IX	7 WELLS	PERMIT	YES	HIGH
Nevada	IX	NO	BANNED	NO	HIGH
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	3 WELLS	PERMIT OR RULE	NO	HIGH
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

TABLE 4-34: SYNOPSIS OF STATE REPORTS FOR SEPTIC SYSTEMS(5W32)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	2 WELLS	N/A	YES	HIGH
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	YES	PERMIT>1K GPD	NO	N/A
Puerto Rico	II	63 WELLS	N/A	YES	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	200 WELLS	PERMIT	NO	LOWEST/3 TYPES
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	3 WELLS	PERMIT	NO	HIGH
California	IX	1,276 WELLS	PERMIT	NO	HIGH
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	YES	PERMIT	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	2,133 WELLS	PERMIT OR RULE	NO	HIGH
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	PERMIT>5K GPD	NO	N/A
Washington	X	108 WELLS	PERMIT	NO	VARIABLE

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

The inventory of Class V systems obviously is not complete. One reason may be a reluctance to address a problem which traditionally has been regulated locally, and which has such tremendous resource implications. The resources do not currently exist in the UIC program to address the inventory of all Class V septic systems.

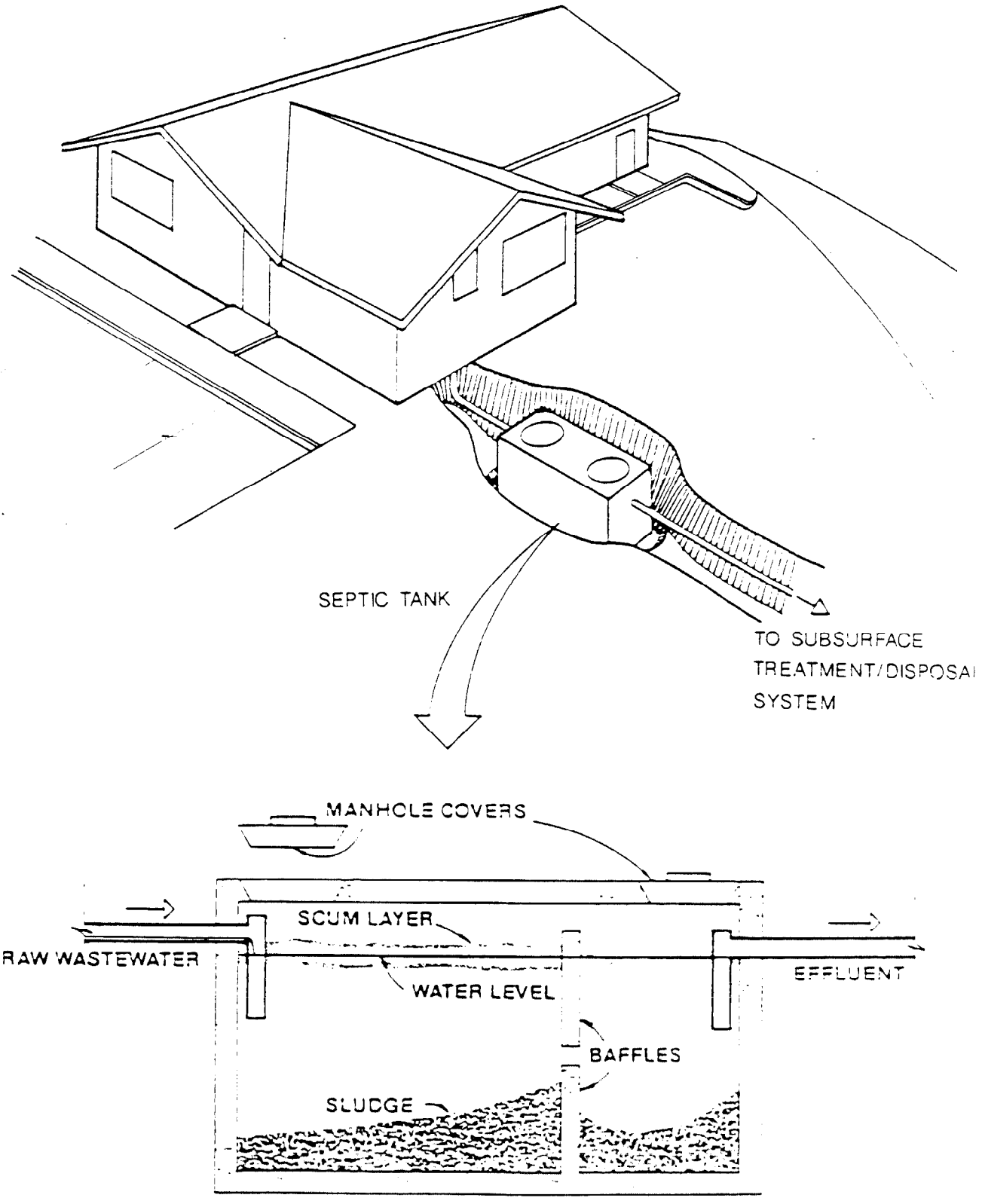
Many "sanitary" septic systems may be found to be "dual purpose" and, in fact, used to dispose of (as opposed to treat) organics and other chemicals which may retard or destroy the treatment capabilities of septic systems.

Construction, Siting and Operation

Septic systems consist of two major components: a septic tank and a subsurface treatment/disposal system. Septic tanks are used to trap floating grease, scum, and settleable solids in wastewater. Solids are anaerobically decomposed within the tank. Baffles within the tank promote the settling of wastewater constituents. Figure 4-23 displays a cross section of a typical concrete septic tank. Conventional septic tank subsurface disposal systems receive partially treated effluent from the septic tank. Two popular subsurface disposal systems are the disposal well and the drainfield.

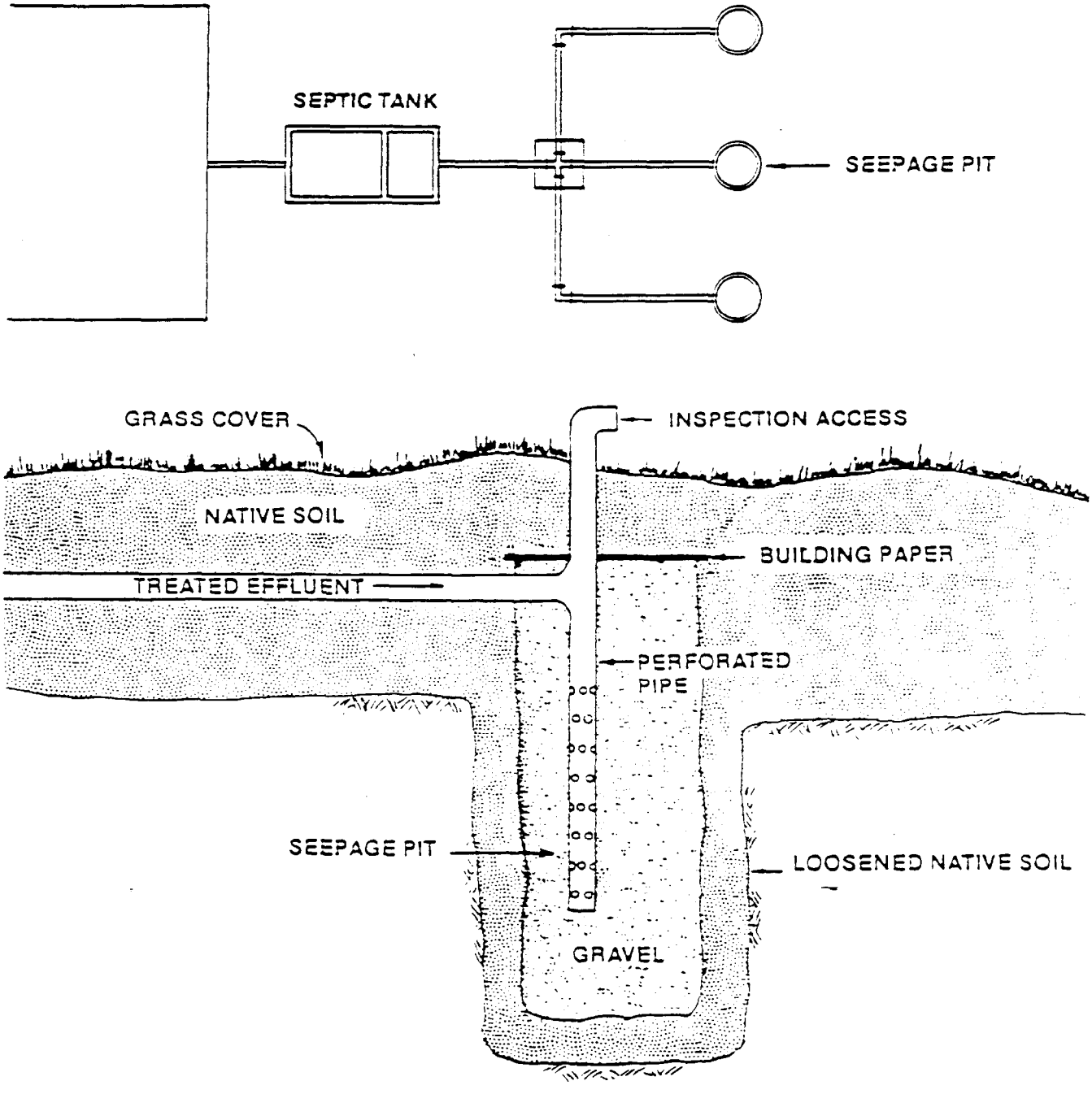
Wells used in conjunction with septic tanks employ simple gravity flow designs. These wells commonly fit into two categories: brick lined cesspool-type wells and seepage pits (some systems in Oregon use drain holes). Seepage pits often are used when drainfields are impractical because of siting or geologic restrictions. The uncased sidewalls and bottom of the seepage pit provide a subsurface disposal interface (Figure 4-24). A series of pits often are used within one septic system. Pits usually are separated by a distance equal to three times their diameter. Seepage pits usually are dug 5 to 10 feet above the water table and are backfilled with coarse gravel (James M. Montgomery, Consulting Engineers, Inc. 1979).

Configurations of drainfields include the conventional drainfield and the absorption mound system. Conventional drainfields consist of a series of perforated distribution pipelines (Figure 4-25) placed in trenches or shallow seepage beds. The perforated pipe is placed in the trench or bed at a slight slope to promote drainage. Gravel or crushed rock also is backfilled around the perforated pipe to improve drainage. Topsoil of at least one foot thickness is placed over the gravel layer. Drainfield trenches generally are 1 to 3 feet wide and beds range in width from 3 to 12 feet. Figure 4-25 shows two cross sections of conventional drainfields. General recommended siting criteria for drainfields, as established by the USEPA, are presented in Table 4-35. Many States have adopted siting guidelines, some of which are incorporated in permit requirements.



CONVENTIONAL SEPTIC TANK

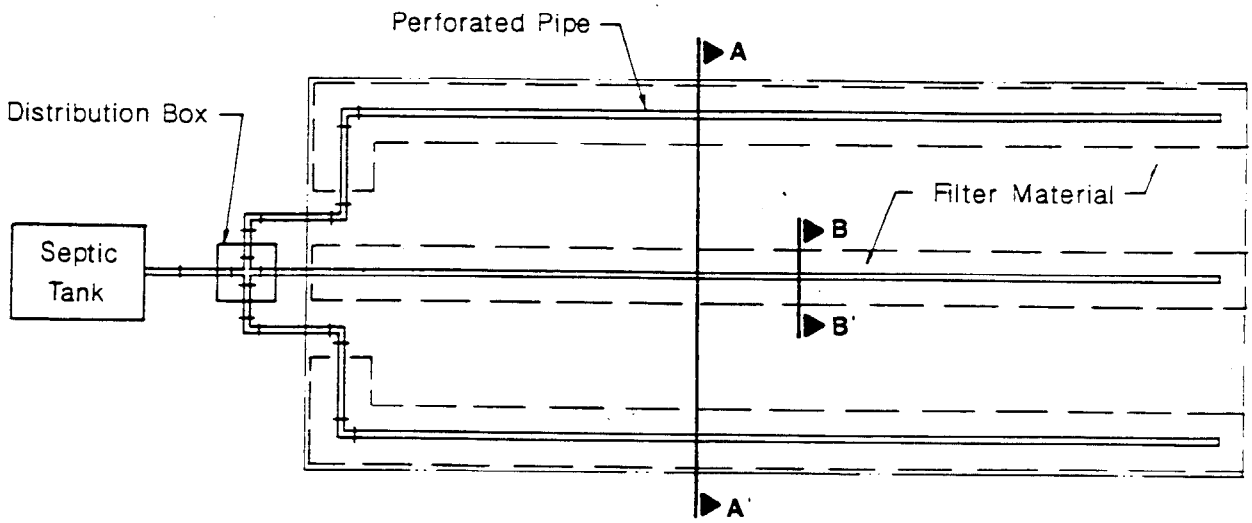
Figure 4-2



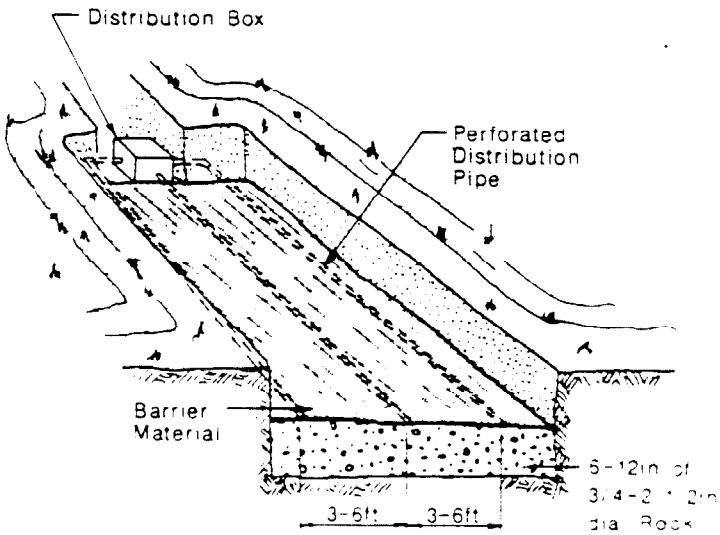
SEEPAGE PIT DISPOSAL SYSTEM

(from James M. Montgomery, Consulting Engineers, 1979)

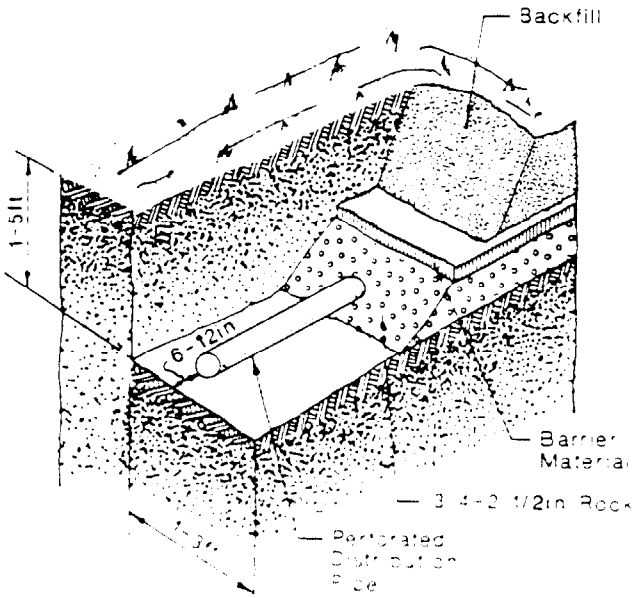
Figure 4-24



PLAN VIEW



SEEPAGE BED DESIGN SECTION A-A



TRENCH DESIGN SECTION B-B

CONVENTIONAL DRAIN FIELD
DISPOSAL SYSTEMS

[illegible] SEPA [illegible]
[illegible] Engineers, 197[illegible]

Figure 4-25

TABLE 4-35

SITE CRITERIA FOR DRAINFIELD AND SEEPAGE BED SYSTEMS
(U.S. EPA, 1980)

ITEM	CRITERIA
Landscape Position[a]	Level, well drained areas, crests of slopes, convex slopes most desirable. Avoid depressions, bases of slopes and concave slopes unless suitable surface drainage is provided.
Slope[a]	0 to 25 percent. Slopes in excess of 25 percent can be utilized but the use of construction machinery may be limited. Bed systems are limited to 0 to 5 percent.
Typical Horizontal Separation Distances[b]	
Water Supply Wells	50 - 100 ft
Surface Waters, Springs	50 - 100 ft
Escarpments, Manmade Cuts	10 - 20 ft
Boundary of Property	5 - 10 ft
Building Foundations	10 - 20 ft
Soil	
Texture	Soils with sandy or loamy textures are best suited. Gravely and cobbley soils with open pores and slowly permeable clay soils are less desirable.
Structure	Strong granular, blocky or prismatic structures are desirable. Platy or unstructured massive soils should be avoided.
Color	Bright, uniform colors indicate well-drained, well-aerated soils. Dull, gray or mottled soils indicate continuous or seasonal saturation and are unsuitable.
Layering	Soils exhibiting layers with distinct textural or structural changes should be carefully evaluated to insure water movement will not be severely restricted.
Unsaturated Depth	2 to 4 ft of unsaturated soil should exist between the bottom of the system and the seasonally high water table or bedrock.

TABLE 4-35, Continued

ITEM	CRITERIA
Percolation Rate	1 to 60 min/in (average of at least 3 percolation tests).[c] Systems can be constructed in soils with slower percolation rates, but soil damage during construction must be avoided.

[a]Landscape position and slope are more restrictive for beds because of the depths of cut on the upslope side.

[b]Intended only as a guide. Safe distance varies from site to site, based upon topography, soil permeability, ground water gradients, geology, etc.

[c]Soils with percolation rates less than 1 min/in can be used for trenches and beds if the soil is replaced with a suitably thick (greater than 2 ft) layer of loamy sand or sand.

Absorption mounds, or elevated drainfields, are alternative subsurface disposal systems. Absorption mounds have been used to replace conventional drainfields where high ground-water tables prevail. Mounds typically are constructed 3 feet above ground level out of clay, sand, and gravel (Figure 4-26). Perforated distribution pipe is set in gravel filled trenches running along the length of the mound. Treated effluent is discharged through the perforated pipe. Water then seeps through the underlying gravel, sand and native soil layers.

Injected Fluids and Injection Zone Interaction

Injected Fluids. The quality of treated wastewater discharged from Class V septic wastewater disposal systems is variable. This quality is dependent upon the quality of untreated wastewater entering the treatment system and the type of Class V septic wastewater disposal system utilized.

Characterization of Untreated Domestic Wastewater

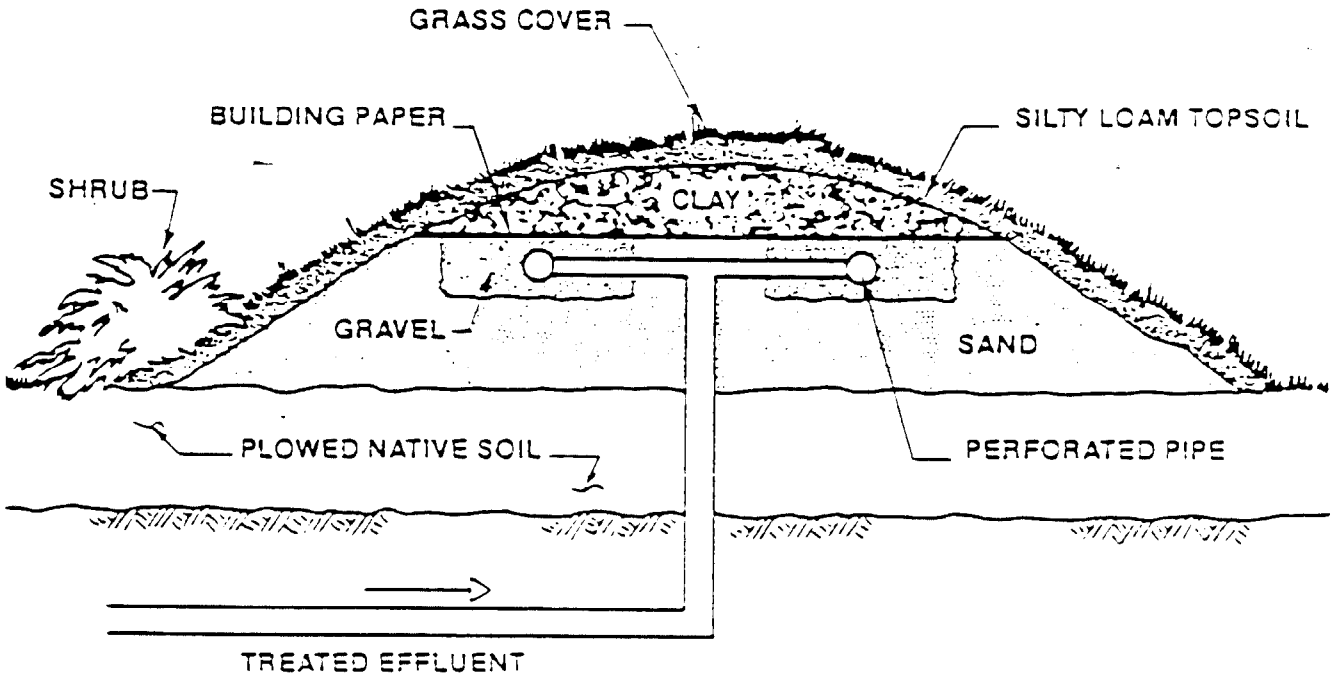
Domestic sewage from individual homes and large residential developments consists of approximately 99.9 percent water (by weight) and 0.03 percent suspended solids. Ranges of constituent concentrations found in domestic sewage are presented in Table 4-30 in the cesspool and raw sewage well assessment section. Of these constituents, nitrates are well known for their capacity to contaminate USDW. Anions of chlorides and sulfates, and cations of sodium and calcium, can also significantly deteriorate drinking water if injected in sufficient volumes (Carriere, 1980).

Organic compounds known to contaminate ground water have been detected only recently and quantified in domestic sewage. In a study conducted by the Washington (State) Department of Health and the University of Washington, untreated domestic sewage was found to contain 49 to 50 organic compounds in excess of 1 ppb; of these, 5 are considered to be priority pollutants (Dewalle, et. al., 1985). Toluene was the most prevalent priority pollutant (as designated by Dewalle) detected in the untreated sewage. Dichloromethane, chloroform, and tetrachlorothene were other priority pollutants found (Dewalle, et. al., 1985).

Pathogenic bacteria and viruses also are present in untreated domestic sewage. Pathogens can constitute a considerable health hazard if they reach potable ground water.

Industrial/Commercial Wastewaters

Wastewater sewage from commercial or industrial establishments can resemble domestic sewage. This is most likely true in waters generated from offices, motels, recreational campgrounds, etc. Other commercial and industrial businesses,



ABSORPTION MOUND DISPOSAL SYSTEM

Figure 4-26

however, discard chemical or industrial wastes in their sewage. Printers dispose of organic solvents and metal degreasers, and the photoprocessing industry disposes of many organic and inorganic chemicals. Laundries and laundromats dispose of soil and stain removers. Dry cleaners discard used solvents such as trichloroethylene and perchloroethylene. Paint dealers and hardware stores discard many harmful solvents and cleaning products. Restaurants must dispose of large volumes of grease and cleaners. Funeral homes handle various chemicals. (See South Carolina Report on Funeral Home Septic Systems.) Gasoline and service stations discard waste oils, degreasers and other solvents, and other automotive fluids. Laboratory wastes also contain many harmful wastes such as dyes. All of these establishments may use septic systems. (USEPA, 1986)

Treatment Capacities of Class V Septic Wastewater Disposal Systems

The ability to treat constituents in sewage wastewater is governed by the treatment process employed. The following briefly describes the treatment capacities and expected effluent compositions of Class V septic system wastewater.

Septic tank systems provide a primary degree of treatment to sewage wastewater. The expected removal efficiency ($[C_{in} - C_{out}]/C_{in}] \times 100\%$) of total solids in septic tanks is 10 to 15 percent (Kerri, 1980). Given this efficiency, effluent concentrations of Total Dissolved Solids (TDS) in strongly concentrated domestic sewage (See Table 4-31) would exceed the National Secondary Drinking Water Standard for TDS.

The expected removal efficiency of bacteria in septic tank systems is 25 to 75 percent (Kerri, 1980). This presumes that the wastewater does not contain chemicals which function as biocides. When these chemicals (biocides) are present, not only are the chemicals not removed, but the anaerobic activity in the tank and the aerobic activity at the soil interface may be retarded or stopped. In this case, the treatment function is thwarted, and the septic system is in reality a disposal mechanism. Attempts to determine removal efficiencies of viruses in septic tank effluent have been impeded. Standard analytical methods for detecting and quantifying low but significant levels of harmful viruses in water are not widely established (Scalf, et. al., 1977).

The removal of nitrogen and phosphorous from septic tank influent is minimal. Cases of ground-water contamination from nitrates produced by septic tank effluent are widespread throughout the nation. A document prepared for the USEPA reports that concentrations of nitrogen, phosphorous, and potassium in waste water are slightly reduced by primary treatment (Batelle Memorial Institute, 1974).

Septic tank systems also are ineffective in treating synthetic organics. This was documented in the University of Washington study previously noted. Influent and effluent domestic waste waters from a five year-old community septic tank were sampled. Essentially no removal of priority pollutants occurred during the two-day detention time in the septic tank (Table 4-36). Organic compounds most often detected in the septic tank effluent were dichloromethane, toluene, dichlorobenzene, bis-pthalate and diethylphthalate (Dewalle, et. al., 1985).

In summary, domestic and industrial sewage constituents are not effectively treated in septic tanks. Soil absorption systems often are expected to provide additional treatment of these constituents. Bacteria, viruses, chlorides, and synthetic organics in septic tank effluent are present in concentrations not found in drinking water. Average effluent concentrations of organic compounds may be especially high if industrial/commercial wastes are handled by the septic system.

Injection Zone Interactions. The injection zone ideally utilized by Class V sewage disposal systems is the unsaturated (vadose) zone. This zone exists above the underlying ground-water table and is largely responsible for contaminant attenuation. Biological activity, including organic matter decomposition and nutrient assimilation by plants, occurs in the upper layer of the vadose zone (Canter and Knox, 1985). Fluid movement is also relatively slow in the vadose zone (unsaturated materials) when compared to saturated media (Freeze and Cherry, 1979). Biological and chemical removal mechanisms in the vadose zone are enhanced by these increased residence times.

Adsorption, ion exchange, and chemical precipitation are important chemical interactions influencing the transport and fate of constituents in soils. A key soil parameter in the removal of inorganic substances is the soil cation exchange capacity (CEC). High values of CEC are desirable and are associated with high organic matter and clay content in soils.

A unique pollutant removal zone known as the clogging layer results when biologically treatable domestic sewage is discharged into soils. The clogging layer is a slimy mass consisting of wastewater solids, mineral precipitates, microorganisms (mostly faculative bacteria but also some protozoa and nematodes), and the by-products of decomposition. Formation of the clogging layer occurs at the interface between the soil and the waste discharge system (drainfield, seepage bed, etc.).

The clogging layer employs physical filtration as well as biological and chemical transformation to partially remove contaminants. The high concentration of microorganisms in the clogging layer makes the layer an efficient biofilter. [illegible], in only rare instances, has been detected [illegible]

TABLE 4-36

DETERMINATION OF TOXIC CHEMICALS IN EFFLUENT FROM COMMUNITY SEPTIC TANK

PURGEABLE ORGANICS	DAILY ANALYSES, 9-22 THRU 9-28, 1980, (ug/L)													
	9-22 I (1)	9-22 E (2)	9-23 I	9-23 E	9-24 I	9-24 E	9-25 I	9-25 E	9-26 I	9-26 E	9-27 I	9-27 E	9-28 I	9-28 E
1. Methane, bromo-														
2. Methane, trichlorofluoro-	14.8													
3. Methane, dichloro (methylenechloride)	4.8	44.4	0.9/ (3) 0.8	0.6	7.3	4.4	3.7	3.7/-	1.9	3.0	0.5	0.8	5.6	9.0
4. Ethene, 1,2-dichloro-														
5. Ethene, 1,1-dichloro-														
6. Chloroform	5.3	0.9			0.82			-/0.3	0.9			0.4	1.9	1.0
7. Toluene	24.9	31.9	38.2/-	22.2	38.1	32.9		28.5/-	47.8	38.4	32.1	48.9	25.3	56.9
8. Ethene, tetrachloro-														
9. Benzene, chloro-														
10. Benzene, ethyl-														
11. Methane, tribromo-								3.5/-						
12. Ethane, 1,1,1-Trichloro														
13. Benzene						0.18								
14. Propane, 1,2-Dichloro-														
15. Ethene, trichloro-														
16. 1-Propene, 1,3-dichloro(2)-														
17. Ethane, 1,1,2-trichloro-														
18. 1,4-dichlorobenzene			0.79/ 2.13		2.57			1.8/ 23	2.9		2.7	2.9	4.7	0.7

(1) Influent.

(2) Effluent.

(3) Two samples.

5W11,31,32

porous soils (Perkins, 1984). As with bacteria, however, viruses are easily absorbed by vadose zone soils and will migrate only under unusual conditions (Carriere, 1980).

Phosphates also are easily absorbed by soils under normal loading rates. Migration of phosphates formed from phosphorous usually is limited and generally does not pose a threat to USDW (Carriere, 1980).

Nitrates are produced in the injection zone when the ammonia-laden effluents from sewage disposal systems are oxidized. Ammonia concentrations are relatively high near the point of injection. These concentrations, however, decrease sharply with depth while the nitrate concentrations increase. Since nitrate is a soluble anion, the soil's cation exchange capacity cannot remove the nitrate ion and nitrates subsequently move with the percolating effluent into groundwater.

Synthetic organic contaminants present in sewage and other wastewater are relatively intractable to microbial degradation in the vadose zone (Scalf, et. al., 1977). The attenuative effects of adsorption/absorption reactions on organic chemicals in the vadose zone are largely unknown. Furthermore, these reactions are dependent on underlying soil characteristics and are therefore site-specific.

All of the above are predicated upon a sufficient depth of appropriate unsaturated soils below the point of injection. Some case studies report a depth to the water table of only one or two feet. There also may be a mound of wastewater under the point of injection. The effect in such cases may be that aerobic treatment is retarded or eliminated. Again, some waste chemicals act as biocides and can partially neutralize the clogging layer.

Hydrogeology and Water Use

Over 30,000 Class V septic tank systems have been reported in the United States and its Possessions and Territories. Consequently, septic systems dispose of treated effluent into a multitude of geologic formations.

Septic systems with drainfields are widely used in geologic formations typified by shallow alluvial deposits. These deposits usually consist of sand with interbedded layers of gravel, clay, and silt. Septic tank systems with conventional drainfields generally are not operated in settings where any of the following hydrogeologic conditions exist:

1. Shallow impermeable layers (i.e. clay, silt, caliche layers)
2. shallow ground water tables; and
3. highly permeable volcanic rocks.

Septic systems with elevated drainfields (also called absorption mounds) are an alternative disposal method used in some States where shallow water tables and/or highly permeable sediments occur.

Septic tanks with wells are used in consolidated and unconsolidated strata. Seepage pits (see Figure 4-24) commonly are used as an alternative to drainfields when shallow impermeable layers lie just below land surfaces. Seepage pits are completed below these shallow impervious layers and into underlying permeable strata. Septic systems with wells also have been reported in areas where shallow bedrock occurs. These wells are drilled into the consolidated stratum and penetrate underlying cracks and solution channels.

The majority of reported Class V septic systems inject treated wastewater above USDW. Due to the large number of USDW involved, generalizations regarding the quality of these waters can not be made. A number of these USDW, however, are used or are in hydraulic communication with aquifers used for drinking water supply sources. Shallow, unconfined USDW are the most susceptible to contamination from septic system discharges. Because domestic wells usually tap shallow aquifers, drinking water from these sources is most immediately threatened. Aquifers used for municipal drinking water supplies are usually deeper and immediately less susceptible to surface discharges. In general, USDW currently or potentially affected by Class V septic systems are used for irrigation, industrial use, domestic and municipal water supplies.

Contamination Potential

Based on the rating system described in Section 4.1, septic systems are assessed to pose a high potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. The fluids may exhibit characteristics or contain constituents listed as hazardous as stated in the RCRA Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment in a region studied on a group/area basis.

In rating septic systems, States have based their judgment upon the conditions in each State. For example, Wyoming has rated them as moderate ("five" on a scale of 1 to 10) <u>because</u> there are few such wells identified. Massachusetts rates them

are permitted, and permit conditions limit both
ing. South Carolina reports over 200 and rates
upon the permitting system in place.

s such as Nevada, Alaska, Ohio, Nebraska, and
ese same sub-types as having high pollution
presents a dilemma in providing a national
t. It seems clear that the best approach is to
tion practices by their unregulated potential.
eptic systems are assessed as having a high
ential.

ems (Well Disposal Method 5W31). In general,
e used in residential areas. Very often they
bination with private or public water supply
into the surficial aquifer. Class V septic
ed in areas which are not publicly sewered or
capacity to service rapid residential

igned, constructed, and operated septic systems
e method of treatment and renovation of human
radable domestic waste. However, evidence is
ems often do not operate as designed. Septic
trogen, microorganisms, and total solids to
Synthetic organic compounds potentially present
not treated. As a result, septic tank effluent
contain contaminants which exceed MCLs (maximum
s) or are "hazardous". This effluent drains
may inject directly into an USDW.

ems (Drainfield Disposal Method, 5W32). The
nature of the injectate applies equally to this
. In fact, systems lacking the septic tank,
drain field only have been reported being used
of industrial wastes. These are rated in
later in the report.

advantage of a septic tank followed by a
t a properly designed and operated system can
and renovation for sanitary wastes. Such a
very practical solution to the disposal of
in unsewered areas. However, in view of the
domestic waste and the widespread potential for
the often reported dual use of residential
e industrial and commercial wastes, such wells
s having a high contamination potential. The
ven higher when it is realized that the [illegible]
y destroy the treatment of pathogens and the
ses in the tank and drainage field. The [illegible]
emplacement of untreated liquid wastes [illegible]

Current Regulatory Approach

Class V septic systems are authorized b
Federally-administered UIC programs (see Section 1
regulate discharges of sanitary sewage to ground
rate categories. In Massachusetts for example,

> Domestic discharges greater than 15
> require a permit and are regulated u
> Groundwater Discharge Permit Program... Disch
> structures or pits that are deeper than they
> qualify as underground injection control f
> Those UIC facilities (which are not exem
> required to obtain a groundwater discharge pe

Many States report that no records are kept o
septic systems. These may be registered
jurisdiction, and approved by a sanitarian, but th
not be available to the State.

South Carolina gives a good description of t
of State Agencies.

> In South Carolina, wastewater disposa
> comprised of septic tank/absorption fi
> regulated by two permitting programs within
> Carolina Department of Health and Envi
> Control. The Bureau of Environmental Sanitat
> permits for facilities involving res
> laundromats, car washes and individual re
> systems. The Bureau of Water Pollution Cont
> construction and operating permits for
> industrial and sanitary land disposal
> including septic tank/tile field systems.
>
> The permitting program of each Bureau
> permit of approval or denial for tile fiel
> only after a rigid assessment of the overall
> environmental impact from the proposed sy
> site specific assessment includes an invest
> potential impact to the shallow aquifer
> takes into consideration wastewater charac
> hydrogeological conditions of the proposed
> any existing and/or potential ground-water
> area. Hydrogeological site assessments are
> by staff hydrogeologists of the Groundwater
> Division for systems regulated by the Burea
> Pollution Control. Soil classifiers (sa
> perform preliminary site assessments for the
> Environmental Sanitation. On occ
> hydrogeologist from the Groundwater Protecti
> assists Environmental Sanitation.

Arizona instituted a Department of Environmental Quality (DEQ) in July of 1987, to protect, among other things, ground-water quality.

Chapter 20 of the Arizona Compilation of Rules and Regulations, passed in 1984, requires the issuance of a ground water quality protection permit for all disposal activities that may adversely affect ground water quality. Operators of waste disposal facilities are required to submit a Notice of Disposal (NOD) describing disposal activities. If the facility is deemed to have no adverse effect on ground water a permit will be issued by the Arizona Department of Health Services (ADHS), which maintains records of all NOD's and permits issued (Wilson, 1986a).

Arizona Department of Health Services guidelines pursuant to Rules and Regulations for Sewage Systems and Treatment Works prohibit some practices and installations. Septic systems are prohibited under the following conditions: 1) when connection to a public sewer system is determined by the ADHS to be practical, 2) when soil conditions or topography are such that septic systems cannot be expected to function properly, 3) where ground-water conditions are such that septic systems may cause contamination of the ground-water supply, and 4) where systems may create an unsanitary condition or public health nuisance. The use of cesspools for waste disposal is prohibited, as is the practice of discharging effluent from any waste treatment device into any crevice, sink-hole, or other natural or artificial opening, or into a formation which may permit the contamination of ground water.

Florida has a permit system based on capacity.

Septic systems are usually permitted in Florida by the county health departments. Regulations which govern these septic systems are contained in Chapter 10D-6 of the Florida Administrative Code (FAC). All industrial septic systems and those domestic septic systems receiving 5,000 gallons of waste per day or more are regulated by the Department of Environmental Regulation (DER). Chapter 17-6, FAC governs all septic systems permitted by the DER.

California is regionalized.

California's Regional Water Quality Control Boards are empowered to regulate waste discharges within the State. Class V sewage waste disposal systems are among those dischargers regulated by the Regional Boards.

Each of the nine Regional Water Quality Control Boards in California have adopted individual regulatory approaches regarding Class V sewage waste water disposal systems. County health departments are heavily relied upon by a majority of the Regional Boards to regulate Class V on-site systems (i.e., septic tank systems) within their respective counties. Municipal waste water disposal systems are exclusively regulated by Regional Boards. Permits for Class V on-site sewage systems are issued and maintained by county health departments and/or Regional Water Quality Control Boards.

Texas describes number of regulating authorities.

The degree and type of existing regulation varies greatly among the three areas of the State in which the Department of Health investigated sewage disposal wells. Much of the study area was not covered by septic tank orders. These areas are, however, subject to regulation by incorporated towns and county health departments. This regulation usually consists of encouraging proper system design and installation, and dissemination of information and guidelines. Often, builders, developers, and architects will consult with local public health officials for recommendations on sewage system design. Another indirect form of regulation is the requirement of a local health department inspection and approval of domestic wastewater facilities for Farmers Home Administration (FHA) financing. This inspection provides a mechanism for enforcing Department of Health guidelines and upgrading some existing facilities.

In the High Plains, three counties and two lake authorities administer septic tank orders. Included within these areas are the cities of Lubbock, Canyon, and Amarillo. These orders cover only a very small part of the High Plains study area. The City of Rocksprings, on the Edwards Plateau, has no regulatory order, but reviews septic tank and disposal well installations for basic design criteria. A similar situation exists in Nueces County, where the Corpus Christi-Nueces County Health Department reviews plans and inspects construction of septic tank and disposal well installations for compliance with design criteria.

Current private sewage facility regulatory programs are generally of recent origin and are effective in controlling design and installation of on-site sewage disposal systems in new construction projects. These programs, however, do not generally assure upgrading of existing systems.

Recommendations

In many States septic systems for the disposal of sanitary wastes are permitted by a county sanitarian. The traditional concern has been to establish that the site "percs" or infiltrates. Miller and Wolf (1975) point out that the issue is more complex.

> Thus the capacity of a soil to transmit and renovate effluents is a function of its behavior under the unsaturated flow conditions imposed by the crusting process that renders the percolation test ineffective as a design criteria, since this estimates saturated hydraulic conductivity, whereas the system eventually operates in the soil medium at unsaturated hydraulic conductivities as governed by the infiltration rate at the clogged surface."

In other words, septic drain fields will not accept the volume of fluid indicated by a percolation test. The system may fail. Therefore, an ongoing training program for sanitarians, is recommended by Minnesota, Puerto Rico, and Maryland.The training should include hydrogeology, groundwater flow, theory of septic system operation, and the potential risks to human health in the disposal of organics, solvents, and other man-made chemicals in septic systems.

It was suggested by Kansas and Nebraska that septic systems should be sited so as not to endanger any water wells. Present local regulations may ignore hydrogeology and allow migration to the owner's and/or neighbor's wells. Septic systems which dispose without adequate treatment should be eliminated.

All septic systems should be individually sited and designed (Texas). A hydrologic study should document the density of septic systems and the total loading to the ground water (Nebraska).

Three states (Florida, Montana, and Oregon) recommended that further study is required. Missouri recommended that proper construction guidelines be developed, and Kansas suggested investigating facilities to ensure quality well construction.

Washington stated that there is a critical need to establish a statewide monitoring system, inventory methodology, and database in order to evaluate design for existing systems, establish ambient water quality in vulnerable aquifer regions, and be able to quantify changes in critical parameters.

Finally, Texas recommended that sewage disposal wells for private facilities be phased out and replaced by alternate methods of treatment and disposal.

4.2.3.3 Domestic Wastewater Treatment Plant Effluent Disposal Wells (5W12)

Well Purpose.

These wells should not be confused with recharge wells (5R21) and salt-water intrusion barrier wells (5B22) even though wastewater is sometimes injected into the latter. This discussion covers only domestic wastewater (sewage) treatment plant disposal (5W12) wells that are intended to dispose of the effluents from wastewater treatment plants by injecting the wastewater into or above USDW. In addition to disposal, highly treated domestic wastewater is sometimes injected between a fresh ground-water body and the leading edge of an encroaching salt water body. In such cases, the sole function of the injected water is to reverse the pressure gradient causing the landward migration of salt water. Wells injecting treated wastewater for this purpose, however, fall under the saline water intrusion barrier well category and therefore are not discussed here. Domestic wastewater injection wells also may be used to reinforce dwindling ground water resources. Where this has been done, the remoteness of domestic water supply wells, combined with the magnitude of dilution thus far has not resulted in any detectable deterioration of ground-water quality in the vicinity of the supply wells. Quite naturally, great effort has been made to select sites that are remote from points of use and to provide a very high degree of treatment -- treatment that produces an effluent meeting all currently applicable maximum concentration levels (MCL's) for drinking water. Again, however, wells injecting treated wastewater for this purpose are classified as 5R21 and will not be discussed in this section. Volumes of wastes handled vary widely, from a few thousands of gallons per day (for motels) to several millions of gallons per day (for cities).

All the facilities reviewed so far have provided at least secondary treatment, and a few could be rated as tertiary treatment plants. Secondary treatment usually involves some form of aeration (activated sludge or trickling filter or equivalent) in addition to the primary treatment (sedimentation and digestion of settleable solids). Clarification (removal of suspended solids) is always involved, and final chlorination of the plant effluent to destroy microorganisms also generally is included. Since clogging of receiving formations can become a serious obstacle in unconsolidated aquifer materials and in sandstones, special efforts to remove still more of the fine suspended solids, by filtration through sand, are likely to be necessary when injecting into such geological formations.

Inventory and Location

At this writing the inventory of type 5W12 wells is incomplete. States reporting Type 5W12 wells and their estimated numbers are shown in Table 4-37.

As seen in Table 4-37, the bulk of 5W12 wells are reported as being in the States of Florida (553 wells) and Hawaii (339 wells). The abundance of cavernous limestones in Florida, and the high permeabilities of the coralline limestones of the Florida Keys make this disposal method popular in that State. Both types of formations accept organic wastes with little tendency to plug.

Hawaii has both fractured, tunneled basalt and highly porous, ancient marine coral reefs which readily accept wastewaters. This is an economical and simple means of disposal for small towns, hotels, and institutions where there are no public sewer systems.

At first glance, the 72 wells reported for Massachusetts is surprising for a State not known for limestones or basalts. However, all 72 wells are seepage pits serving a condominium complex.

California (40 wells) and Texas (10 wells) are both in arid regions where the heavy withdrawal of ground water for irrigation has led to some of the first serious attempts to replenish freshwater aquifers with highly treated wastewater plant effluents.

Construction, Siting, and Operation

Construction. Construction details vary widely. Some well constructions show evidence of good casing and cementing programs, good screen designs in the injection zone, and dependable flow and pressure monitoring/recording systems. Others are little more than a few feet of pipe inserted into a bore hole some [illegible] feet in depth. Construction details appear to be controlled more by the need to keep the wells operating than by a desire to confine the discharge to a predetermined zone.

The ability of a disposal well to inject a given discharge rate into the injection zone is primarily a function of several factors: 1) the permeability of the geological formation comprising the receiving zone, 2) the thickness of the receiving formation, 3) the design of the screen or [illegible] the receiving interval, 4) the differential pressure [illegible] force the waste water into the formation, 5) the [illegible] of

TABLE 4-37: SYNOPSIS OF STATE REPORTS FOR DOMESTIC WASTE WATER TREATMENT PLANT EFFLUENT DISPOSAL WELLS(5W12

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	72 WELLS	PERMIT>15K GPD	YES	LOW
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	21 WELLS	PERMIT	NO	N/A
Puerto Rico	II	1 WELL	PERMIT	YES	HIGH
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	4 WELLS	N/A	NO	4TH HIGHEST/6 TYPES
Virginia	III	1 WELL	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	553 WELLS	PERMIT	YES	2ND HIGHEST/8 TYPES
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	3 WELLS	ELIMINATE	NO	SERIOUS
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	1 WELL	RULE	NO	N/A
Indiana	V	27 WELLS	PERMIT	NO	N/A
Michigan	V	2 WELLS	PERMIT	NO	N/A
Minnesota	V	11 WELLS	N/A	NO	N/A
Ohio	V	YES	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	RULE/PERMIT	YES	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	YES	N/A	NO	N/A
Arizona	IX	1 WELL	PERMIT	NO	HIGH
California	IX	22 WELLS	PERMIT	NO	HIGH
Hawaii	IX	335 WELLS	PERMIT	YES	HIGH
Nevada	IX	NO	BANNED	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	4 WELLS	PERMIT OR RULE	NO	HIGH
Idaho	X	9 WELLS	RULE	NO	7TH HIGHEST/14 TYPES
Oregon	X	32 WELLS	N/A	NO	N/A
Washington	X	NO	RULE	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

treatment before injection, and 6) the chemical compatibility of the injectate with clays in the receiving formation.

A single term called "transmissivity" combines the first two factors mentioned above: permeability and formation thickness. The rate at which the receiving formation will accept the injected fluid is directly proportional to its transmissivity.

For injection wells in sand and gravel formations, specially designed "screens" are installed in the injection zone. These screens provide a large percentage of open area and have slot sizes that prevent movement of formation sand into the well during "development." Development is a process of agitation and removal of materials around the well intake (screen) that are fine enough to pass through the slots in the screen; it lowers the resistance to flow close to the well thereby increasing the efficiency and capacity of the well. Development is necessary before placing the well in service and is required periodically, to remove plugging materials from the face of the borehole and restore well capacity.

Frequently 18-8 stainless steel or some other suitable alloy is used as the material for the well screen; 18-8 stainless (18% minimum chromium, 8% minimum nickel, 2% maximum manganese, 0.2% maximum carbon, balance iron) is an alloy commonly used for water well screens. It is noted for its excellent resistance to corrosion by aggressive water and by harsh chemicals that sometimes must be used during redevelopment. A well screen whose length will cover a high percentage of the formation thickness is specified.

Where highly permeable formations are used for the injection zones, most disposal wells operate successfully "on gravity," that is, the pressure provided by the column of water in the well casing is sufficient to cause the wastewater to flow into the receiving formation without overflowing onto the ground surface. There are numerous examples of "gravity flow" injection wells in Florida, Kentucky, Tennessee, Hawaii, Puerto Rico and many other States where such formations exist.

Where only sand or gravel beds are available, the resistance to flow provided by the formation may require the use of pumps. In such cases, the well casing is connected directly to the pipe carrying the treatment plant effluent and the pumps maintain both the pipe and casing under pressure.

Completeness of treatment prior to injection is crucial to the successful hydraulic performance of an injection well completed in unconsolidated materials (sands and gravels). The more complete the treatment -- especially the removal of suspended solids -- the longer the well will operate at reasonable pressures before it must be shut down and

rehabilitated. The plugging material may be fine sand, silt, organic matter, and microorganisms. Bacteria and certain other microorganisms find an ideal habitat within the screened portion of the injection well, where a constant supply of nutrients at nearly constant temperature is being provided by the effluent stream. Final chlorination of the effluent before injection can destroy most microorganisms and retard the growth of others within the well; unfortunately, the concentrations of chlorine necessary to be effective in water so high in organic materials also produce a wide range of chlorinated organic compounds, some of which are known to be toxic.

Siting. Injection well sites are selected for the usual considerations: economics, convenience, suitability of the target receiving formation, and, for the hydraulic effect the injection will have on the receiving formations.

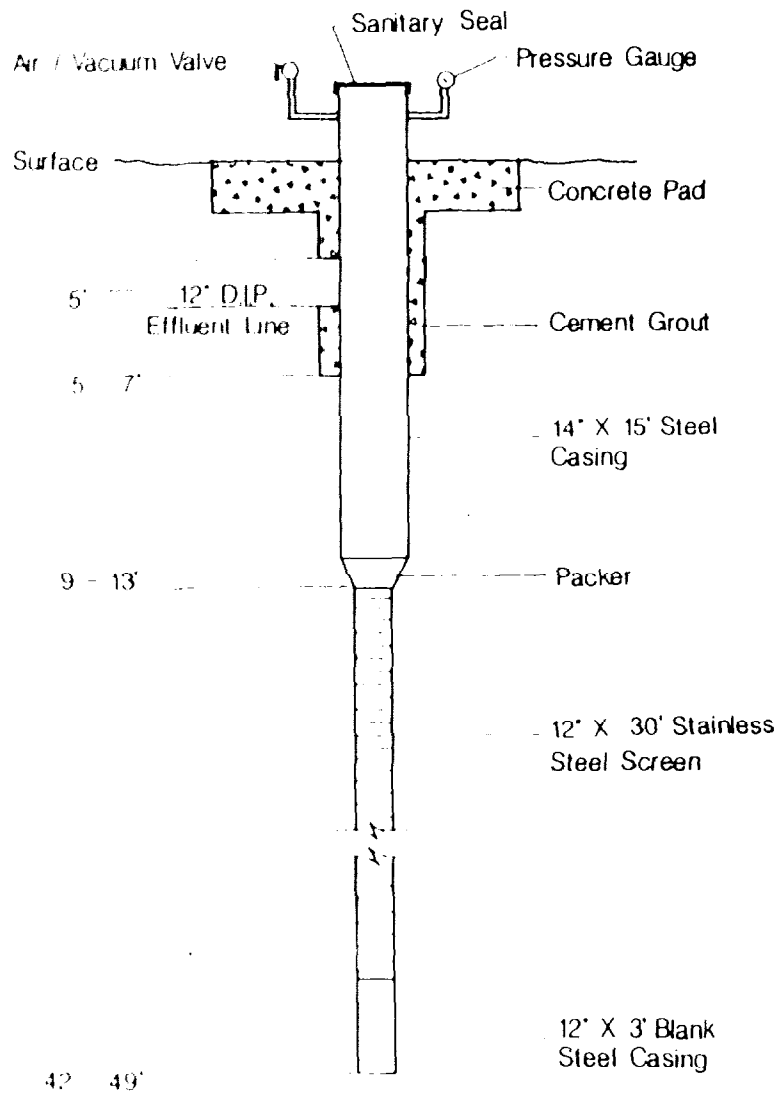
The first consideration given is to drill the well as near as practical to the waste treatment facility it will serve. If the well can be constructed on land owned by the facility, additional land or rights-of-way will not have to be purchased. The closer the well is located to the point of discharge, the lower pipeline, trenching, and pumping costs will be.

In addition, the well must be located where suitable receiving formations are available, as this will have a direct bearing on the efficiency, serviceability and dependability of the well. As in the case of water supply wells, an exploratory drilling program to locate and evaluate the injection formation may be necessary if the desired information is not already available.

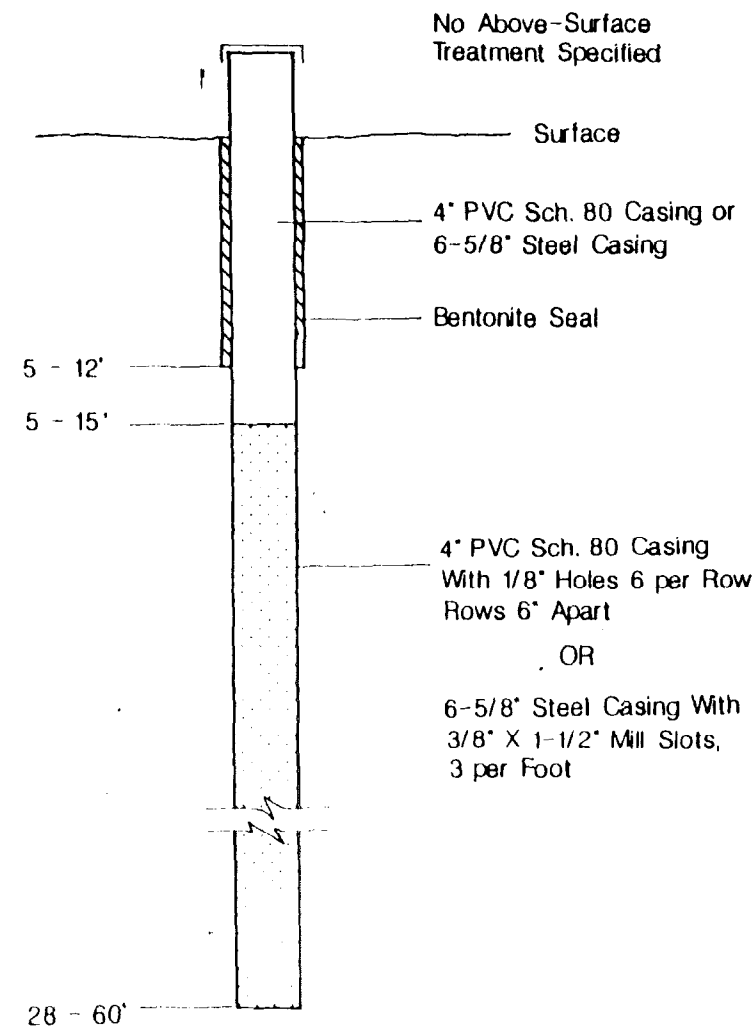
Operation. Operation of injection wells for disposal of domestic treatment plant wastewater may range from very simple to relatively complex. Disposal wells in the Florida Keys, delivering effluent to shallow (25 to 30 ft.) wells completed in coralline limestones, operate by gravity flow with virtually no attention. There is no monitoring of flow or water quality, and there are no monitoring wells to track the lateral movement of the injected waters.

At the other extreme are operations such as that at Jackson Hole, Wyoming (Figures 4-27 and 4-28), where the plant effluent quality is monitored for quality and measured for volume regularly to assure that concentrations of constituents listed in the USEPA regulations never approach the MCL's for drinking water; and samples downgradient of the well are withdrawn at regular intervals to detect any significant change in ground water quality.

TYPICAL COMPLETION DIAGRAM OF RECHARGE AND MONITOR WELLS

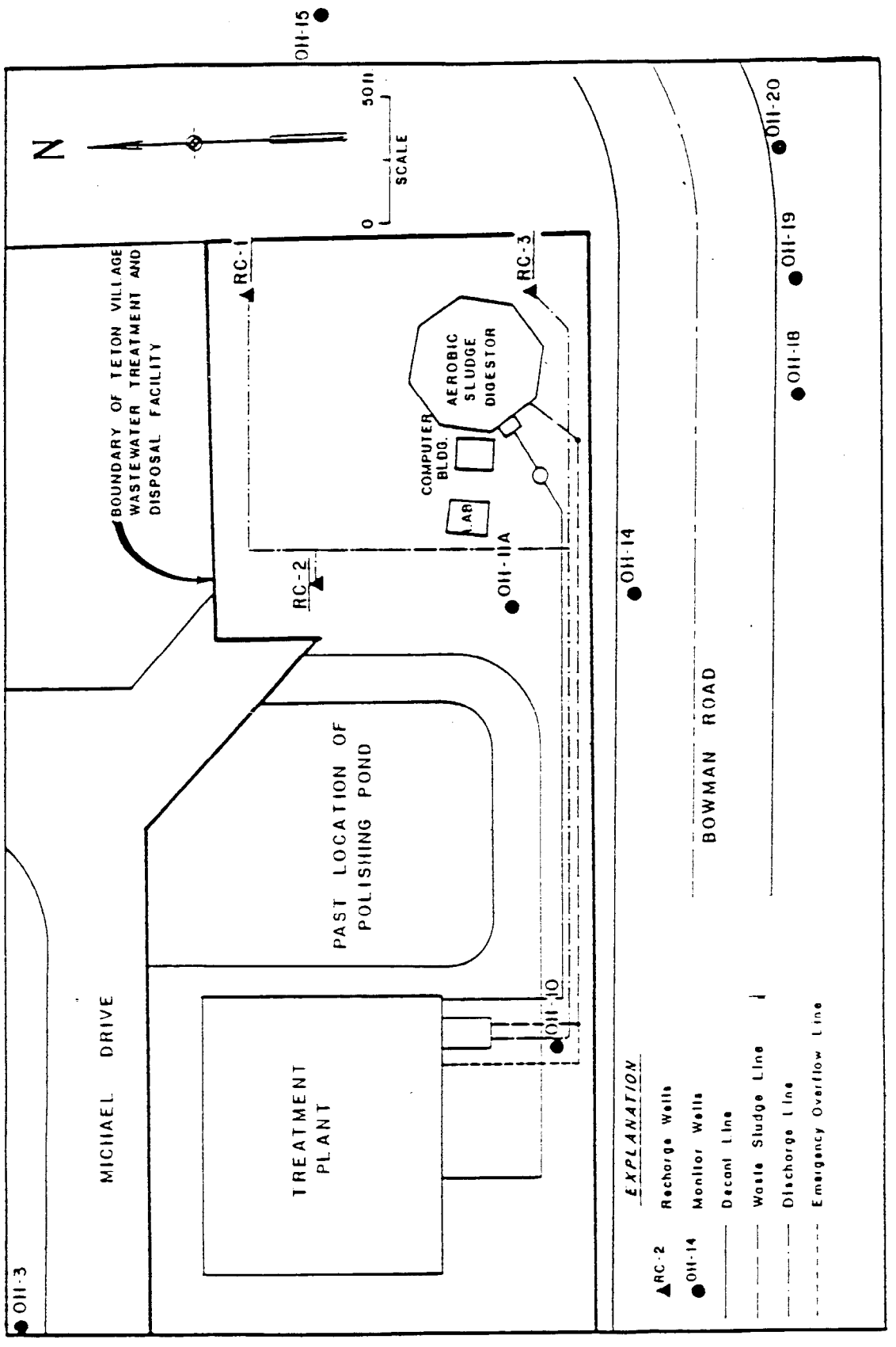


TYPICAL RECHARGE WELL



TYPICAL MONITOR WELL

Figure 4-2



TETON VILLAGE WASTEWATER TREATMENT AND DISPOSAL FACILITY, TETON COUNTY, WYOMING

(modified after Nelson Engineering and Culp Wesner Culp, 1979)

Figure 4-28

At Bay City, New York, on Long Island, an experimental domestic wastewater injection well has been operated for more than two decades by the U.S. Geological Survey and the Nassau County Department of Public Works (this experiment has been terminated and the facility is no longer operating). Water quality parameters for the injectate have been meticulously monitored throughout the period. Despite intensive treatment of the injectate, clogging has been an ever-present problem at Bay City. Bacterial contamination has been limited to a few feet radially from the injection well (Ehrlich, et al, 1979).

Both pressure and rate of injection are monitored at wells injecting into sand and gravel formations, as these values indicate when the well should be shut down for rehabilitation. Clogging elevates pumping costs and reduces the rate of injection.

Gravity-flow wells injecting into highly permeable, channeled, and cavernous limestones and into basalts are not susceptible to clogging, so operation is relatively simple with no need to monitor pressures at the well head. Limestones and basalts, however, are ineffective barriers to the movement of bacteria. Wastewater treatment plant injection wells completed in such formations, therefore, are a greater threat to public health. Destruction of pathogens during treatment before injection is more critical than for wells injecting into sand formations.

Injected Fluids and Injection Zone Interactions

Numerous studies have shown that bacteria are unable to travel more than a few feet through unconsolidated sand and gravel materials. The possibility of infections from bacteria moving through such materials any appreciable distance therefore appears not to be a concern. Phosphates and nitrates, however, are present in all domestic waste treatment plant effluents, and are completely mobile. Nitrates are permitted in drinking water only in concentrations as high as 10 mg. per liter (10 parts per million) as nitrogen; when concentrations in drinking water exceed this value, they can be reduced by a process called "denitrification."

The nature of domestic wastewater (unaffected by industrial discharges) is such that, after treatment in a secondary or tertiary wastewater treatment plant, it may approach chemical compatibility with the water in the receiving formation.

There are two general categories of chemical reactions that can result when the injectate mixes with formation water. One is dissolution of aquifer rock materials; the other is the production of chemical precipitates.

If the injectate is acidic (pH less than 7.0), some of the rock matrix or minerals may be dissolved. This clearly can happen in limestones and dolomites, with no consequence unless the rocks happen to release significant amounts of undesirable minerals as they dissolve or the solution channels are increased in number or size. At Bay City, New York, the low pH of the injectate dissolved iron-bearing minerals in the sand, elevating iron concentrations in the vicinity of the injection well.

High alkalinity and higher pH (above 7.0) are more likely to cause chemical precipitation when the injectate reacts with the formation water. In this case the precipitates formed are likely to plug granular formations, especially medium to fine sands. Chemical precipates would not plug channeled formations such as limestones or basalts.

There is another type of reaction that often takes place when injectate comes in contact with native clays. Many clays are sensitive to changes in pH or the presence of certain ions -- especially sodium. A very small amount of clay dispersed within a sand aquifer can effectively block the flow of water if it swells as a result of a pH change or the presence of certain ions. These phenomena are well known to the petroleum industry, where extensive injectate water conditioning is sometimes necessary to maintain the injectivity of water flood and salt water disposal wells.

Hydrogeology and Water Use

If USDW are to be protected from possible contamination by injectates from Class V injection wells, full advantage should be taken of hydrogeological factors affecting the direction and rate of travel of injectates. The formations with the greatest permeabilities and, hence, those that accept injected water most readily are those that possess networks of interconnected channels, fractures, caverns and tunnels. Examples of these are the weathered limestones (especially the "karst" limestones) and certain types of volcanics (especially certain basalts). These types of formations also offer the additional advantage of not being vulnerable to plugging by suspended materials in the wastewater. As we shall note later, however, this inability to intercept and hold suspended materials becomes a disadvantage when public health considerations are taken into account.

Formations with low permeabilities, such as those composed of fine sand or sand with quantities of silts and clays, do not accept injectates as readily as the channeled limestones and basalts and are far more susceptible to plugging by suspended materials in the wastewater. For this reason a great deal of attention needs to be paid to carrying, to a high degree of completion, the treatment of the wastewater -- especially the

removal of suspended matter. "Polishing" beds of sand, or lagoons, are sometimes placed in service (following the normal secondary treatment) to accomplish this end.

Ideally, the injection well is located so that none of the injectate would ever reach a drinking water supply source. At the very least, it should be so situated that its effect at the water supply source would be undetectable. This is not always the case, though, as can be seen from a facility in Florida.

The Florida domestic wastewater treatment plant near the town of Florida in the Arecibo District of Puerto Rico is situated in karst topography with numerous sinkholes. It was found to be operating at about double its design capacity and with the final, tertiary treatment section (sand bed filtration) out of service. The effluent, confirmed by plant operating records, was incompletely treated. It is likely that the plant effluent, some 360,000 gallons per day discharged into a sinkhole, travels downward through fissured and channeled limestone to the water table aquifer below. The same aquifer is the source of water for the town of Florida and several other nearby groups of houses.

Contamination Potential

Based on the rating system described in Section 4.1, domestic wastewater treatment plant effluent disposal wells are assessed to pose a high to low potential to contaminate USDW. These facilities typically do inject into or above Class I or Class II USDW. Well construction, operation, and maintenance may, in certain geological settings, allow fluid injection or migration into unintended zones. Injection fluids sometimes have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations and are of poorer quality (relative to standards of the National Primary or Secondary Drinking Water Standards or RCRA Regulations) than the fluids within any USDW in communication with the injection zone. However, fluids may be of equivalent or better quality (relative to standards of the National Primary or Secondary Drinking Water Standards and RCRA regulations) than the fluids within any USDW in connection with the injection zone. Based on injectate characteristics and possibilities for attenuation and dilution, injection sometimes occurs in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter.

The potential for Type 5W12 wells to contaminate USDW will vary from high to low depending on the following considerations:

1. Class V wells that inject into or above USDW are, by virtue of the location of these target injection zones alone, a threat to aquifers. Elevation alone provides the "head" or driving force necessary for the injectate to tend to move toward the USDW.

2. Where there is no geological formation providing an effective barrier separating the injectate from the USDW, as in the case of vugular limestones or basalts, bacteria may be carried by flow of the injectate to the USDW.

3. Unconsolidated sediments such as sands and fine gravels effectively filter out bacteria and other suspended solids within a few feet of the injection well.

4. When only domestic sewage is being treated, that is, no industrial wastes are present, the only soluble constituents that are fully mobile and of concern are phosphates and nitrates. Of these, only nitrates are of public health concern; they may require special treatment prior to injection.

5. Wastewater treatment plants accepting industrial wastes may present a special threat, in that many organic chemicals, as well as some "heavy" metals (frequently toxic) pass through the treatment process essentially unaffected.

6. Treatment facilities discharging into porous and channeled limestones or basalts require constant vigilance and monitoring, as these activities constitute the only barriers to potential contamination of USDW.

7. The origin of the water and the purity of the injectate require continuous vigilance by plant operators and dependability of mechanical devices.

Current Regulatory Approach

Class V domestic wastewater treatment effluent disposal wells are authorized by rule under Federally-administered UIC programs (see Section 1). Of the 19 States reporting the existence of type 5W12 wells, Florida and Hawaii have, by far, the most (80% of them).

Florida. The Florida Department of Environmental Regulation (FDER) issues construction permits for Class 5W12 wells. Permits are also required for both operation and for plugging and abandonment (P&A) of 5W12 wells. In addition, the FDER is authorized to specify monitoring requirements as a condition to operation.

The application-for-construction permit is a 3-page, rather comprehensive document that requires the presentation of information such as location and construction details of the well, the general nature and volume of the injectate, a description of the injection system, and definition of the area of review showing all water supply wells, surface water bodies, injection wells, etc. It specifies that contamination caused by the proposed well can result in revocation of the operating permit. The corresponding operating permit is non-renewable and non-expiring (except for violations of the law) and is transferable to another owner. The FDER may elaborate on specific conditions set for operation of the facility within the permit.

The FDER also requires that a permit to plug and abandon be obtained when a 5W12 well is permanently removed from service. The application requires a detailed description of the P&A plan. Upon completion of the P&A operations, the owner is required to complete a "Certification of Plugging Completion Class I, III or V Well" and record it at the FDER.

The FDER has included in its State report a draft of proposed "Revisions to the Florida UIC Class V Regulations." It deals primarily with proposed rules tightening the effluent water quality requirements and specifying the types of treatment that are expected to be used in bringing the quality up to levels safe for injection.

Hawaii. The Department of Health of the State of Hawaii issues permits for Class V wells, including the 5W12's. A single 5-page application form is required to be filled out, whether it be for an existing well, a new well, abandon and seal procedures, or other activity.

The accompanying instructions are comprehensive, calling for information on the facility such as, all wells within one-quarter mile, geology and climatology, nature and source of injectate, operating parameters, geohydrology, well logs, nature of groundwater, results of injectivity tests.

State of Hawaii statutes prohibit the operation, construction or modification of an injection well without a permit issued by the Department of Health.

California. Regional Water Quality Boards (RWQB), of which there are nine in the State, are the permitting agencies for 5W12 injection wells.

Texas. Registration is conducted by the Texas Department of Water Resources (DWR). Existing Class V wells are regulated by rule, on condition they're registered by January 6, 1983. Proposed new Class V wells must be registered with Department of Water Resources prior to construction. The Department may continue regulation by rule, or may develop "other regulating approaches for specific categories of Class V wells." The following information is required to be submitted: (1) name of facility; (2) name and address of legal contact; (3) owner; (4) nature, type and operating status of each injection well; and (5) location, depth, and construction of each well. After the Executive Director of the DWR has reviewed the proposed operation, he may require that the owner or operator apply for an injection well permit.

Oregon. Registration is with the Department of Environmental Quality (DEQ) of Oregon. The Department of Water Resources (DWR) regulates and issues permits for groundwater recharge. Individual permit drafting and source oversight are the responsibility of the five DEQ regional offices.

Alaska. Class V injection wells are under the jurisdiction of the Alaska Department of Environmental Conservation (ADEC). General permits describing the features of the facility are issued by ADEC. In addition, local regulations may control in certain areas. Currently many changes are occurring in local regulations as the need for coordination is recognized.

Idaho. All Class V wells deeper than 18 feet below land surface require permits issued by the Department of Water Resources. An application must be filed with the DWR for construction, maintenance or modification of an injection well. No well is permitted by DWR if it contaminates an USDW.

Indiana. The main State regulatory statute in Indiana for the control of pollution of both surface and groundwater is 330IAC 3-1. The Stream Pollution Control Board (SPCB) is responsible for its enforcement. All discharges from Class V wells into ground water require a permit from the SPCB <u>except</u> the following:

1. approved and/or properly operating septic tanks with less than 4,000 gallons of liquid capacity;

2. discharges composed only of storm runoff; and

3. air conditioning/cooling water return wells which do not use water additives.

The Indiana State Board of Health administers the discharge permitting program through several state sub-agencies.

Michigan. The Water Resources Commission is responsible for controlling the pollution of both surface and groundwater in the State. The Commission would require a permit be issued for any 5W12 type injection well.

Other States. Other States that indicated the existence of 5W12-type wells have not yet provided the information on permitting, or have provided information so general that its relationship to 5W12 wells is unclear. There is some evidence to suggest that several States misclassified the wells.

Recommendations

Siting. Recommendations for location of injection wells so as to protect USDW are likely to be different from those aimed at consideration of cost, land ownership and convenience. Although economics will play an important role in every case, this report will stress only those that enhance the protection of USDW.

Hydrogeologic data on the proposed injection zone and contiguous formations must be collected and interpreted in order to understand existing ground-water occurrence and movement and to predict how these likely will be affected by the injection operation (AL, WY, HI). This might include complete pumping tests (both withdrawal and injection) with sufficient observation wells available to maximize usefulness of the data.

Operation. Each injection well should be permitted to operate at a maximum predetermined injection rate and a maximum pressure, determined by site-specific hydraulic conditions -- prevailing and foreseen (NY, AL, HI).

Remedial Action. Any 5W12-type injection well injecting treatment plant effluent into an USDW and not meeting the NPDES maximum concentration levels for drinking water requires remedial actions. Specific remedy(ies) will depend on the nature of the threat to water supplies and the nature of the treatment process. In some cases, wells should be plugged (NY).

Alternative disposal methods and feasibility of upgrading existing plants should be evaluated (VA).

4.2.4 MINERAL AND FOSSIL FUEL RECOVERY RELATED WELLS

4.2.4.1 Mining, Sand, or Other Backfill Wells (5X13)

Well Purpose

Backfill wells are used to place hydraulic (water) or pneumatic (air) slurries of sand, gravel, cement, mill tailings/refuse, or fly ash into underground mines. Mines may be backfilled in order to:

(1) Prevent subsidence attributable to mine cave-in;
(2) Create structural stability in active mines;
(3) Dispose of mill tailings/refuse or fly ash;
(4) Control or extinguish underground mines fires; and
(5) Fill in dangerous mine openings (Texas).

This operation entails drilling wells from the surface to the roof of the mine void, casing the well, and gravity feeding or pumping a slurry down the well into the mine. In Idaho, mine tailings are mixed with water to form a slurry and are piped through existing mine tunnels into excavated portions of subsurface mines.

The term "mine backfill wells" also has been used in reference to water wells or monitor wells installed into the backfill of surface mines. The latter definition of mine backfill wells does not fit the Federal Underground Injection Control (UIC) Program regulatory definition. According to 40 CFR 146.5 (e)(8), sand backfill and other backfill wells are used to inject a mixture of water and sand, mill tailings, or other solids into mined-out portions of subsurface mines (whether what is injected is a radioactive waste or not), and are Class V injection wells.

Inventory and Location

The Federal Underground Injection Control Reporting System (FURS) database indicates an inventory of 548 mine backfill wells in 6 states while the 54 State inventory and assessment reports received at this writing indicate the existence of 6,500 wells in 16 states. The discrepancy may be attributable to the fact that many mine backfill operations are now regulated by State or Federal mine bureaus or agencies who have little contact with UIC regulators. As a result, many backfill operation regulators are not aware of FURS or the EPA UIC Program requirements. The fact

that FURS does not differentiate 5X well types also may add to the inaccuracy of the FURS inventory (mine backfill wells are one of many 5X type wells).

The "State Report" inventory (Table 4-38) includes only active and temporarily abandoned mine backfill wells. There are over 20,000 permanently abandoned wells of this type in the United States. The Pennsylvania State report identified over 19,000 wells. Many backfill wells are utilized for less than 2 days, then plugged and abandoned.

Mine backfill wells are limited to the continental United States and only those States where shaft mining exists. An abundance of water for slurry transport is a significant requirement for backfill well feasibility. Therefore, mines in arid regions with low water tables are not as likely to be hydraulically backfilled as mines in the wetter regions of the country.

Construction, Siting, and Operation

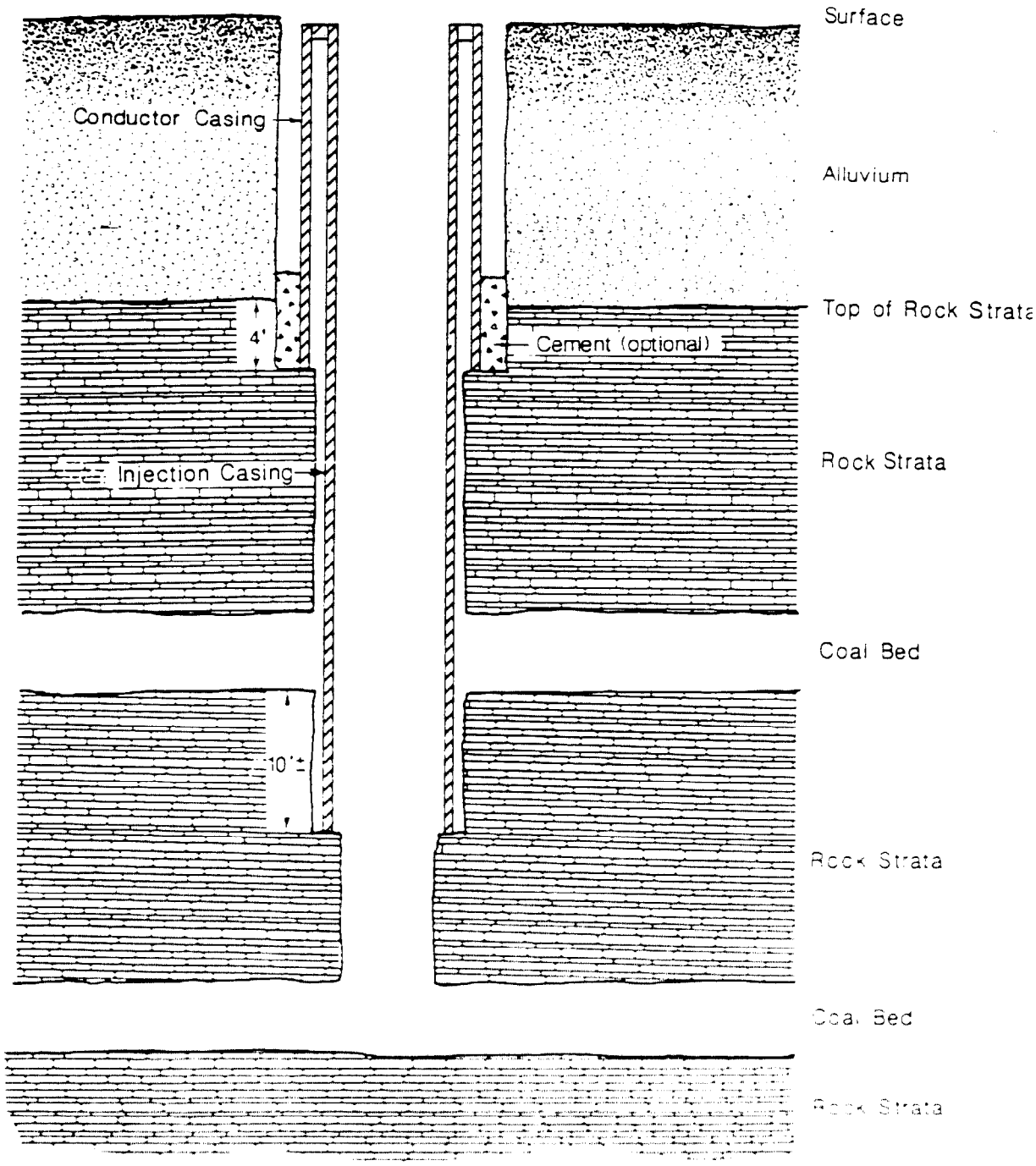
Several different types of mining-related injection wells utilize the mined-out portions of deep mines as the injection/disposal zone. Even though each well type performs a unique function, similar techniques and injected material are utilized. Operation and construction details of each mining related injection well are described below. Figures 4-29 and 4-30 present a typical mine backfill well construction and a typical subsidence control operation.

Subsidence Control. Hydraulic flushing is a technique commonly employed as a means of minimizing surface damage resulting from underground mine collapse (subsidence). It involves the use of strategically placed injection wells for the purpose of sluicing a slurry of solids into a mine void until full. Hydraulic flushing allows for substantially complete filling of all void spaces (to a predictable radius) around the well bore. Extent of fill, both laterally and vertically, is controlled by the solids concentration of the slurry and the injection rate, thus lending design flexibility dictated by mine void configuration. Bulkheads within the mine are sometimes constructed to control slurry emplacement. Hydraulic flushing for subsidence control can be applicable both above and below drainage coal seams. Economics dictate that readily available, abundant, and inexpensive fill materials be used. The fill materials commonly used are mine refuse, fly ash, cement, and crushed sandstone. Combinations of these materials are also used.

TABLE 4-38: SYNOPSIS OF STATE REPORTS FOR MINING BACKFILL WELLS(5X13)

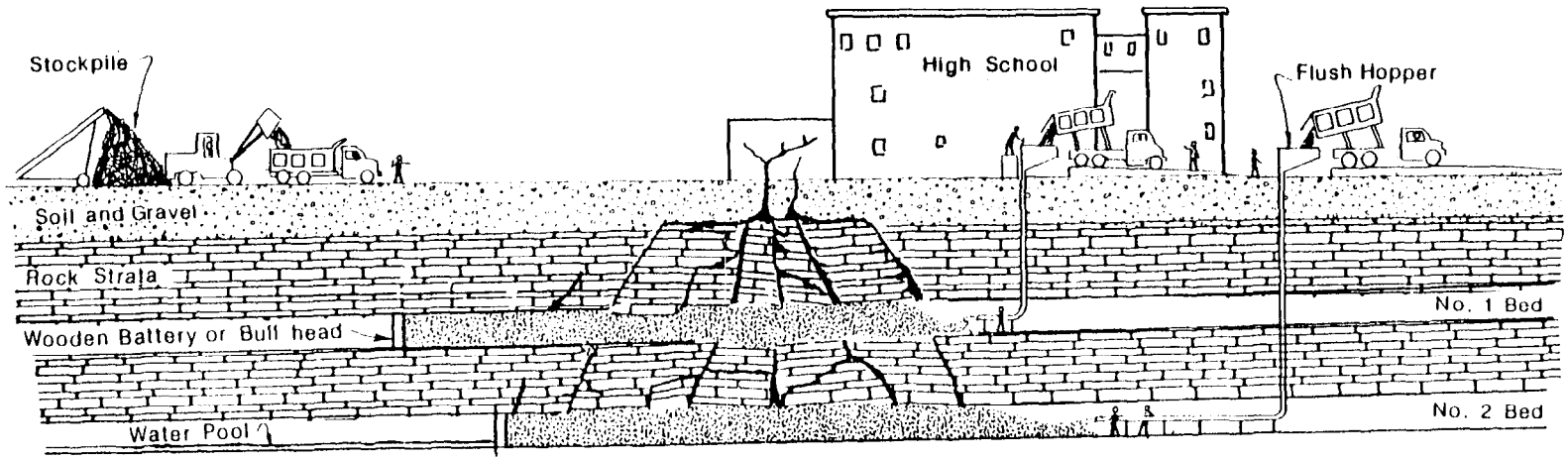
REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	1 WELL	PERMIT	NO	N/A
Pennsylvania	III	811 WELLS	MINE OPERATION	NO	5TH HIGHEST/6 TYPES
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	258 WELLS	MINE OPERATION	NO	LOW
Alabama	IV	YES	PERMIT	NO	VARIABLE
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	61 WELLS	PERMIT	NO	SERIOUS
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	YES	N/A	NO	N/A
Illinois	V	5 WELLS	RULE	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	11 WELLS	N/A	YES	LOW
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	65 WELLS	RULE	NO	LOW
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	4,326 WELLS(abd)	NONE	YES	LOW
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	2 WELLS	RULE	NO	N/A
Montana	VIII	10 WELLS	PERMIT	NO	N/A
North Dakota	VIII	300 WELLS	RULE	NO	POSITIVE
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	RULE	NO	N/A
Wyoming	VIII	74 WELLS	PERMIT	NO	3RD-10TH HI/10 TYPES
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	1 WELL	N/A	NO	UNKNOWN
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	575 WELLS	RULE	NO	3RD HIGHEST/14 TYPES
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



TYPICAL MINE BACKFILL WELL CONSTRUCTION

Figure 4-2



TYPICAL SUSBSIDENCE CONTROL MINE
BACKFILL OPERATION

Figure 4-30

5X13

Typically, subsidence control injection wells are drilled with a rotary rig and are less than 500 feet deep. Unconsolidated surface materials are sealed off with conductor pipe. A 5- to 10-inch diameter hole then is completed into the mine void. Casing then is installed at depths to ensure delivery of the slurry materials through higher mined out or permeable zones into the mine. In most cases, neither casing is cemented during construction. The slurry material then is pumped (or gravity fed) through the borehole into the mine until the maximum radius around the well is effected and slurry refusal occurs. Upon refusal, both casing strings are removed and the well is plugged with cement from top to bottom. The delivery time required for, and total volume of, slurry emplacement is a function of mine configuration. The number of backfill injection wells necessary to complete a mine subsidence control project is contingent upon the total void volume to be filled as well as mine configuration. Delivery times range from as little as two days to a number of months. This accounts for the large number of permanently abandoned mine backfill wells.

Hydraulic flushing as a mine subsidence control technique has proven very successful in the United States and abroad. Excavations into mines which have employed this technique for coal refuse have showed that nearly total void filling had occurred and the material had drained and compacted to form competent supporting material.

Waste Disposal. Underground mining and related processes generate extremely large volumes of solid and liquid waste. Both types of waste can be generically categorized as potentially acidic and highly mineralized representing the major cause of concern for potential groundwater-quality degradation. When deep mining coal, substantial volumes of non-coal material are also extracted from the subsurface. The waste material, or mine refuse, generated is essentially sandstone, carbonaceous shale, and low grade coal. The mine refuse and coal itself are heavily concentrated with iron, manganese, and sulfide bearing minerals. These minerals, primarily pyrite, degrade the quality of the coal, and therefore it is desirable to separate the coal from the refuse and the pyrite from the coal. The refuse and the iron-sulfide precipitate (yellow-boy) formed when removing pyrite then often is injected into the mine void for disposal.

Many times the mine void is not available or is not used for mine refuse disposal and this material is deposited in "spoil" piles outside the mine portal. The pyrite and other metal-bearing minerals abundant in the spoil rapidly begin oxidizing. Water from rainfall percolates through the spoil, dissolving the oxidized material and creating a highly acidic, highly mineralized acid mine drainage. Similarly, ground water flows through abandoned deep mined becoming increasingly acidic and

mineralized as it comes in contact with exposed mineral-containing rocks until it too is considered acid mine drainage. The acid mine drainage then flows by gravity down-dip to a surface discharge point, or in some instances it must be pumped from the mine for de-watering purposes to allow mining operations to continue. In either situation, the acid mine water must be treated prior to surface water discharge. Treatment consists of neutralizing the acidic nature of the mine water and aeration to allow for precipitation of metals. The sludge generated is then injected into the mine void. Also, it is not uncommon for acid water, which has been removed from an active mine, to be injected into an abandoned mine untreated. In these instances, the receiving mine is sealed to prevent gravity discharge of these acid waters.

Waste disposal well construction is typical of other mine backfill well construction. Specifically, a 5- to 10-inch diameter borehole is drilled to the mine void. Conductor pipe may or may not be used, dependent upon problems associated with unconsolidated surface material and borehole integrity. Cement is rarely used if casing is installed. The major difference between the operation of this and other backfill wells is the length of time the borehole is in service as an injection well. Waste disposal wells generally inject relatively moderate volumes of solids over extended periods of time.

A USEPA Region IV national assessment of Class V wells in the Region indicated an inventory of coal processing wastewater injection wells throughout Kentucky and Tennessee. In a number of cases a slurry is formed by consolidating wastewater from the coal washing process with coal clay and fragments of rock passed through mesh screen of No. 28 size. Chemical flocculants then are added to the mixture to facilitate settling of suspended materials. The jellied slurry, comprised of 25% to 30% firm material is injected into the mine void.

The slurry injection wells for coal processing wastewater injection in USEPA Region IV vary from 100 to 400 feet in depth. The slurry (injectate) often is transported from the processing facility to the injection well site by a pipeline and injected into the borehole which, more often than not, is without casing. In one case, the operator utilized the shaft of the mine as the injection well. Based on the USEPA Region IV study, injection rates for coal processing wastewater injection wells range from 2.7 to 350 gallons per minute, with total volume dependent upon the extent of the mine void.

Mine Fire Control. Underground mine fires, as evidenced by the number of mine fire control wells, are a significant problem in Pennsylvania. The technique found to be most effective in controlling mine fires is hydraulic flushing. Flushing is essentially flooding with a slurry of solid material as opposed to

water alone. When flushing, the water portion of the slurry has sufficient heat capacity to extinguish some of the fires and dissipate heat while the solids seal the mine (see discussion of subsidence control wells), depriving the fire of oxygen and effectively putting the fire out. The solid material used to form the slurry is often mine refuse. Fly ash is another readily available waste material frequently used. Sandstone is used sometimes but is generally cost prohibitive. In some instances, only water is injected into the mine for fire control. Typically, the slurry emplacement boreholes are 8 inches in diameter and less than 100 feet deep. Eight-inch casing may be installed through any alluvial material to a maximum depth of 20 to 30 feet. This casing is never cemented. Quite often, when unconsolidated material on the surface is absent, no casing is used. On average, a well/borehole is never used for actual injection for more than a few days. The total volume of solid material injected through any one bore hole can range from 100 to more than 1,000 cubic yards. The wells are plugged immediately, from top to bottom with cement after their useful life is complete and any casing is removed.

One of the Nation's most publicized mine fires was discovered near Centralia, Colombia County, Pennsylvania in May 1962. The fire has not yet been extinguished. During the period 1962 to 1980, 1,535 boreholes were constructed for hydraulic flushing in an attempt to control the fire. Incomplete records indicate that in excess of 200,000 cubic yards of combustibly-inert solids were injected into the mine for various fire control purposes.

Injected Fluids and Injection Zones Interactions

Typical injected fluids are hydraulic or pneumatic slurries. The solid portion of the slurries may be:

1. sand;
2. gravel;
3. cement;
4. mill tailings/refuse; or
5. fly ash.

If a pneumatic slurry is emplaced in the mine, injection zone (mine shaft) interactions will be limited to oxidation if the mine itself is dry. Injection (mine shaft) interactions of hydraulic slurries range from slight water quality improvement to possible contamination from leachates or acid mine drainage. The degree and type of interaction within the mine after slurry emplacement is dependent on the source of water and type of slurry solid.

If water not affected by acid mine drainage is pumped during mining and used to emplace sand, gravel, or cement slurries, no adverse interactions within the mine are to

expected. In this case, mine waters are being introduced back into the mine with sand, gravel, or cement, which are essentially inert.

When slurry waters are acid mine water or ore extraction process wastewater, interactions within the mine may increase. Acid mine water will have a tendency to react with some portions of slurry solids, mine walls, or surrounding soils and mobilize potential groundwater contaminants. Process wastewaters may contain chemicals used in ore extraction that may cause interactions.

The use of mill tailings/refuse and fly ash as fill material may cause detrimental interactions. Mill tailings are low quality ore and, in the case of coal mining, are high in sulphur. Fly ash is the waste product of burned coal and has been found to contain arsenic and salts (particularly sodium sulfate). The leaching of these compounds does occur.

Mine backfill operations present special problems where, and if, ground water migrates through the backfilled mine voids and leaches high concentrations of chemical species such has heavy metals, sulfuric acid, cyanide, and other byproducts of milling processes, from the backfill material itself.

When precipitated sludge from acid mine drainage pools is emplaced in a mine containing acid mine water, the alkaline nature of the sludge may tend to neutralize the acid water and decrease the solubility of metals.

Hydrogeology and Water Usage

The mine backfill well category incorporates three operationally distinct coal mining related injection wells. Even though the wells inject for different purposes, the characteristics of the injected material are essentially the same.

Existing USDW chemical quality is critically important when assessing mine backfill wells. Mine water and interconnected groundwater is generally of moderate to poor quality with a high dissolved metals content and a potentially high pH. Therefore, the introduction of "wastes" consistent with the existing environment may not be considered degradation. An in-depth evaluation of mine backfill wells in West Virginia concludes in part that the "enhanced" pollution caused by such wells is very nearly impossible to quantify because of the low quality of receiving waters. It should be noted that mine water and aquifer quality is a function of the chemical composition of the mined out seam. Specifically, some seams have excellent water quality and, to a limited extent, serve as public drinking water supplies.

Mine backfill wells, in general, have little negative impact on ground-water quality. Short term use wells (subsidence and mine fire control) only can be considered beneficial. However, injections of acid mine drainage (AMD), AMD precipitate, and coal waste slurry are potentially detrimental, especially into mines which traverse formations serving as drinking water supplies.

It must be noted that, in many cases, surface and ground water contamination from mine waste surface piles may be more serious than contamination within a mine backfilled with that material.

Contamination Potential

Based on the rating system described in Section 4.1, mine backfill wells are assessed to pose a moderate potential to contaminate USDW. These facilities typically do inject into or above Class I or Class II USDW. In Idaho, however, this is not the case. Typical well construction, operation, and maintenance would not allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does not occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter, or in a region studied on a group/area basis.

Current Regulatory Approach

Mine backfill wells are regulated in one of three approaches:

1. By permit
2. By rule
3. As part of the overall mining operation.

The distribution of the various approaches is fairly even as evidenced by Table 4-39. The tendency, however, is to authorize these wells by rule until directives resulting from the national Class V Inventory and Assessment are issued from USEPA. Available regulatory details of each state (where mine backfilling is conducted) are included in Table 4-39.

It is believed that a significant hindrance to the EPA inventory is the fact that mining bureaus/agencies have regulatory jurisdiction in many States, and these entities are not completely familiar with the UIC program.

TABLE 4-39

REGULATORY APPROACH FOR MINE BACKFILL WELLS

STATE	REGULATORY AGENCY	PERMIT	RULE	OTHER
Alabama	State Dept. of Environmental Management	Federal UIC Regulations are utilized		
Colorado	USEPA Region VIII		Authorized by rule and inventoried. Low inventory response rate.	
Idaho	State Dept. of Water Resources		Authorized by rule until Inventory and Assessment efforts are complete. Operators must submit inventory information.	
Maryland	State Dept. of Health and Mental Hygiene	Classified as Industrial drainage and waste disposal wells. Requires groundwater discharge permit and public hearing through Waste Management Administration.		
Missouri	State Division of Geology and Land Survey			Not regulated. Expecting regulatory guidance from USEPA at completion of National Inventory and Assessment.
Montana	Bureau of Abandoned Mines	Regulated by Permit.		
North Dakota	State Department Health		Authorized by rule. Director must be notified of operations. New wells must submit drillers log and inventory information. Director may require permit.	
Pennsylvania	State Bureau of Mines and Reclamation			Regulated as part of overall mine operation.
Texas	State Water Commission		Existing well authorized by rule. Regulated through register and review process.	
West Virginia	Division of Mining			Regulated as part of overall mine operation.
Wyoming	State Dept. of Environmental	Regulated by Permit		

Recommendations

Several States provided recommendations for mining backfill operations. Some of them are summarized as follows. The siting, design, construction, and operation of mine backfill wells, when possible, should be included in overall mine operation plans and permit requirements (Illinois, Kentucky, Idaho). In many cases, this is done today, due to backfill well regulatory responsibility of State mining regulators. Contamination potential for backfill wells occurs in the mine void and not in the well-bore itself.

While injecting, slurry volumes should be monitored and compared to calculated mine volume as a check that no catastrophic failures occur (West Virginia).

Ground-water monitoring is recommended in areas that contain potable water in the stratigraphic vicinity of backfilled mine workings (Missouri). Migration of water through, or out of, backfilled mines appears to be the scenario which constitutes the primary ground-water contamination concern. Figure 4-31 presents possible ground-water contamination scenarios.

The Montana report recommended that site specific studies by conducted to determine the nature and extent of degradation due to mine backfill wells. Idaho recommends continuing authorization of mine backfill wells without permits in cases where the tailings are injected into formations that are effectively isolated from USDW.

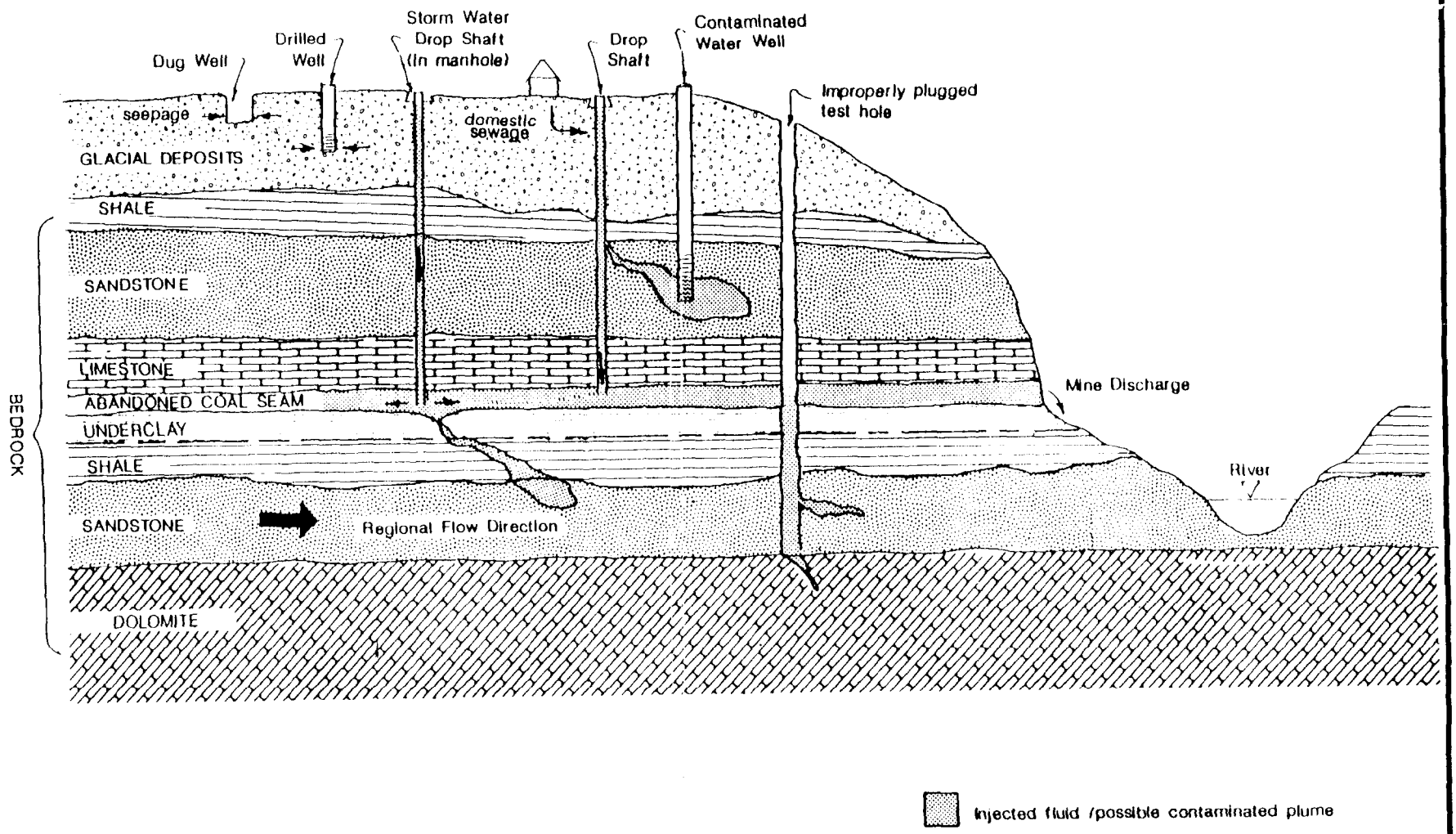
4.2.4.2 Solution Mining Wells (5X14)

Well Purpose

In-situ or solution mining utilizes injection and recovery well techniques to bring minerals from underground deposits to the surface (Texas Department of Water Resources Report 274, 1983). Fluids designed to mobilize mineral resources are injected into an ore body, and the resulting "pregnant" solution is extracted. Minerals typically extracted by this procedure include copper, uranium, trona, borate, gold, silver, and zinc.

Solution mining falls into three general categories (Ahlness and Pojar, 1983):

1. Commercial operations with ore body preparation including such activities as blasting, block caving, and hydrofracturing, specifically to fragment the ore body;



SCENARIOS FOR POTENTIAL GROUNDWATER CONTAMINATION FOR MINE BACKFILL WELLS

Figure 4-31

2. Commercial operations in old mine workings, including those done in open pits, worked out black caved areas, and backfilled stopes where leaching is conducted following conventional mining; and,

3. Experimental programs conducted on small scales to assess the economical and engineering feasibility of such projects.

The latter two categories are the types of programs associated with Class V injection, whereas the first category is associated with Class III injection. In-situ leaching of conventional mines is used to recover additional metals from old mine workings when conventional techniques such as open pit or tunnel recovery are economically unfeasible due to low grade ore or insufficient size of deposit. Experimental programs are typically pilot-scale feasibility studies which may or may not employ "experimental" procedures.

Inventory and Location.

Available inventory data indicate that there are presently 2,025 active and idle Class V solution mining injection wells in the United States and associated Possessions and Territories. This information has been derived from the various Class V State reports submitted. The solution mining well inventory data is presented in Table 4-40. Many more solution mining facilities actually have been reported for the United States than are indicated in the Table. These facilities are actually pilot-scale feasibility operations and are technically defined as experimental technology disposal wells (5X25). They are inventoried in the experimental technology section of this report, but their purpose and operation are consistent with injection wells used for stopes leaching solution mining.

Construction, Operation, and Siting

Specific aspects of injection wells associated with solution mining may vary from facility to facility, but construction designs generally are consistent. Plastic piping, typically PVC or CPVC, or Fiberglas pipe is used for casing, although light-weight steel casing also has been used for this purpose at certain Wyoming facilities. Casing diameters have been found to range from two to eight inches, with typical diameters of four to six inches. Depths of injection wells typically vary from about 200 ft to more than 1,000 ft and are dependent upon the depth of the ore body. The well completion may be open hole if total depth is into the ore body. If the well is seated below the ore

TABLE 4-40: SYNOPSIS OF STATE REPORTS FOR SOLUTION MINING WELLS(5X14)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	48 WELLS	PERMIT	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	15 WELLS	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	1,073 WELLS	PERMIT	YES	LOW
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	PERMIT	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	14 WELLS	PERMIT	YES	HIGHEST/10 TYPES
Arizona	IX	870 WELLS	PERMIT	YES	LOW/MODERATE
California	IX	5 WELLS	PERMIT	YES	UNKNOWN
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

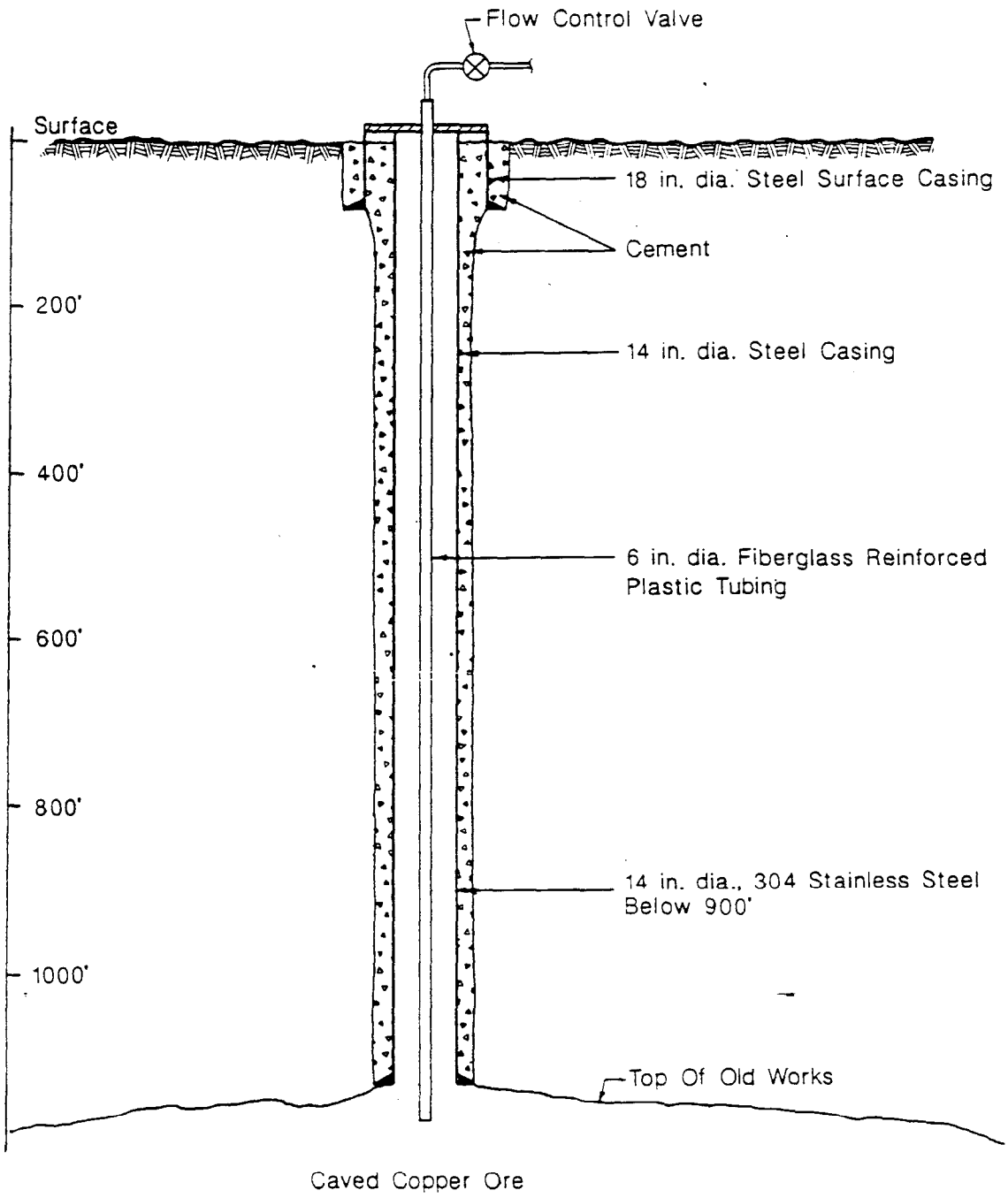
body, screened openings or perforations may be used to inject fluid into the ore body. The entire annulus between borehole and casing generally is cemented from total depth to surface. Some operators use an acid-resistant cement across the injection zone, where injectate is actually in contact with the cement job. Several centralizers may be used to assure proper positioning of casing within the wellbore. A typical construction design for solution mining injection wells is presented in Figure 4-32. In general, construction designs seem to be relatively simple and trouble free. Injection is gravity fed, and bursts in the casing due to high pressure rarely occur. However, operators do not typically conduct mechanical integrity tests. Therefore, the possibility that injection fluids unknowingly could migrate into unintended zones may exist.

In-situ leaching is the most common method used with Class V solution mining. Injection and recovery wells are constructed into an ore body that has been fragmented through blasting, block caving, or hydrofracturing. The majority of the wells inventoried in the United States are constructed in or around block caved zones. This method of in-situ solution mining involves four steps. First, a lixiviant, or "barren" solution composed of an acidic or basic oxidizing agent, is injected. This fluid will vary, depending upon the type of ore being mined. The injection of lixiviant causes mobilization of the mineral from the host ore body by creating a soluble complex salt. Third, the mineral-bearing lixiviant ("pregnant" solution) is recovered using extraction wells. Finally, the mineral is recovered from the pregnant solution at the surface using certain ion exchange techniques. One such technique is known as solvent extraction - electrowinning (SX-EW). Ideally, after solution mining activities are discontinued, a fifth step would be conducted which involves the restoration of groundwater to a prescribed post-mining quality. A schematic representation of in-situ solution mining is presented in Figure 4-33.

In-situ solution mining injection wells are sited in patterns sufficient to cover what geologic analysis has defined as the three-dimensional extent of the ore body. Spacing between wells is a function of several parameters. A primary consideration is intended injection volumes. Volumes used are directly related to the amount of fracture permeability induced by block caving. Also, capacity of the recovery system must be considered. Finally, the hydrogeologic properties of the ore body, principally porosity and permeability, must be allowed in determining adequate well spacing.

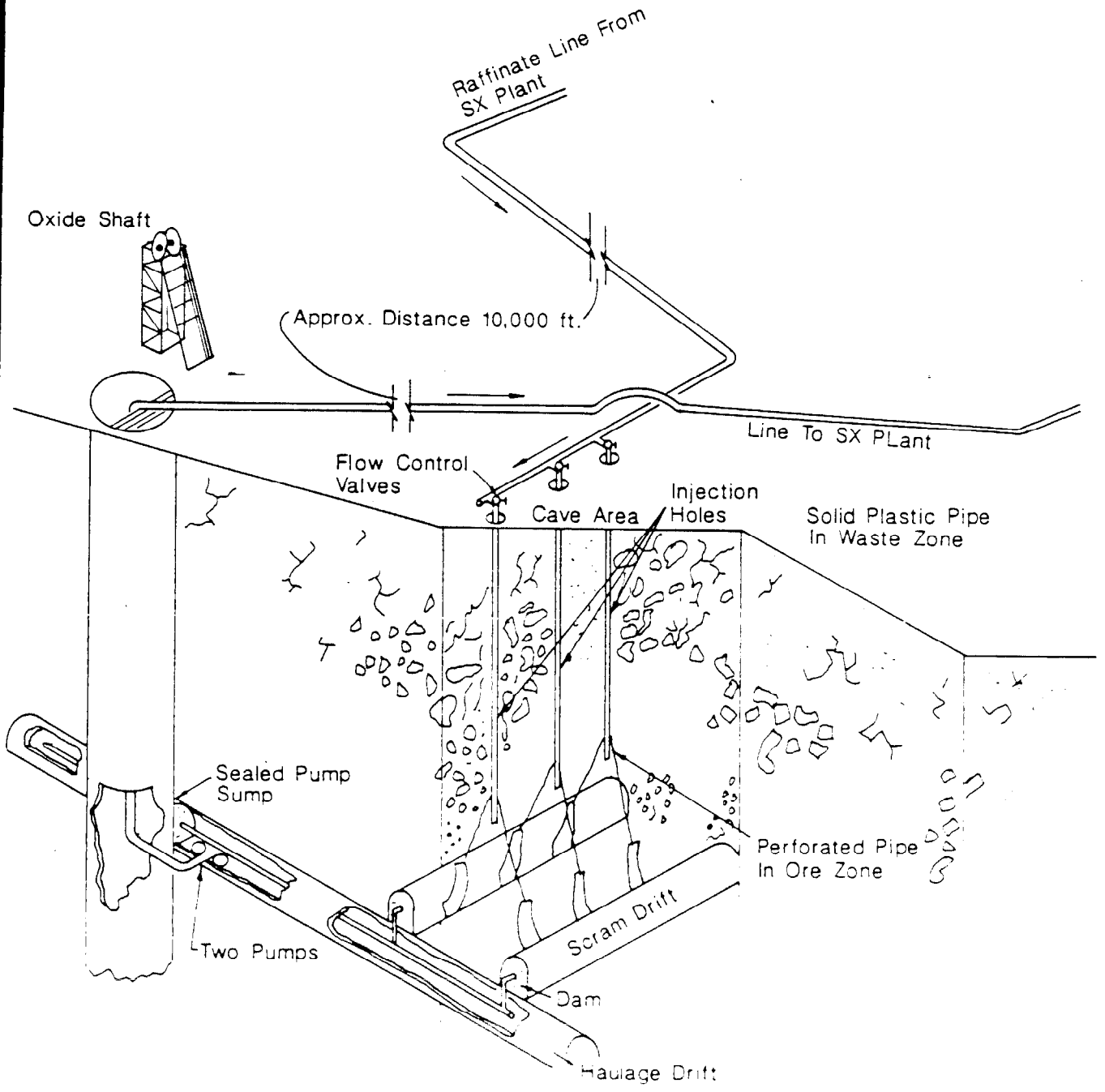
Injected Fluids and Injection Zone Interactions

Injection fluids will vary depending upon the type of mineral to be recovered. Copper and uranium are currently the



LARGE DIAMETER, HIGH VOLUME, CLASS V
SOLUTION MINING INJECTION WELLS
PROPOSED BY KOCIDE CHEMICAL CORPORATION

Figure 4-32



BLOCK DIAGRAM ILLUSTRATING
APPLICATION AND COLLECTION
OF LEACHING FLUID

Figure 4-33

most widely mined minerals using in-situ procedures. Common lixiviants used for oxidizing these minerals include weak solutions (1-4%) of sulfuric or hydrochloric acid, ammonium carbonate, and sodium carbonate/bicarbonate. Ferric cyanide solutions typically are used to recovery gold, silver and other precious metals.

Operations have reported that block caved zones are actually "sumps" to ground-water flow. That is, hydraulic gradients from surrounding aquifers toward the block caved zone have been established. Because conventionally mined ore bodies usually are sulfide deposits, infiltrating ground water tends to oxidize the sulfide minerals. This process lowers the pH and increases heavy metal content within the ground water. Injection of weak acid solutions associated with solution mining only serves to enhance the natural reactivity of the sulfide minerals. Injected fluids are usually slightly more acidic than the ground water within block caved zones, as indicated by monitoring well data (Noranda Lakeshore Mines, Personal Communication, 1986).

Hydrogeology and Water Use

Ore bodies containing copper, uranium, and other precious metals are referred to as hydrothermal deposits (Tennissen, 1974). These are deposits formed in rock from hydrothermal fluids at high temperatures and pressures. Hydrothermal solutions responsible for ore deposits are of diverse origin, and sources include magmatic, meteoric, and connate waters. Ore bodies such as these are typically present within crystalline rocks of igneous or metamorphic origin that have been structurally emplaced adjacent to sedimentary rocks. Hydrothermal fluids enter the crystalline rock mass through the porous sedimentary media or fault-related fractures, or both.

Specific hydrogeologic parameters will vary among solution mining projects across the nation, but certain generalizations can be made. In mining districts of the western United States, sediments adjacent to ore bodies tend to be coarse-grained, poorly sorted alluvial valley fill. Depending upon the depth of burial, these sediments may be consolidated, semi-consolidated, or unconsolidated. Permeability within such sediments can be high, resulting in a high degree of communication between mine workings and adjacent alluvial aquifers. These aquifers may or may not be an USDW.

As discussed previously, the process of block caving creates massive void spaces in and around the ore body. Void spaces tend to establish sumps to ground-water flow, and hydraulic gradients toward the mine workings develop almost instantaneously following block caving. Volumetric data support this claim in that operators report recovery volumes as much as 20% higher than the

amount of fluid injected. As long as withdrawal is approximately continual, and a positive hydraulic gradient toward the block caved zone is maintained, losses of fluid from the workings into surrounding aquifers should be minimal. If, however, an operation is left idle for a period of time sufficient to allow development of hydraulic equilibrium, migration of contaminants along natural ground-water flow gradients could occur. This may result in the degradation of USDW adjacent and downgradient to the mine workings.

In light of these hydrogeological considerations, lithologic confinement to ground-water flow is of secondary importance. As discussed, ore bodies are usually present within crystalline rocks with relatively low primary porosity and permeability. Secondary permeability, in the form of structure-related fractures is common. These fractures may have propagated into adjacent sedimentary rocks. As such, the lithologic character of "confining" units is of less concern than is the degree of fracture pervasiveness within the crystalline mass and surrounding sediments.

Contamination Potential

Based on the rating system described in Section 4.1, solution mining wells are assessed to pose a low potential to contaminate USDW. These facilities typically inject below USDW with little or no potential for migration of fluids into any USDW. Typical well construction, operation, and maintenance would not allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does not occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter.

While a variety of minerals are extracted in the United States using in-situ leaching, procedures and hydrogeologic parameters are generally very similar. Specific details regarding these considerations are not known for all solution mining facilities, but a generic assessment of contamination potential can be made using generalized, or "typical" data.

Injection of acidic or basic lixiviants used in solution mining is into block caved or hydrofractured zones generally adjacent, along at least one boundary, to consolidated or semi-consolidated sediments. These sediments are generally water-bearing, as indicated by positive flow of fluids into mine

workings reported by operators. No data exist to show these ground waters are of USDW quality. With a few exceptions, such operations are in semi-remote areas away from population centers. At this time, it cannot be concluded that injection is into or above potentially useable Class IIB aquifers. Because of the general water quality conditions in alluvial aquifers of the desert Southwest, where most solution mining is occurring, it is believed that "usable" USDW are generally sparse.

As discussed, typical construction and operational aspects of solution mining are relatively simple. As such, the potential for malfunction leading to migration of fluids into USDW is considered minimal, particularly considering these mine workings are ground-water sinks. However, it must be pointed out that provisions for conducting mechanical integrity tests are not part of operational plans.

Injectate composition must be kept constant for a solution mining operation. As a result, it is easy to characterize injectate water quality. Injectates are typically acids, though weak bases are used occasionally for in-situ leaching operations for uranium. For acidic injectates, pH levels of 1-4 are typical. This clearly exceeds National Secondary Drinking Water Regulations for pH, and probably exceeds corrosivity levels as well.

Depending upon the size of the operation, injected volumes can be very large, exceeding 500,000 gallons per day. If natural ground-water flow conditions existed within and around these operations, it could be easily concluded that such volumes would cause degradation of groundwater in a large area around the facility. However, because active solution mining facilities maintain a positive flow gradient toward the mine workings, degradation beyond the facility boundary would not be anticipated.

It is hereby concluded that contamination potential attributable to in-situ solution mining is generally low. This is a generic assessment based upon the overall database for this well type. This seemingly is contradictory to the Wyoming State Report, that ranked solution mining operations as the most dangerous of the known Class V facilities within that State. However, it must be stressed that they are mining a radioactive substance (uranium) which in its own right can be considered dangerous. Secondly, there are only 199 such wells at 14 facilities in Wyoming, representing only 0.6% of the total solution mining injection wells in the United States. This percentile cannot be interpreted as "typical" for that well type.

As in other assessments for well types having limited databases, any new data acquired that supplement (or supersede) broad generalizations will be used to re-define contamination

potential. Such data would include demonstration that contaminants are migrating into adjacent ground water following operation closing or that failed mechanical integrity has resulted in contamination of shallow or adjacent aquifers. Another factor would be the demonstration that an adjacent aquifer is of Class IIB quality or better. Such findings would lead to an assessment of higher contamination potential.

Current Regulatory Approach

Solution mining wells are authorized by rule under Federally-administered UIC programs (see Section 1). The best data for regulatory oversight of solution mining facilities were found in the Wyoming and Arizona State reports. It is believed that regulatory information contained therein represents typical approaches to this type of Class V injection.

Both States have established broad sweeping legislation that addresses the protection of all "waters of the State." In Arizona, enforcement of those rules is the responsibility of the Department of Health Services (ADHS). In Wyoming, the regulatory body is the Land Quality Division (LQD) of the Wyoming Department of Environmental Quality. These agencies require the submittal of applications for waste discharge permits by any operator proposing underground injection of any institutional, commercial, agricultural, or residential waste fluids. While injected fluids used for in-situ leaching operations are not technically "waste" material, operators are still bound by the terms of waste discharge permits.

Applicants for permits in the two States are required to supply detailed information about proposed injection operations. This information includes, but is not limited to, a complete description of fluids to be injected; the numbers and construction details of injection wells to be used; characteristics of the intended injection zone and all affected aquifers; all nearby ground-water users; and the materials and equipment to be used in the injection process. In some areas, a hydrogeological report and disposal impact assessment may be required. Additional conditions required with respect to permitting such wells include monitoring frequency specifications, constituents to be monitored at each monitoring well, reporting requirements, injectate quality limits, and definition of what constitutes a permit violation. An important aspect of new permit application reviews is the specification of closure plans and the restoration of the aquifer after solution mining operations have been terminated (post-closure plan). This latter aspect is a relatively new permit requirement, and several facilities exist that were permitted prior to its adoption. As such, these facilities may not be bound to any post-closure requirements at the present time.

In some States, active solution mining facilities are known to exist on Federal land or on land regulated by Federal authority, such as tribal lands. Specific management of such solution mining activities, where known, is the responsibility of the Bureau of Land Management (BLM). Initial approval of these activities on tribal lands must be granted by the tribe of concern, in conjunction with the United States Bureau of Indian Affairs (USBIA). The BLM provides technical assistance for permit approval, and requires submittal of an Environmental Assessment (EA) by the operator. Addressed specifically in the EA are the proposed solution mining plan, existing hydrogeologic conditions, and potential environmental impacts. Approval requirements include a hydrogeologic monitoring program. Leach solution applied, fresh water inflows to the facility, and amounts of leachate recovered must be specified. Moisture lost in exhaust air must be monitored as well. Finally, a ground-water monitoring network and plan is established specifying analysis requirements and reporting intervals. Closure plans discussing site reclamation, sealing of mine works, and continued hydrogeologic monitoring are not included in the EA.

Recommendations

Injection wells associated with solution mining must be sited so as to efficiently supply the necessary volumes of leachate to the disturbed ore body. While several experimental procedures for applying leachate are being tested in the United States, the best approach to large-scale operations is to site wells directly above the block caved zone and inject flood leachate by gravity flow. As such, the network of injection wells need not extend beyond the surface projection of the underground mine workings. These recommendations are contained within the Arizona report.

The preservation of mechanical integrity should be an important concern of operators. At the present time, mechanical integrity requirements are not part of permit specifications for most solution mining operations. Part of the problem is that there are not well defined procedures for determining mechanical integrity in such simple wells. The Arizona report recommends that possible types of mechanical integrity tests should be studied in the near future, and an effort to implement reliable testing should follow.

The Arizona report makes another significant recommendation. One aspect of solution mining that has the potential for broad scale contamination of ground water beyond facility boundaries concerns post-closure plans. As discussed, ground-water flow gradients toward the mine workings are anticipated while injection and recovery operations are active. However, when operations are terminated, artificial hydrogeologic conditions

established during solution mining will approach equilibrium with regional hydrogeologic gradients. If proper closure and ground-water restoration are not practiced, migration of acidic ground water into adjacent alluvial aquifers would likely occur. At the present time, closure and remedial action plans are not part of permit requirements for facilities on federal lands, or lands under federal regulation. To assure this well type a future low ground-water contamination potential rating, implementation of adequate closure and remedial plans is essential.

Supporting Data

Case studies are listed in Appendix E and include Noranda's Lakeshore Mines, Pinal County, Arizona. These data are in the form of a UIC Inspection Report, dated September 9, 1986, and subsequent file review material. The inspection was conducted by representatives of Engineering Enterprises, Inc. and USEPA Region IX.

4.2.4.3 In-Situ Fossil Fuel Recovery Wells (5X15)

Well Purpose

Wells designed as In-Situ Fossil Fuel Recovery Wells are used to inject water, air, oxygen, solvents, combustibles, or explosives into underground coal or oil shale beds in order to liberate fossil fuels which can be produced to the surface by wells. To date these methods have been experimental. This is not expected to change in the near future due to the worldwide depression in oil prices. Injection wells used in in-situ processes that recover heavy oils from tar sands in the United States are part of "Enhanced Oil Recovery" methods. As such, these wells are regulated as Class II injection wells and should not be within the scope of this report. Many in-situ methods used to recover heavy oils are commercial.

Underground coal gasification (UCG) utilizes Class V injection wells to deliver air, oxygen, steam and air, or steam and oxygen mixtures into a target coal bed in order to initiate and maintain combustion of the bed and liberate a low grade gas. Target beds for underground coal gasification generally are unminable coal beds such as low grade or deep coal seams, and steeply dipping beds.

Recovery of synthetic oil "Synfuels" from oil shale usually is accomplished by burning (retorting) oil shale rubble. If it is impossible to mine and retort the oil shale at the surface, retorting is accomplished underground (in-situ). Class V injection wells are used to deliver air, oxygen, combustibles, or explosives in order to rubblize the bed, and initiate and main-

tain in-situ combustion. Liberated "Syncrude" is produced to the surface via production wells. "Syncrude" also can be produced by circulating hot fluids.

Inventory and Location

According to State reports, 66 in-situ fossil fuel recovery wells have been used in 5 States; Colorado, Indiana, Michigan, Texas, and Wyoming. The Federal UIC Reporting System (FURS) indicates that 38 of these wells exist in Colorado only. Wells are known, however, to have existed in Utah also. At least three of the 66 wells are known to be permanently abandoned. Due to depressed oil prices it is believed all 5X15 wells are abandoned or in the process of being abandoned. Table 4-41 indicates the well type inventories and summarize their assessment. The difference between State reports and FURS inventories may be attributable to confusion over the extent to which abandoned operations should be inventoried.

Figures 4-34, 4-35, and 4-36 indicate locations of coal fields, oil shale, and other potential synfuel resources in the United States.

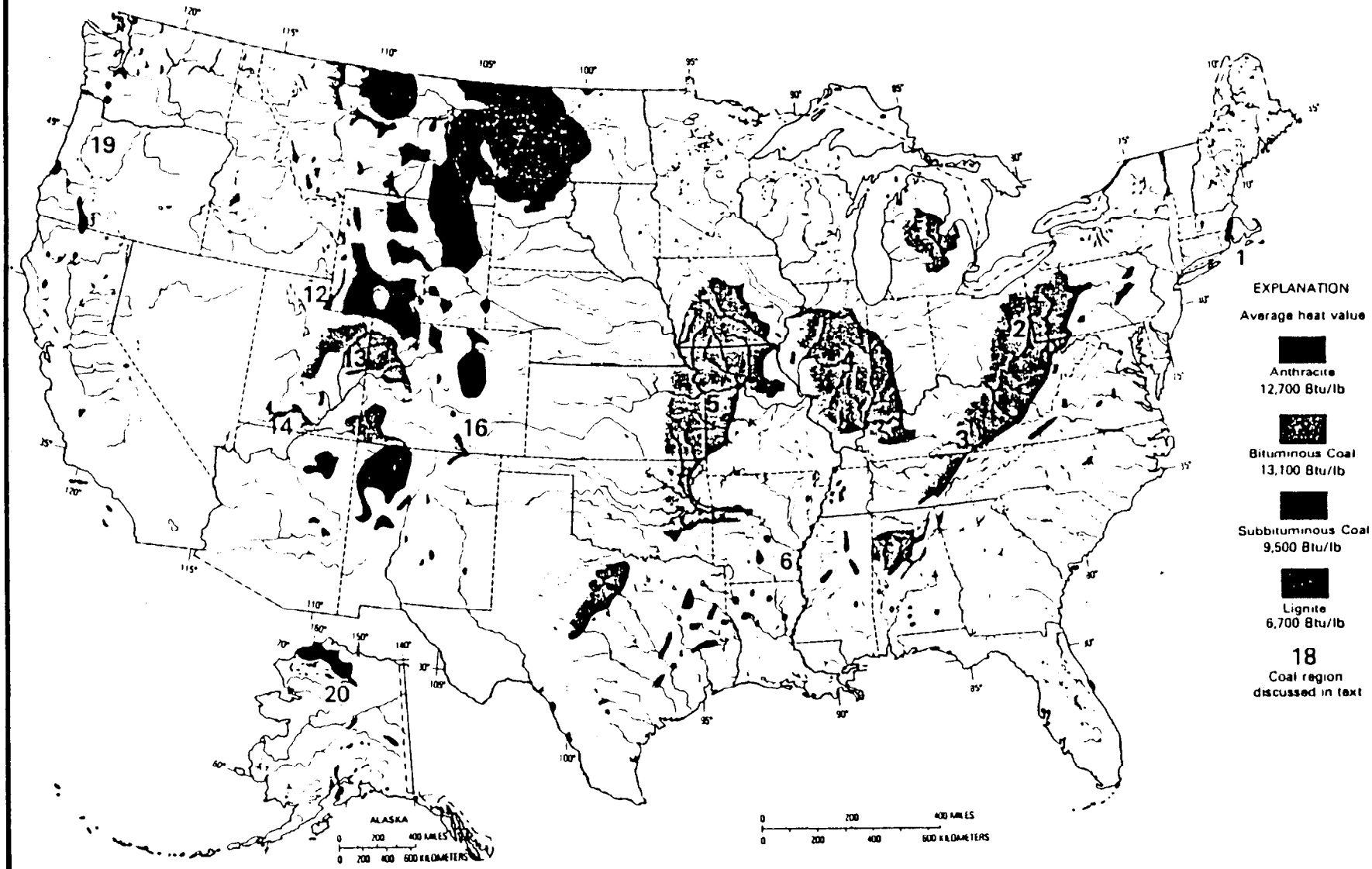
Construction, Siting, and Operation

Underground Coal Gasification. Underground coal gasification (UCG) is a process for recovering fuel from coal that is not economically or technically feasible to recover by conventional mining techniques because of its low heating value, thin seam thickness, great depth, high ash or excessive moisture content, large seam dip angle, or undesirable overburden properties. The UCG process converts coal into a useful gas product by partially combusting the coal underground in the presence of water and a limited amount of air, oxygen, steam and air, or steam and oxygen mixtures. Figure 4-37 presents a schematic cross section of the UCG process. In a simplified two-well model, an injection well and a production well are drilled into the coal deposit. The permeability of the coal seam must then be increased to permit reasonable gasification rates and prevent condensation of tars and other volatile organic matter from the produced gas as it passes through cooler parts of the coal seam. Permeability enhancement is referred to as linking (a permeable flow path is linked between the injector and producer). Linking can be accomplished by reverse combustion, directional drilling,

TABLE 4-41: SYNOPSIS OF STATE REPORTS FOR IN SITU FOSSIL FUEL RECOVERY WELLS(5X15)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	1 WELL	N/A	NO	N/A
Michigan	V	1 WELL	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	YES	PERMIT	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	23 WELLS	RULE	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	PERMIT	NO	N/A
Wyoming	VIII	41 WELLS	PERMIT	YES	4TH-7TH HI/10 TYPES
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

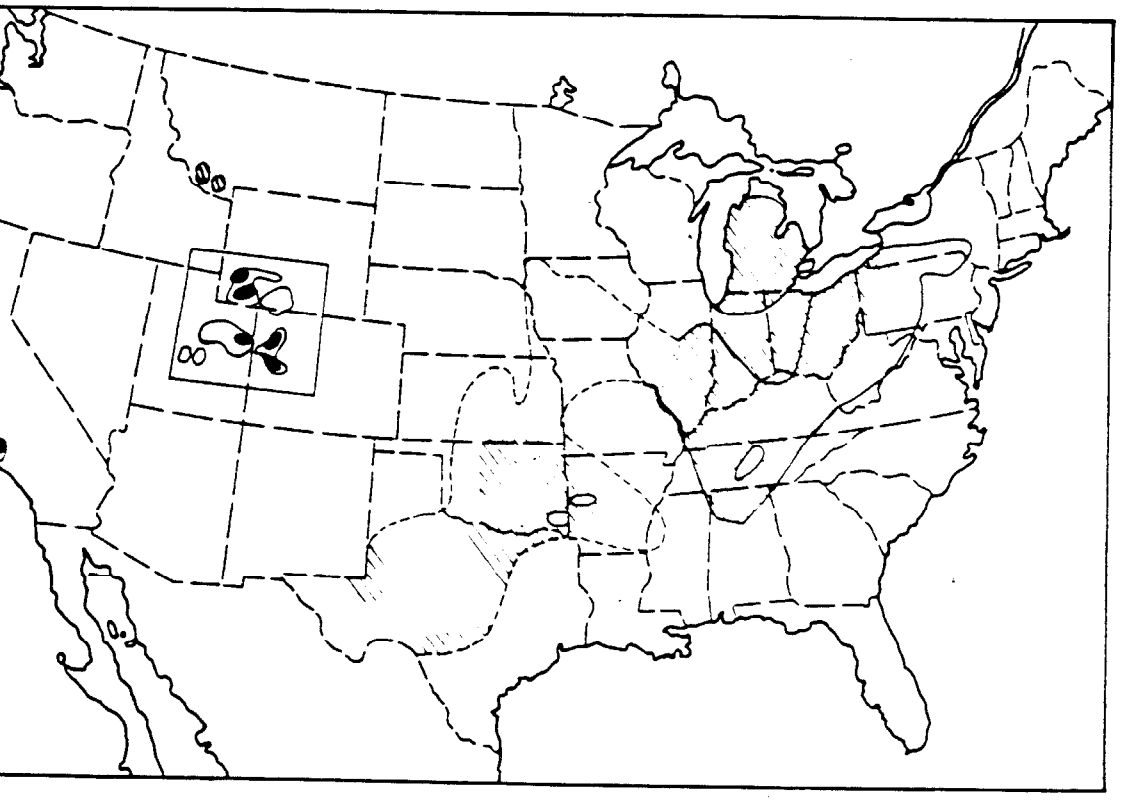
NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



COAL FIELDS OF THE UNITED STATES

(from Rickert et.al., Synthetic Fuels Development: Earth Science Considerations)

Figure 4-34



rce: Ranney, M.W., 1979, Oil Shale and Tar Sands Technology.

LEGEND

Tertiary Deposits, Green River Formation in Colorado, Utah, and Wyoming; Monterey Formation, California; Middle Tertiary Deposits in Montana. Black areas are Known High-Grade Deposits.

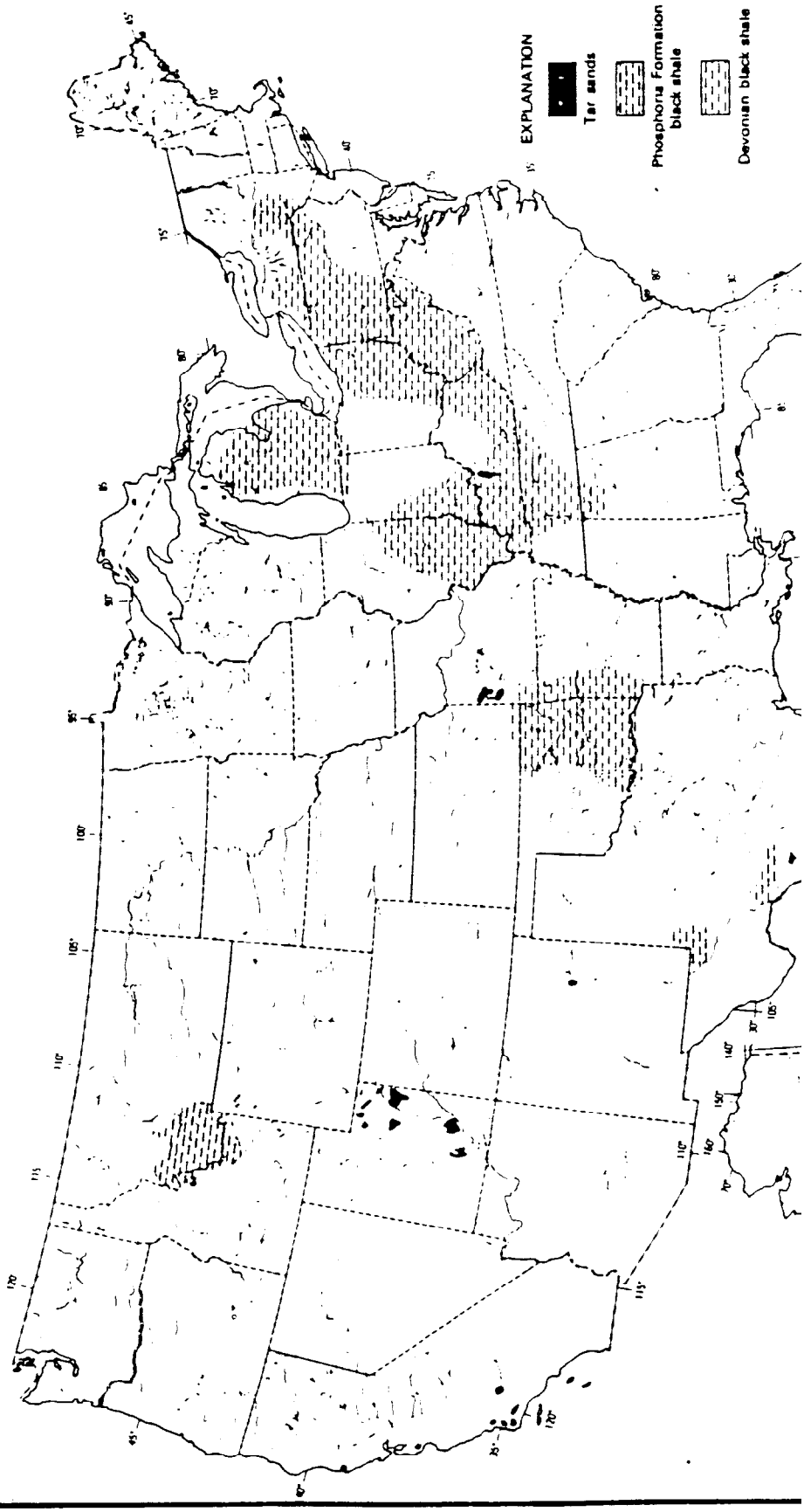
Permian Deposits, Phosphoria Formation, Montana.

Devonian and Mississippian Deposits (Resource Estimates Included for Hachured Areas Only). Boundary Dashed where Concealed or Where Location is Uncertain.

LE DEPOSITS OF THE UNITED STATES

9 Oil Shale and Tar Sands Technology

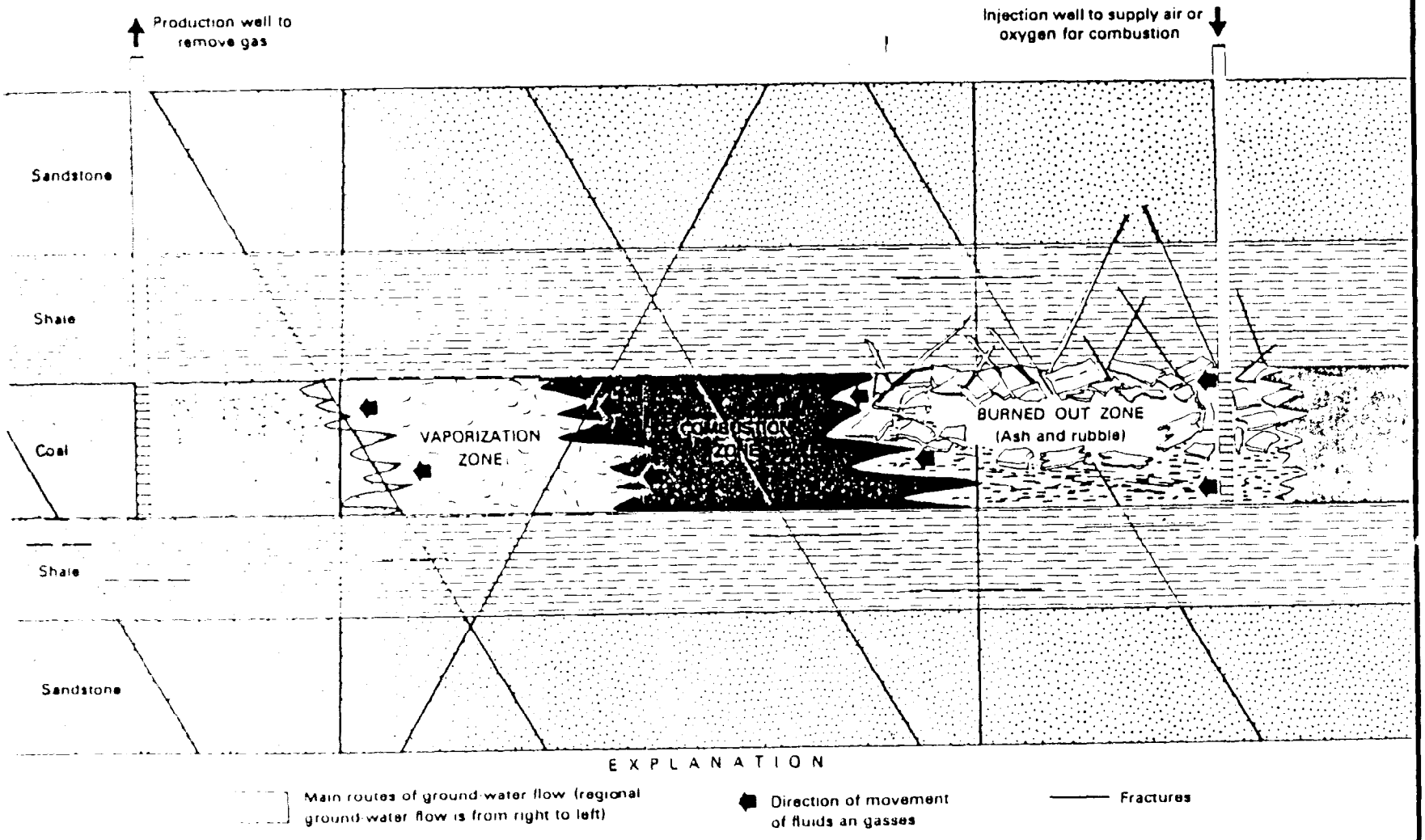
Figure 4-35



OTHER POTENTIAL SYNFUEL RESOURCES

(from Rickert et.al., Synthetic Fuels Development: Earth Science Considerations)

SCHEMATIC CROSS SECTION OF AN IN-SITU COAL GASIFICATION PROCESS

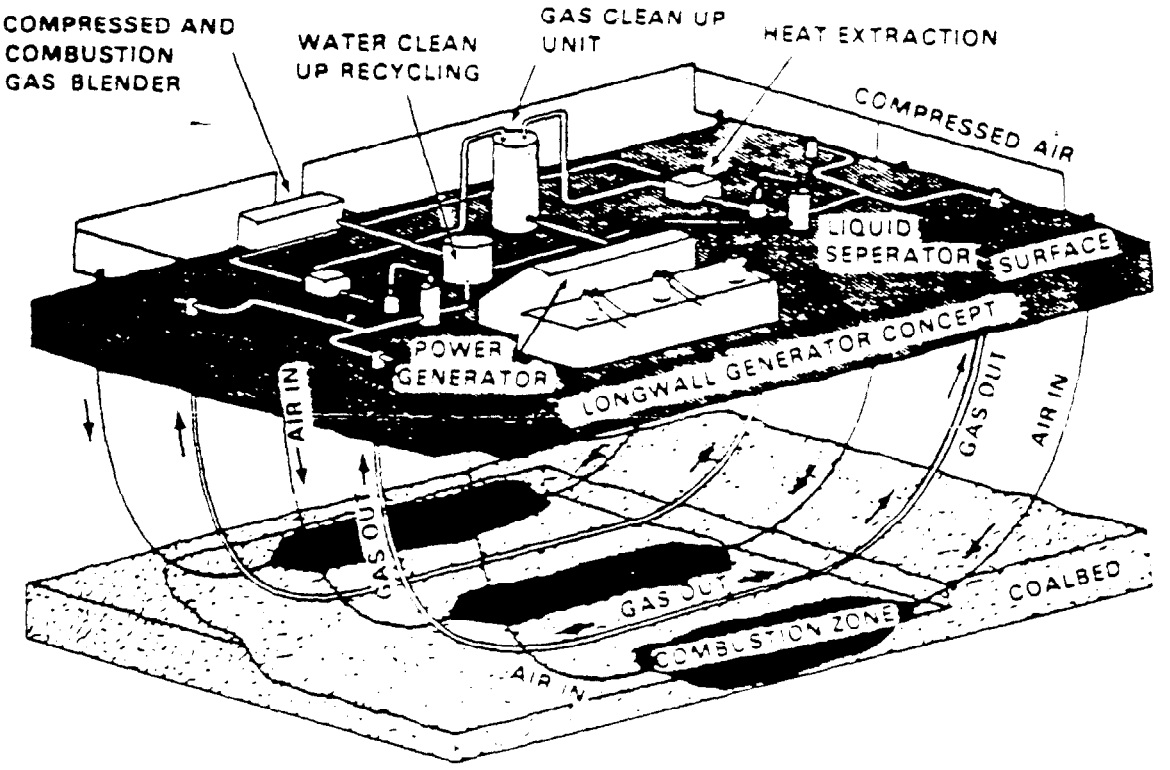


electrolinking, or hydraulic fracturing. Once linking is complete a gasifying agent, usually air or oxygen-enriched air, is injected throughout the operation to sustain combustion and effect gasification of the coal. Gases produced by the burning coal escape through the flow channel and are removed through the production well. In a commercial scale operation, several pairs of wells (or other configurations) would be simultaneously gasified.

As gasification continues, a cavity is formed in the coal seam. Its geometry continues to change as the burn proceeds. Early in the gasification process the cavity is empty. As the coal burns, the cavity roof may subside or collapse, partially filling the cavity with rubble which subsequently alters the gaseous flow patterns and burn geometry. Injection wells used to initially ignite the coal seam and maintain combustion vary widely in design although the injection fluids are similar (air, oxygen, steam, or combination). For example, in operations utilizing the reverse linking process, injection and production wells are of similar design since their respective functions are switched after initial combustion is achieved. Figures 4-38 - 4-41 show four major types of UCG processes and their respective well configurations.

Injection wells are completed in high temperature combustion zones and are exposed to subsidence. The injection well may be subjected to temperatures up to 2,735°F (1,500°C) for several hours. Special well constructions are necessary to withstand such an environment. In addition to high temperatures and possible melting, the well materials (casing, cement, wellhead, and surface valves) are subjected to sulfidation and oxidation from combustion, thermal expansion and contraction forces, and cement shrinking and parting due to overburden drying or volatilization. Subsidence of overburden materials must be accurately predicted and accounted for in the well's design and siting to avoid damage. Well completion depths generally are less than 600 ft. Wells are cased with carbon or high strength stainless steel.

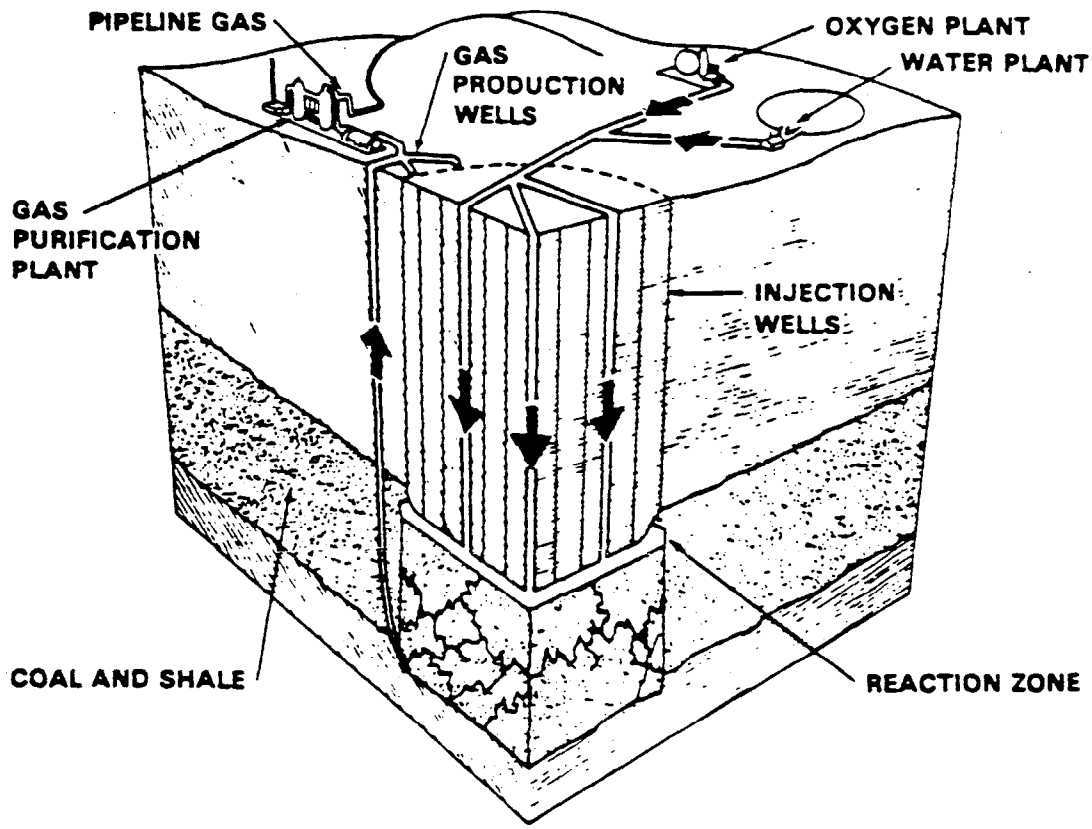
In Situ Recovery of Oil Shale. Oil shale is a fine-grained sedimentary rock that contains an oil-yielding organic material called Kerogen. Oil shale is composed of approximately 86% mineral material and 14% organic material. It is classified geologically as a marlstone because the mineral matter is primarily carbonaceous material. The organic portion is composed of 10% bitumen and 90% Kerogen. Bitumen is soluble in many organic solvents. Kerogen has a molecular weight greater than 3,000 and is insoluble in most organic solvents. Kerogen and bitumen are thermally unstable and, when heated to 480°F (250°C) or higher, thermally decompose to form gaseous and liquid products than can be refined to synthetic crude oil (Syncrude).



UNDERGROUND COAL GASIFICATION
LONGWALL GENERATOR PROCESS

from Morgantown Energy Research Center Proceedings August [illegible]

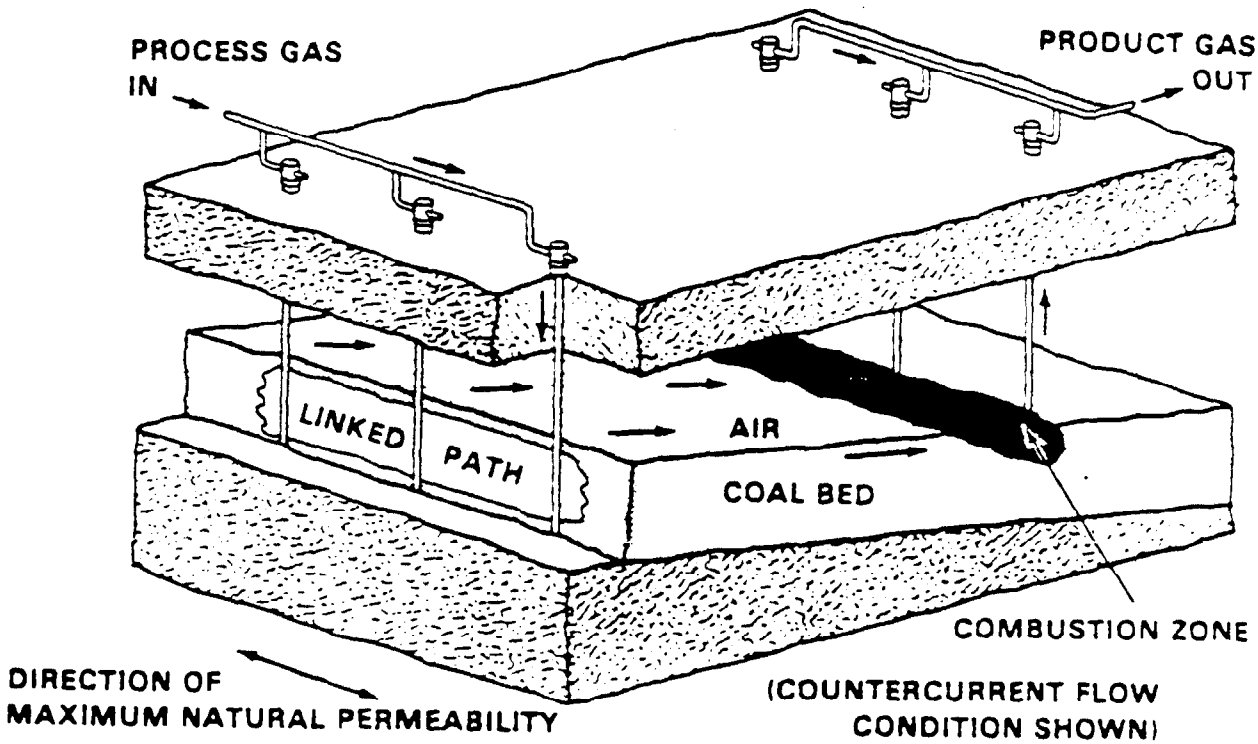
Figure 4-38



UNDERGROUND COAL GASIFICATION
PACKED BED PROCESS

(from Morgantown Energy Research Center, Proceedings; August 10-12, 1976)

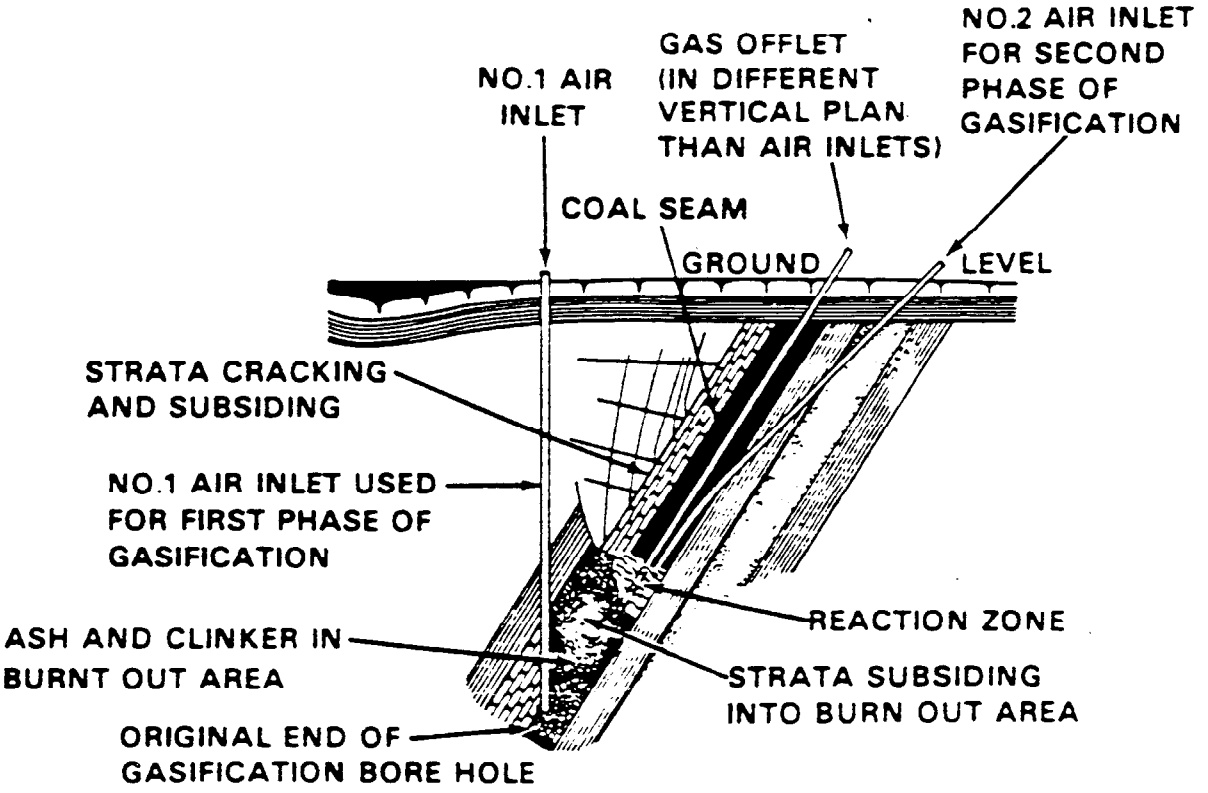
Figur



UNDERGROUND COAL GASIFICATION
LINKED VERTICAL WELLS

from Morgantown Energy Research Center Proceedings August 10-12, 1976

Figure 4-40



UNDERGROUND COAL GASIFICATION
STEEPLY DIPPING BED CONCEPT

(from Morgantown Energy Research Center, Proceedings; August 10-12, 1976)

Figure 4-41

At least three different technologies are utilized to extract petroleum products from oil shale. They are above ground retorting, in-situ, and modified in-situ (MIS). The latter two processes involve underground retorts which utilize Class V injection wells. Retorting is the process in which oil shale is heated to free the oil it contains. Above-ground retorts may be containers into which mined crushed oil shale is placed for burning. Underground retorts are simply the zones of oil shale which are to be heated. Both in-situ and MIS processes use underground retorts.

Modified in-situ processes involve partial mining of an underground retort and subsequent burning of the oil shale. Some companies have used MIS systems in which hot inert gas and air are injected by pipes into the retorts to facilitate burning. Each retort uses a number of injection conduits, the number depending on the stage of the project. This technology is usually proprietary and details of retort construction could not be obtained by States.

In the in-situ recovery process, the shale formation is initially fractured by explosives or hydraulic fracturing methods to increase permeability. A portion of the shale's organic material is then burned to obtain heat for retorting. Upon strong heating (retorting) the organic material decomposes to gas, condensable liquids, and residual carbonaceous matter which remains on the spent shale. An external fuel may be used to start and control the burning. The retorted oil shale product is extracted by pumping in a manner similar to crude oil production.

A large number of in-situ recovery techniques have been patented by various individuals and companies. However, most of these techniques are proprietary and not publicly available. A typical in-situ oil shale operation may consist of a two-well system (one injection well and one production well) or a five-spot pattern (four injection wells and one production well in the center of the pattern) completed within the oil shale bed. Injection wells are used to initially combust the oil shale and sustain the retort by continuously injection a pyrolyzing fluid. Production wells are used to recover the gaseous and liquid products which will be refined to syncrude.

Patents exist for several different in-situ oil shale production methods; each production method utilizes uniquely designed injection and production wells and varying fluids. Generally, well completion depths range from 100 to 1,000 feet below land surface. Wells are cased with carbon or higher strength stainless steel casing. Stainless steel may be used near the injection horizon. Casing is cemented to surface to keep overlying groundwater from entering the well bore by the standard high temperature oil field practices.

Injected Fluids and Injection Zone Interactions

As stated previously, in-situ fossil fuel recovery injection wells may inject water, air, oxygen, solvents, combustibles, or explosives. More specifically, underground coal gasification wells may inject:

1. Air
2. Oxygen
3. Steam
4. Water
5. Igniting agents such as ammonium nitrate-fuel oil (ANFO) or propane.

In-situ oil shale retort wells may inject:

1. Air
2. Oxygen
3. Steam
4. Water
5. Sand
6. Explosives
7. Igniting agents (generally propane).

The purpose of injection in both cases is to initiate and sustain combustion in the zone.

Air, oxygen, steam, water, and sand should not damage environmental quality by themselves. The environmental impact of explosives, igniting agents, and especially combustion products on ground-water quality is the main subject of concern for this well type. Combustion products include:

1. Polynuclear aromatics
2. Cyanides
3. Nitrites
4. Phenols.

UCG Interactions. During the gasification phase, high temperature gases can migrate from the burn cavity into surrounding strata, where cooling occurs and various chemical compounds are condensed or deposited. Most of the condensed chemicals are organic compounds including light hydrocarbons, phenols, oils, and tars. The heavier organics include some polynuclear aromatic hydrocarbons and heterocyclic compounds. Other gaseous components that condense or are absorbed in surrounding ground water are ammonia, carbon dioxide, hydrogen sulfide, and methane. After gasification, an ash residue remains in the burn cavity which yields soluble inorganic components to reinvading ground water, greatly increasing the total dissolved solids content of the ground water. These soluble components include a wide array

of ionic species, mostly calcium, sodium, sulfate, and bicarbonate. Additionally, many other inorganic materials are leached into the ground water in lesser quantities and include aluminum, arsenic, barium, boron, iron, zinc, cyanide, selenium, and hydroxide. (Humenick, Edgar, and Charbeneau, 1983). Table 4-42 presents water quality changes in the combustion zone after gasification.

Extensive fracturing of the surrounding rocks, and subsidence and collapse of the overburden material greatly enhance the ground-water contamination potential of UCG operations and can seriously effect the economic success of these operations. Fracturing, subsidence, and collapse occur due to the high thermal stresses of gasification and especially from the removal of coal material by gasification (ever expanding void areas are created as the coal burn progresses). Potential environmental effects include contamination of adjacent aquifers by escaping gases (fractures, voids, and damaged well bores are potential conduits) and structural disruption of overlying aquifers. Additionally, any major deformation or collapse of the overburden rock will ultimately be reflected at the surface as subsidence. Subsidence may create new pathways for surficial contaminants to enter USDW.

Oil Shale Retort Interactions. Large quantities of water are removed from oil shale during retorting (up to 1.5% of the raw shale by weight). Soluble and particulate organic matter are the components most likely to limit its environmental integrity. The pyrolytic retorting processes can produce a variety of polynuclear aromatic hydrocarbons (PAH). In addition, shale oil contains much higher concentrations of polar heterocyclic components than do crude oils. The environmental significance of the presence of large concentrations of polar and heterocyclic components in shale oil is two-fold. First, a number of organic compound types are potentially toxic and/or carcinogenic, and second, the polar characteristics increase their solubility and accommodation in water systems. Retort waste is amenable to treatment by charcoal sorption with eventual destruction of its organic compounds by heating, thus preventing adverse environmental effects.

Hydrogeology and Water Usage

In-situ fossil fuel recovery operations typically have occurred at depths less than 1,000 ft but may be technically feasible at depths up to 3,000 ft. As a result, for this well type, injection may occur above, below, or into USDW.

Water quality in coal and oil shale beds is typically poor. Even though these waters may meet USDW definition [illegible]

TABLE 4-42 WATER QUALITY CHANGES AFTER GASIFICATION

(Source: Humenick and Mattox, 1976)

Parameter	Before, mg l^{-1}	After, mg l^{-1}
Ca^{2+}	20	200
Mg^{2+}	5	15
Na^{+}	100	300
HCO_3	300	500
CO_3	2	0
SO_4	4	1150
H_2S	0.02	0.4
Cl^-	30	40
F^-	0.1	0.7
NO_3	--	2.0
NH_3	1.0	100
TDS	350	2300
Phenols	0.1	20
TOC	20	200
Volatile dissolved solids	--	300
CN^-	--	<0.01
CNS^-	--	<0.5
CH_4	0.42	0.16
pH	--	7.6
As	--	<0.01
Ba	--	<1
Cd	--	<0.01
Cu	--	<0.1
Cr (total)	--	<0.05
Mn	--	0.07
Hg	--	0.002
Se	--	<0.01
Ag	--	<0.05
Zn	--	<0.1
B	--	0.3

10,000 mg/l) their usefulness is questionable. The main threat to water quality is migration out of the zone during and after combustion. Zone roof collapse and resulting subsidence further adds to this concern.

If confinement within the zone can be established, several ground-water contamination concerns can be alleviated. Ground water contamination outside combustion horizons has not been substantiated. This may be due to the lack of pressure build-up and resulting flow in the combustion zone over time due to pressure release through producing wells. Water migration through the combustion zone and dispersion are the primary contaminant transport mechanisms.

Complete hydrogeologic and water usage information should be considered in any site selection process.

Contamination Potential

Based on the rating system described in Section 4.1, in-situ fossil fuel recovery wells are assessed to pose a moderate potential to contaminate USDW. These facilities typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does not occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in groundwater, or endanger human health or the environment beyond the facility perimeter.

Lack of injection zone pressure build-up and resulting flow potential out of the zone precludes this well type from having a high contamination potential. Dispersion and through zone migration are the primary contaminant transport mechanisms. At present, no wells are known to operate in the United States due to economic conditions. This is not expected to change in the near future.

Current Regulatory Approach

In-situ fossil fuel recovery related wells are authorized by rule in Federally-administered UIC programs (see Section 1). This well type has only existed in Colorado, Indiana, Michigan, Utah, Texas, and Wyoming. Table 4-43 details the known responsible regulators and their approach in each State. At present none of these well types are known to be operating.

TABLE 4-43
CURRENT REGULATORY APPROACH FOR IN-SITU FOSSIL FUEL RECOVERY WELLS

STATE	REGULATORY AGENCY	PERMIT	RULE
Colorado	USEPA Region VIII	---	Regulated by rule
Texas	State Railroad Commission	Regulated by permit	
Utah	State Dept. of Health, Bureau of Water Pollution Control	In cooperation with State Dept. of Health. Dept. of Health can require a permit if deemed necessary	---
Wyoming	State Dept. of Environmental Quality (Land Quality Division)	Regulated by permit	---

The regulatory tendency for this well type is for State agencies to regulate by permit. Colorado is the only State where the Federal UIC program has primacy and thus regulates these wells by rule.

Recommendations

In-situ fossil fuel recovery injection wells are similar to Class I injection wells in that if wellbore integrity can be confirmed, and injection fluids or by-products are confined to the target zone, USDW protection is possible; if not, serious ground-water contamination can occur. Certainly, complete geologic and hydrogeologic investigations should be part of any operations plan (Wyoming).

Wyoming also suggests that if long term confinement of combustion zone fluids cannot be assured, remediation of zone fluids may be a way of stopping or minimizing future contamination.

Supporting Data

Supporting data (Appendix E, page 4) consists of case studies of U.S. Department of Energy projects in Wyoming.

4.2.4.4 Spent Brine Return Flow Wells (5X16)

Well Purpose

Spent brine return flow wells are used to reinject spent brine into the same formation from which it was withdrawn after the extraction of halogens or their salts. Although there are similarities between spent brine return flow wells and wells used in association with solution mining processes (Class III injection wells), the spent brine return flow wells are classified as Class V injection wells. The purpose of these wells is the reemplacement of the spent fluids into the source formation as opposed to use as an integral part of the mining or extraction process.

Inventory and Location

Spent brine return flow wells have been reported in relatively few States. This, of course, corresponds to the location of geologic formations conducive to the extraction of halogens or salts in an economically feasible process. The largest inventory of spent brine return flow wells has been reported in Arkansas, followed by the inventory reported for Michigan. Other States reporting spent brine return flow wells include Indiana, New

York, North Dakota, Oklahoma, and West Virginia. Reported to date, the national inventory of this well type is 121 wells.

The inventory numbers reported by the States are reliable, since industries utilizing these wells are easily identifiable. Table 4-44 provides a synopsis of the inventory data from the State reports.

Well Construction, Operation, and Siting

The only information on well construction of spent brine return flow wells was received from Arkansas. Wells located in Arkansas are constructed just the same as wells used to dispose of oilfield brines (Class II injection wells). The wells have multiple strings of casing cemented in the hole, and injection is through steel tubing which generally is isolated from the casing with a packer. (See Figures 4-42 and 4-43.) The well construction reported by the State of Arkansas is compatible with the expected well usage.

The operation of spent brine return flow wells consists of injecting large volumes of fluid, typically 10,000 - 20,000 barrels of fluid per day. The injection operations are continuous, but generally injection is not at high pressures. Gravity fed wells (i.e. no applied surface pressure) are common.

The siting of any spent brine return flow well is determined by the geology of the area for the optimum production of halogen-rich brine. Siting, therefore, is limited to areas with economically recoverable brines.

Injected Fluids and Injection Zone Interactions

The injection fluids, by definition are limited to brines from which halogens or salts have been extracted. Since the brine is re-injected into the same formation from which it was produced, injection zone interactions with the injection fluid are not a problem.

However, there have been unconfirmed reports that occasionally other fluids, possibly hazardous wastes, are added to the injection stream. The effect of emplacing unknown fluids into the injection zone cannot be determined, but reports of this practice do indicate the need for strong regulation of spent brine return flow wells.

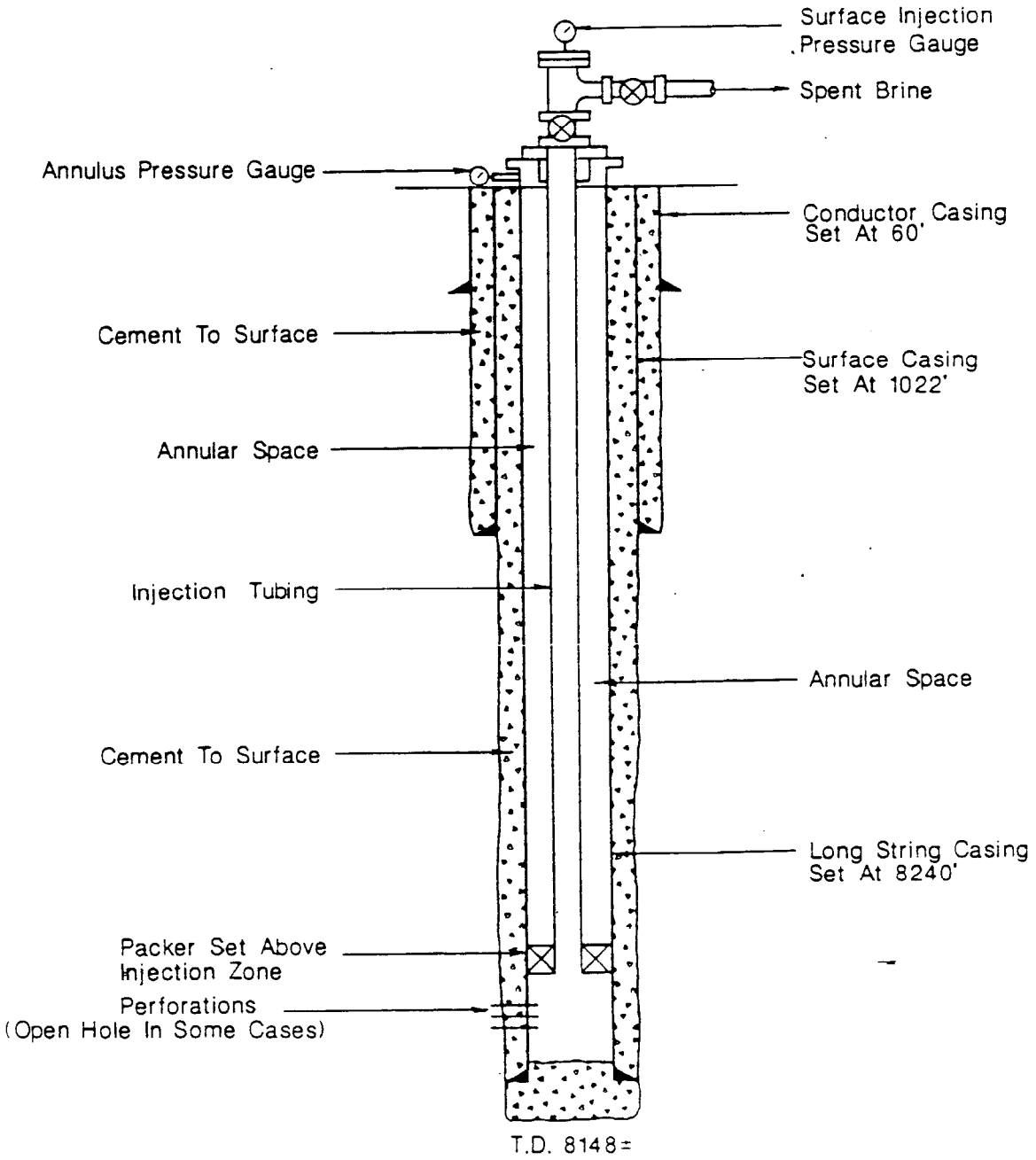
Hydrogeology and Water Usage

Spent brine return flow wells do not inject into USDW. Due to the high dissolved solids content of the brines, all reported halogen- or salt-rich brines have underlain all USDW, and are separated from fresh waters by confining layers.

TABLE 4-44: SYNOPSIS OF STATE REPORTS FOR SPENT BRINE RETURN FLOW WELLS(SARB)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	N/A	NO	N/A
New York	II	YES	PERMIT	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	2 WELLS	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	NO	N/A	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	NO	N/A	NO	N/A
Indiana	V	8 WELLS	N/A	NO	N/A
Michigan	V	33 WELLS	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	70 WELLS	PERMIT	YES	MODERATE
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	NO	N/A	NO	N/A
Oklahoma	VI	7 WELLS	RULE	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	1 WELL	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	RULE	NO	N/A
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	NO	N/A	NO	N/A
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

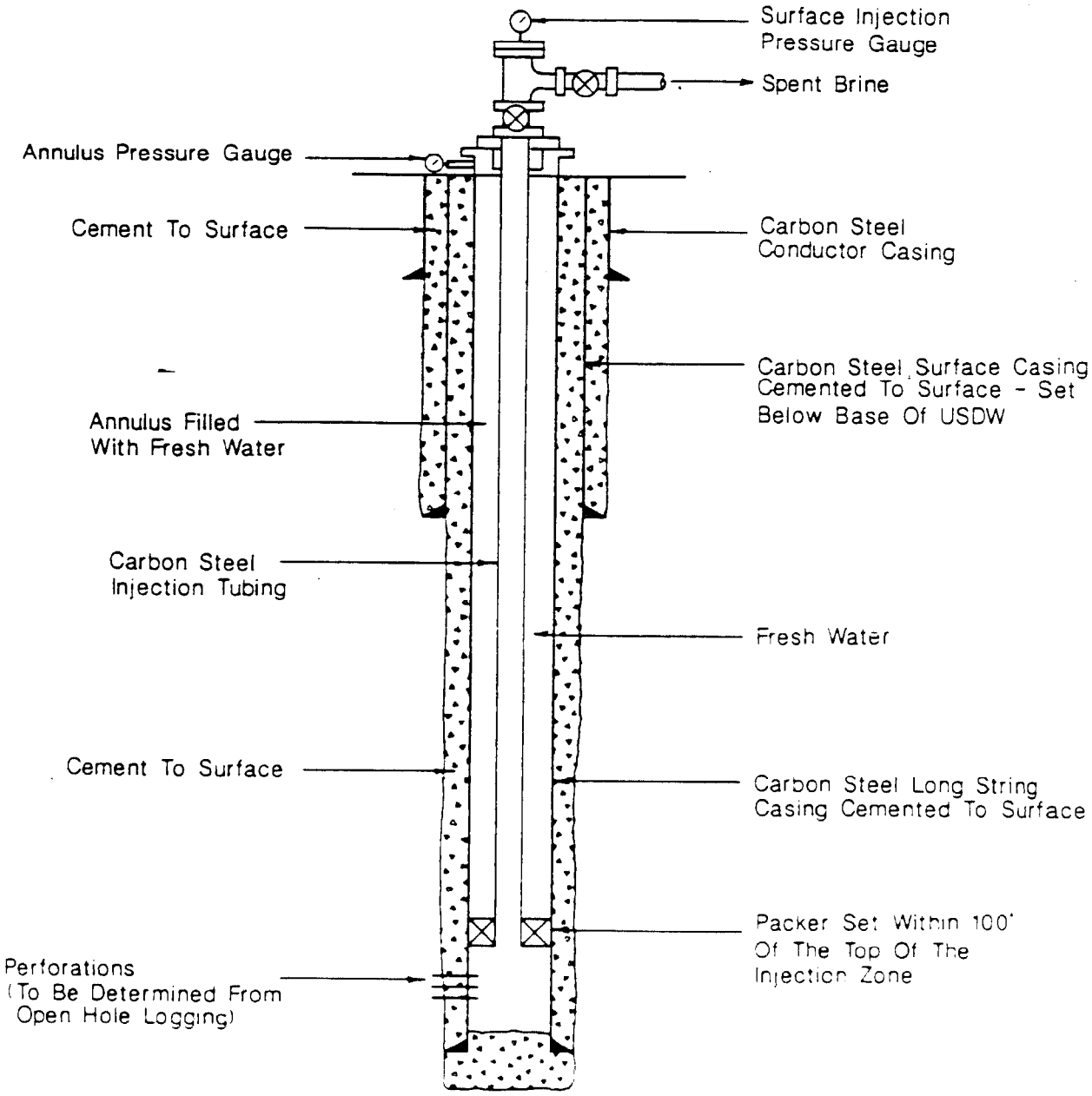


Scale: None

EXISTING CLASS V BRINE DISPOSAL
INJECTION WELL
GREAT LAKES CHEMICAL CORPORATION

(Source: Arkansas, 1985)

Figure 4-42



Scale None

CONSTRUCTION REQUIREMENTS FOR NEW CLASS V BRINE DISPOSAL INJECTION WELLS

(Source: Arkansas, 1985)

Figure 4-4

Contamination Potential

Based on the rating system described in Section 4.1, spent brine return flow wells are assessed to pose a low potential to contaminate USDW. These facilities typically inject below USDW with little or no potential for migration of fluids into any USDW. Typical well construction, operation, and maintenance would not allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does not occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the national Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter.

Since the spent brine return flow wells inject fluids through adequately constructed injection wells and into confined formations which are not USDW, the contamination potential is limited. Proper operation of the wells would ensure a low contamination potential.

Current Regulatory Approach

Spent brine return flow wells are authorized by rule under Federally-administered UIC program (See Section 1). The State of Arkansas requires a permit for spent brine return wells, while the State of Oklahoma allows injection by rule-authorization. Other agencies have not reported their regulatory approach.

The State of Arkansas appears to be effectively ensuring proper operation of the spent brine return flow wells located in the State through their permitting process. Well construction requirements must be met, and requirements for mechanical integrity verification and reporting of operating parameters are stipulated. Arkansas is implementing comprehensive sampling of the original brine and of the injection fluid as a further regulatory requirement.

Recommendations

The only significant recommendations provided came from the Arkansas state report and are summarized as follows: technical requirements for spent brine return flow wells should be similar to those for oilfield brine injection wells (Class II injection wells). Construction requirements should be developed based upon the operating parameters of the well, and mechanical integrity tests should be required. Comprehensive fluid sampling and analysis also should be done periodically. Volumes of produced and injected fluids should be compared periodically to determine

if additional unlicensed wastes are being injected. The last two monitoring activities mentioned should be performed on a semi-annual or more frequent basis.

West Virginia recommends that spent brine return flow wells should be regulated in a similar manner to Class III wells.

Supporting Data

Supporting data on spent brine return flow wells have been taken in whole from the Arkansas Department of Pollution Control and Ecology Class V Report. Refer to the list in Appendix E.

4.2.5 OIL FIELD PRODUCTION WASTE DISPOSAL WELLS

4.2.5.1 Air Scrubber Waste and Water Softener Regeneration Brine Disposal Wells (5X17,5X18)

Although included in Table 1-1 as Class V injection wells, air scrubber waste and water softener regeneration brine disposal wells, types 5X17 and 5X18, are not included in the inventory and assessment portion of this report. At the time the State Class V injection well reports were written, air scrubber waste and water softener regeneration brine disposal wells were categorized as Class V injection wells. As a result, however, of a July 31, 1987, USEPA policy decision, these well types, in certain situations, may fall under the Class II category rather than Class V. This was determined to be the case with those 5X17 and 5X18 wells inventoried in the State reports.

4.2.6 INDUSTRIAL, COMMERCIAL, UTILITY DISPOSAL WELLS

4.2.6.1 Cooling Water Return Flow Wells (5A19)

Well Purpose

The low specific heat of water (the amount of energy required to raise the temperature of water by 1°C) makes water an excellent "heat sink" (readily absorbs heat). Various industries take advantage of this property of water by using it in heat exchange systems to cool processes, equipment, or products. These cooling systems often require large quantities of water to operate efficiently. Ground water is used if it is available in sufficient quantities or at low enough costs. Utilization of ground water in the cooling system most commonly entails the return of these large volumes of water to the subsurface through injection wells. Cooling water return flow wells are installed to dispose of the used cooling water, to prevent subsidence, and to avoid depletion of ground-water supplies. These wells are classified as Class V wells under 40 CFR Section 144.5 [illegible].

Inventory and Location

The collation of an inventory of cooling water return flow wells on a national level has been complicated by: 1) State reports which contradict the Federal Underground Injection Control Reporting System (FURS) listings, 2) insufficient delineation of subclasses within FURS and State reports, and 3) the errant classification of cooling water return flow wells as heat pump/air conditioning return flow wells and vice versa.

There are 291 cooling water return flow wells inventoried to date and their distribution is presented in Table 4-45. There are some States whose FURS listing reported 5A types which were undifferentiable based on facility name. It is expected that some of these are cooling water return flow wells (5A19).

Well Construction, Operation, and Siting

Well construction varies greatly throughout the United States. Wells used to inject cooling water typically are completed at shallow depths (less than 300 feet). In some areas, due to special conditions, such as arctic provinces where permafrost occurs, wells are completed at much greater depths. Based on inventory information, the range of these cooling water return flow wells is 10 to 600 feet deep. Wells may be cased to depth, cased at the surface, or open hole for the entire depth. Due to the wide variation in construction practices, no typical well construction diagram has been included. Return flow wells are completed most commonly in the source aquifer but can be completed in another aquifer. Injection generally is achieved through gravity drainage.

There are three basic designs for the circulation of cooling waters through a cooling system. The most common design is the "closed" system which does not expose ground water to the air at any point between withdrawal and reinjection. "Open" systems, on the other hand, expose ground water to the air at some point prior to reinjection. The third system is the "contact" system which runs ground water over (in direct contact) the product to cool it. This system may be easily abused in that industrial fluids may be commingled with the cooling water.

Spent cooling fluids can be injected into several different zones. They can be returned to the source aquifer through the supply well or through another well, or they can be injected into a different aquifer. Returning spent fluids to the source aquifer is the most commonly practiced method.

Injected Fluids and Injection Zone Interactions

Injected Fluids. The nature of injected fluids depends heavily upon the type of system in place, the type of additives (if any) which are added to supply waters, and the temperature of

TABLE 4-45: SYNOPSIS OF STATE REPORTS FOR COOLING WATER RETURN FLOW WELLS(5A19)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	3 WELLS	PERMIT>2K GPD	YES	LOW
New Hampshire	I	3 WELLS	N/A	YES	N/A
Rhode Island	I	8 WELLS	N/A	YES	HIGH
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	5 WELLS	NJPDES PERMIT	NO	N/A
New York	II	NO	N/A	NO	N/A
Puerto Rico	II	1 WELL	N/A	YES	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	YES	N/A	NO	N/A
Virginia	III	YES	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	33 WELLS	PERMIT	NO	VARIABLE
Florida	IV	35 WELLS	PERMIT	YES	5TH HIGHEST/8 TYPES
Georgia	IV	5 WELLS	PERMIT	NO	LOW
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	2 FACILITIES	RULE	YES	2ND HIGHEST/3 TYPES
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	10 WELLS	RULE	NO	N/A
Indiana	V	22 WELLS	N/A	NO	N/A
Michigan	V	52 WELLS	N/A	NO	N/A
Minnesota	V	4 WELLS	N/A	NO	N/A
Ohio	V	YES	N/A	NO	N/A
Wisconsin	V	2 WELLS	RULE	NO	N/A
Arkansas	VI	1 WELL	NONE	NO	LOW
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	6 WELLS	REGISTRATION	NO	LOW
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	5 WELLS	PERMIT	NO	N/A
Kansas	VII	3 WELLS	N/A	NO	POSSIBLE
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	8 WELLS	RULE	NO	VARIABLE
Colorado	VIII	1 WELL	N/A	NO	LOW
Montana	VIII	YES	N/A	NO	LOW
North Dakota	VIII	1 WELL	N/A	NO	UNKNOWN
South Dakota	VIII	1 WELL	N/A	NO	N/A
Utah	VIII	3 WELLS	PERMIT	NO	4 (7=HIGHEST)
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	20 WELLS	PERMIT	NO	UNKNOWN
Hawaii	IX	6 WELLS	PERMIT	YES	LOW-MODERATE
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	2 WELLS	PERMIT	NO	MODERATE
Idaho	X	49 WELLS	PERMIT	NO	11TH HIGHEST/14TYPES
Oregon	X	NO	PERMIT>5K GPD	NO	N/A
Washington	X	YES	PERMIT	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

the water. If water runs through a closed pipe system with no additives introduced at any point, only the temperature of the water is altered. This is the most common operation in the United States. There are, however, open pipe systems which expose water to accidental introduction of surface contaminants, spills of industrial fluids, or unauthorized disposal of wastes. In addition, contact systems may alter the chemical makeup of waters by introducing contaminated fluids directly to the receiving aquifer. Contamination of the fluids may be a result of commingling of fluids or as a result of absorption or leaching of matter from products. Any additives used to improve well performance also are directly introduced to receiving aquifers.

Volumes of injected waters depend chiefly on the size of the operation. Private industries which reinject cooling water may inject only a few gallons of water per day, whereas larger industries, such as public utilities, may inject several million gallons per day.

Injection Zone Interactions. Injection of cooling water results in temperature increases within the injection zone. Effects of the temperature increase may include the dissolution of additional salts and minerals and/or the hydrolysis of certain metals within the aquifer. Injection into an aquifer other than the source aquifer can result in any number of chemical reactions, all subject to the chemical compatibilities of the different waters.

Hydrogeology and Water Use

Operators of cooling water return flow wells often inject into the shallowest aquifer which will handle the volume of water they dispose. For example, in Illinois, cooling water return flow is discharged into abandoned underground coal mines. Injection into shallow aquifers is preferred over injection into deep aquifers because of lower drilling costs. In the United States, most cooling water is injected into USDW. Wells which supply private or public waters and are located downgradient of cooling water return flow wells are threatened by thermal and/or chemical changes in the aquifer. The degree of threat to supply wells is a function of their distance from injection operations, volumes of fluid injected at those operations, hydraulics of the aquifer, the amount of water drawn in the supply wells, etc.

Contamination Potential

Based on the rating system described in Section 4.1, cooling water return flow wells are assessed to pose a moderate to low potential to contaminate USDW. These facilities typically do inject into or above Class I or Class II USDW.. Since well construction, operation, and maintenance practices vary widely, injection or migration of fluids into unintended zones may occur

as a result of improper construction or operation. Injection fluids may have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. However, injectates from closed systems are likely to be of equivalent quality (relative to standards of the National Primary or Secondary Drinking Water Standards and RCRA regulations) to the fluids within any USDW in connection with the injection zone. Based on injectate characteristics and possibilities for attenuation and dilution, injection may occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter when contaminants are present in the injectate.

The most significant threat to USDW from cooling water injection wells results from the use of contact cooling waters and the addition of chemicals to the cooling waters. Open-pipe systems have only slightly lower contamination potential. Their contamination potential depends primarily on the steps taken to maintain the water's integrity. Any introduction of chemicals to the cooling water results in direct dispersion of chemicals into the receiving aquifer and constitutes degradation if the receiving waters are of drinking water standards. Closed-pipe systems do not chemically alter waters; therefore, their potential for contamination is limited to the chemical reactions which occur as a result of thermal alteration.

North Dakota reports that closed-loop systems generally are designed to shut down automatically in the event of pressure loss due to a below-ground pipe break. Also, most closed-loop well casings are filled with nearly impermeable grout compound which surrounds the circulation piping. This is necessary to assure proper heat conduction. Therefore, North Dakota concludes, ground-water contamination from closed loop systems is extremely low.

Thermal degradation occurs in every application of these systems. The degree to which degradation occurs, however, depends on several factors including volume of the aquifer, disparity between temperatures of injected and receiving waters, and volume of injected fluids. The chemical interaction between warm injectate water and cool water inherent to the injection zone is not well documented. Many chemical alterations are possible within an aquifer as a result of a temperature rise. Solids present in an aquifer are at equilibrium, which is to say that all those solids that will dissolve under the present conditions have done so. Changing physical conditions (such as temperature) will alter the equilibrium in the aquifer. Usually a temperature increase brings more solids into solution. This rise in total dissolved solids (TDS) constitutes degradation of the aquifer. As a result, drinking water standards may no longer be met, natural water flow may change, and biological activity may

increase within the thermally altered area. Degradation may also result from the hydrolysis of certain metals in an aquifer. High levels of dissolved metals may disqualify an aquifer from drinking water classification and can cause clogging of an aquifer among other problems.

Thermal degradation and resulting chemical changes are not well documented in the United States. Much more study of the chemical alteration due to thermal degradation of aquifers is needed.

Current Regulatory Approach

Class V wells, which include cooling water return flow wells, are authorized by rule. States with primacy approach the regulation of cooling water return flow wells in many different ways, but these States have provided only minimal detail on their current regulatory programs. Some States require a permit prior to construction or operation; others authorize by rule. At least thirteen States have some type of permitting program which mandates permits for operation of cooling water return flow wells. Some of these programs are conditional and require permits for injections in excess of set volumes or for certain system designs (e.g. contact systems). In Texas, cooling water return flow wells are regulated as Class I injection wells. While regulations are diverse throughout States with primacy, most State reports recommend construction standards which may include return to the source aquifer, minimum separation between supply and injection wells, casing requirements, etc. In a few States, construction standards are included in the current regulatory programs.

Little or no information is available in State reports on local jurisdiction. Municipalities typically do not regulate cooling water return flow wells.

Recommendations

Regulation of cooling water return flow wells may best be carried out after development of specific guidelines for these wells. These guidelines should set minimum requirements for construction, siting, and monitoring. Some of the most common siting and construction standards recommended in State reports include the following:

1. Prohibition of open loop cooling water return flow wells (FL, AR, NE, UT);

2. Casing from the surface through the top of the uppermost supply and injection formation (AR);

3. Cemented casing from the top of the supply and injection formation to the land surface (AR);

4. A minimum of two wells: a supply well and a return well, maintaining proper distances between the two (AR, SC);

5. Supply and return well system construction so that spent fluids are returned to source aquifers (AR, SC);

6. Plugged cooling water return flow wells upon abandonment (by filling them with cement) (AR);

7. Restriction that nothing other than spent cooling water originating at the supply well(s) be injected (AR);

8. Various minimum locating requirements for injection wells relative to any municipal supply wells (NE, SC).

Permits to construct could be issued after submittal of an application specifically for cooling water return flow wells. According to Nebraska and Iowa, the permit application should include:

1. Detailed map showing location of injection well and all municipal, domestic, and stock wells within one mile of the well;

2. Diagram of the injection well including screen depths, casing, gravel pack, grout, etc.;

3. Diagram of the entire system; and

4. Type and volume of injected fluids (IA). This information may discuss additives, mixed waters, and other wastes which might be disposed with cooling waters.

Supporting Data

Appendix E lists abbreviated case studies from five states which were used in preparing this assessment.

4.2.6.2 Industrial Process Water and Waste Disposal Wells (5W20)

Well Purpose

Industrial process water and waste disposal wells are used to dispose of a variety of industrial wastes. Twenty-[illegible] case studies of industrial disposal well [illegible]

assessing this well type are listed in Appendix E and illustrate the variety of processes for which industrial disposal wells are used. Table 4-46 provides a summary of each case study. The reader will note that the case studies indicate several wells injecting wastewater which contains apparently "hazardous" materials. By definition, these may be Class IV wells. However, proving injection of "hazardous" waste as described under 40 CFR 261 Subparts C and D is very difficult. Until these facilities can be proven to inject hazardous waste or are proven to be sources of contamination or to adversely affect public health, they may be reported as Class V wells. Several types of facilities which may utilize industrial disposal wells include:

- petroleum refineries
- high-tech electric component manufacturers
- small machine manufacturers
- asphalt manufacturers
- metal plating and fabricating facilities
- reverse osmosis reject water facilities
- automobile dealers and car washes
- laundries and dry cleaners
- funeral homes and mortuaries
- chicken farmers.

Inventory and Location

Results. There are 1,938 industrial process water and waste disposal wells inventoried to date. Table 4-47 lists their numbers and distributions by State. It is likely that many more exist.

The distribution of industrial process water and waste disposal wells appears sporadic. Data may be interpreted to indicate higher numbers of wells on the coasts of the United States and lower numbers in the mid-continent. These trends may be expected due to increased industrial activity and larger populations on the coasts. However, several additional factors may affect the apparent distribution. These factors are discussed in the **Evaluation** of the inventory and include 1) difficulty identifying wells, 2) reluctancy of owners/operators to report their wells, and 3) difficulty classifying wells.

Evaluation. In general, the inventory of industrial disposal wells is believed to be poor to fair. Several factors are responsible for the lack of quality (detail) and completeness (accurate number of wells). First, the wells are difficult to locate and identify. Problems are similar to those related to

TABLE 4-46

Case Studies (5W20-Industrial Disposal Wells)

Company Name Location (Region) Nature of Business	Description
Components, Inc. Keenebunk, ME (Reg I) Capacitor Manufacturer	Used an acid solution process involving dilute solutions of nitric acid, sulfuric acid, and tantalum powder. Groundwater was determined to be locally contaminated with manganese, nitrates, and sodium. Company moved. Monitoring continues.
Southern Maine Finishing Co. East Waterboro, ME (Reg I) Metal Plating and Fabricating Plant	Operated a rudimentary wastewater treatment plant which resulted in contamination of ground and surface water. New treatment system was designed which could treat cyanide chromium acid and alkali.
York Aviation Sanford Airport Industrial Park, ME (Reg I) Aircraft Maintenance	Waste paint, spent solvents, and associated material were washed to a collection dump. After removal of solids, wastewater was disposed in a drainfield. Matter is under investigation by Maine's Department of Environmental Protection.
Eastern Air Devices Dover, NH (Reg I) Electric Motor Manufacturer	Two dry wells had been used for waste disposal. The wells were cleaned out, and fluids and solid samples were analyzed. Some organic compounds were identified (primarily tetrachloroethylene, or PCE). Hydrogeology of the area was assessed and contamination is believed to be contained.
Viscase Puerto Rico Corporation, Barceloneta, P.R. (Reg II) Food Casing Manufacturer	Process wastewater, ancillary cooling water, power house water, and filter backwashes were neutralized in concrete basins, filtered through anthracite filters, and then injected. Wells were plugged after approximately 10 years of use.
RCA del Caribe, Inc. Barceloneta, P.R. (Reg II) Aperture Mask Manufacturer	Wastewater contains acids, alkalis, ferric chloride, ferrous chloride, organic material, and chromium. Discharge violates several limits imposed by Environmental Quality Board. Closure monitoring is recommended.

TABLE 4-46 (Continued)

Glamourette Fashion Mills Quebradillas, P.R. (Reg II) Apparel Manufacturer - Dyeing Operations	The USEPA considers certain dyes to be hazardous. The company declined to provide information on the kinds, quantities, and concentrations of dyes in the injectate. This matter is under investigation by USEPA, Region II.
Lotus (Land Authority of Puerto Rico - Pineapple Division) Barceloneta, P.R. (Reg II) Tropical Fruit Processing and Canning	Industrial wastes come from the cooling process, pineapple washing, and pineapple extraction. The organic waste is higher than that of typical domestic sewage. Recommended limits for phenol, total dissolved solids, and surfactants are exceeded. Monitoring program is recommended.
Kendall McGraw Laboratories Sabana Grande, P.R. (Reg II) Parenteral Medical Accessories Manufacturer	Septic tank receives sanitary wastes (71%) process water (24%), and washing water (5%).
Various Automobile Dealers Long Island, NY (Reg II) Car Dealers Car Washes	The NJDEP found a Toyota dealer removing cosmolene from automobiles with formula R-E-L (87% Petroleum Hydrocarbons, 11% trichloroethane, 4% Detergents) and washing it into a dry well. Several other car dealers in New York were observed using hydrocarbons to remove cosmolene.
Permit Compliance System New York (Reg II) Permit Complaince (SPDES)	Preliminary results of an EEI investigation. Includes evaluatin of fluids injected into industrial waste disposal wells in Nassau and Suffolk Counties.
Lehigh Portland Cement Co. Woodsboro, MD (Reg III) Mining and Crushing for Cement Aggregate	Disposal well receives storm water runoff and wash water that is used to rinse rock crushing dust from the outside of trucks.
Applied Electro-Mechanics, Inc., Point of Rocks, MD (Reg III) Manufacturer of Public Address Systems	Well used for disposal of rinse water from the metal irridite and anodizing process. Drainfield used for disposal of rinsewater from the printed circuit and photographic processes. Samples showed elevated levels of copper. Facility will continue to be monitored.

TABLE 4-46 (Continued)

Hammermill Paper Co. Erie, PA (Reg III) Pulp and Paper Mill	During seven and one half years of operation, over one billion gallons of waste pulping liquors were injected. Wells were plugged when a new process for making paper was developed.
Rodale (Square D) Emmaus Borough, PA (Reg III) Electrical Products Manufacturing Plant	Approximately 3,000 gallons per day of electroplating waste containing up to 118.4 ppm cyanide were illegally dumped into 3 injection wells. Area wells (serving 10,000 people) have been sampled and no contamination found.
National Wood Preservers Haverford Township, PA (Reg III) Wood Treatment and Preservation	Pentachlorophenol (PCP) and fuel oil were discharged into disposal well. Subsequently, PCP and fuel oil migrated to the top of the water table and flowed downgradient killing or heavily depressing aquatic life for 5 1/2 miles downstream.
Highway Auto Service Station, Pittstown Township, PA (Reg III) Auto Service Station	Petrochemicals, cyanides, 2,2 dichlorobenzene, and a host of other known and unknown carcinogenic, teratogenic, mutagenic, and toxic chemicals were present in discharge from a mine tunnel to the Susquehanna River. Sampling analyses indicated pollution came from the station. Case study describes severe damages. Extensive clean-up and monitoring efforts continue.
Franklin A. Holland & Son New Church, VA (Reg III) Chicken Farm	Pit was constructed to dispose of fowl that die prior to being sold. Increased nitrate, organic, and bacteriological levels could be expected, but no information on nature of the liquid waste that enters the water table is available. One pit probably does not constitute high contamination potential; however, if many pits are utilized in one area, evaluation of quality and quantity of leachate may be required.
Facility Name- Not Available Florida (Reg IV) Reverse Osmosis Brine	Some Class V wells in Florida are used to dispose of reject water (brine) from water treatment plants using [illegible] technology ([illegible]) to render poor quality groundwater potable. Of particular interest are the high levels of radionuclides.

TABLE 4-46 (Continued)

American Cyanamid Company Michigan City, IN (Reg V) Catalyst Manufacturers	Injected waste generally contains high levels of total solids, Na, and SO_4. The injection zone lies between two USDW. The upper USDW is currently a source of drinking water, and the lower zone is a potential source of drinking water. It is recommended that these wells be phased out.
PureGro Co. Bakersfield, CA (Reg IX) Fertilizer and Pesticide Distributor Facility	Well used to collect rinse water runoff and spillage that occurred during material transfers. Chemicals handled on site included 1,2-dibromo-3-chloropropane (DBCP) until the State of California banned its use because of possible carcinogenic and toxic effects. Order was issued requiring subsurface investigations and soil contamination assessments. Use of this well was discontinued in 1980.
Mefford Field Tulare, CA (Reg IX) Crop Dusting	Wells were used for disposal of agricultural chemicals and hydrocarbons, wash water used to clean cropdusting planes and chemical containers, and waste petroleum products. Groundwater contamination has been documented. Additional monitoring wells should be installed.
KPF Electric Company Stockton, CA (Reg IX) Manufacturing, Silver Plating, Galvanizing	Rinse waters from silver plating contained concentrations of copper, cyanide, and silver in excess of 1 mg/l. Waste streams from galvanizing contained high concentrations of lead and zinc. Data is inadequate to delineate extent of subsurface contamination.
T.H. Agriculture and Nutrition Co. Fresno, CA (Reg IX) Agricultural Chemical Formulation, Packaging, and Warehousing Plant	Designated Superfund site. Ten areas containing industrial waste contaminants have been identified. Industrial disposal wells and an industrial leach field were responsible for soil contamination at four locations. Groundwater contamination on and downgradient from the property is well documented. Injection ceased in 1983.
Various Petroleum Refineries California (Reg IX) Petroleum Marketing	Three refinery waste injection wells at two facilities were located and investigated in California. Average injection volumes are approximately 40-50 million gallons annually. A variety of organic and inorganic constituents are found in the waste stream.

TABLE 4-46 (Continued)

UniDynamics Goodyear, AZ (Reg IX) Manufacturing Plant for Defense and Aerospace Equipment	Designated Superfund site (Phoenix Litchfield Airport). Wells and ponds were used to dispose of solvents. Groundwater contamination on site has been documented downgradient of the wells. TCE has migrated into a drinking water aquifer. The wells were closed in 1982.
Honeywell Phoenix, AZ (Reg IX)	Paint sludges, thinners, varnish, and solvents are disposed in two wells. Wastes generated by circuit board manufacturing processes were disposed in three wells. Given the hydrogeologic information collected to date, the threat to groundwater formerly posed by the disposal wells cannot be assessed. The wells were closed in 1982.

TABLE 4-47: SYNOPSIS OF STATE REPORTS FOR INDUSTRIAL PROCESS WATER AND WASTE DISPOSAL WELLS(5W20)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	6 WELLS	PERMIT	YES	MODERATE
Maine	I	15 WELLS	N/A	YES	VARIABLE
Massachusetts	I	1 WELL	PERMIT	YES	MODERATE
New Hampshire	I	13 WELLS	N/A	YES	VARIABLE
Rhode Island	I	59 WELLS	N/A	YES	MODERATE-HIGH
Vermont	I	5 WELLS	N/A	YES	MODERATE
New Jersey	II	20 WELLS	NJPDES PERMIT	YES	VARIABLE
New York	II	350 WELLS	PERMIT	YES	SIGNIFICANT
Puerto Rico	II	28 WELLS	N/A	YES	N/A
Virgin Islands	II	3 WELLS	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	9 WELLS	PERMIT	YES	HIGHEST/3 TYPES
Pennsylvania	III	19 WELLS	PERMIT	YES	DELETERIOUS
Virginia	III	2 WELLS	N/A	YES	VARIABLE
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	98 WELLS	PERMIT	YES	VARIABLE
Florida	IV	20 WELLS	PERMIT	YES	4TH HIGHEST/8 TYPES
Georgia	IV	NO	N/A	YES	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	200 DRAINFIELDS	PERMIT	YES	LOWEST/3 TYPES
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	16 WELLS	RULE	YES	MODERATE
Indiana	V	30 WELLS	N/A	NO	N/A
Michigan	V	9 WELLS	N/A	NO	N/A
Minnesota	V	1 WELL	N/A	NO	N/A
Ohio	V	467 WELLS	N/A	NO	HIGH
Wisconsin	V	4 WELLS	PERMIT	NO	UNKNOWN
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	2 WELLS	N/A	YES	MODERATE
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	2 WELLS	CLASS I	NO	N/A
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	4 WELLS	BANNED	NO	RANGE 5-7(7=HIGHEST)
Wyoming	VIII	32 WELLS	PERMIT	NO	3RD HIGHEST/10 TYPES
Arizona	IX	72 WELLS	PERMIT	YES	HIGH
California	IX	93 WELLS	PERMIT	YES	HIGH
Hawaii	IX	44 WELLS	PERMIT	YES	HIGH
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	230 WELLS	PERMIT	NO	HIGH
Idaho	X	46 WELLS	PERMIT>18 FT	NO	10TH HIGHEST/14TYPES
Oregon	X	20 WELLS	PERMIT	YES	LOW
Washington	X	69 WELLS	N/A	NO	UNKNOWN

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.

the inventory of septic systems. Because records have not been kept on many of the wells, the inventory may never be complete. Differences in record-keeping systems among States, among agencies, and even among facilities make it difficult to use only one inventory method.

Second, owners/operators are often hesitant to report their industrial waste disposal wells. Fear of breaking the law, being shut down, and drawing bad publicity adds to their reluctance. Increased public awareness concerning the severe implications of ground-water contamination has rendered them wary.

Third, classification problems severely affect the results of inventory efforts. In some States (Texas, for example), all industrial disposal wells are regulated as Class I wells rather than Class V wells. Another problem involves the subclassification system. In some questionnaires, recipients were asked to report "dry wells used for the injection of wastes." The terminology was problematic because industrial disposal wells were consequently restricted to dry wells (a type of well construction). Therefore, septic tanks with soil absorption systems which were used to dispose industrial wastes were not identified as industrial waste facilities. Rather, they were more likely identified as septic systems and were confused with wells that receive solely sanitary wastes.

Methods. Methods used to inventory industrial disposal wells were similar to those used for other wells. In States where permits were already issued, files of those permits generally were considered the primary source of information. Where permit files were not available, information was gained from a variety of Federal, State, County, and City Agencies. County Health Departments were consistently valuable sources of information.

A variety of private industries were also contacted for information on industrial disposal wells. The list is too lengthy to print in its entirety, but examples include:

- drilling and boring contractors
- water well and oil well drillers
- civil and consulting engineers
- manufacturing and processing companies
- petroleum refineries
- laundromats and dry cleaners
- mortuaries and funeral homes
- auto dealers and car washes.

Most agencies and facilities were contacted by mail and asked to complete a questionnaire concerning well types, injected fluid characteristics, and construction features. When facilities were contacted by telephone or in person, response rates were consistently higher.

Summary. Results of the inventory effort are believed to be poor to fair. Over 1,900 industrial waste disposal wells have been inventoried to date, but it is likely that many wells have not been reported. Many States (including Puerto Rico, Indiana, Wisconsin, Arkansas, and Wyoming) have stated that inventory efforts should continue, and further efforts should be made to improve the quality and precision of the existing inventory.

Well Construction, Operation, and Siting

Industrial waste disposal wells are designed and constructed in a variety of widths, depths, and configurations. The following "wells" which formerly received industrial wastes in California demonstrate the variability of industrial disposal wells with regard to construction and design:

- a buried 55 gallon drum (flush with land surface) with no ends;
- an uncased 22 ft deep borehole backfilled with porcelain from a foundry on site;
- a 17 ft deep brick lined cistern backfilled with gravel and designed to receive septic tank effluent;
- a slotted 4-inch diameter PVC pipe leach line designed to receive septic tank effluent; and
- an abandoned cased water well penetrating deep water bearing zones.

Tables 1, 2, and 3 listed in Appendix E describe the well construction features for a wider variety of wells in California.

According to the report submitted for New York, it was discovered that the terms "dry well," "leach pit," and "cesspool" often are used interchangeably and given different meanings. For example, cesspools designed for the disposal of sanitary wastes generally are constructed of buried concrete rings stacked on top of each other. The bottoms are sand or gravel. However, cesspools with this construction often are used for the disposal of wastewaters other than sanitary waste. Furthermore, the cesspools may or may not have a manhole cover to provide access.

The New York report continues to note that "dry wells" are similar in construction to cesspools and often are considered to be cesspools. A dry well has an open bottom, according to that report, and receives only liquid wastes such as the effluent from a septic tank or series of settling ponds. The effluent percolates into the subsurface depending on the soil permeabilities. The theory behind using "dry wells" is to "filter" the effluent through earth materials in the unsaturated zone so that the liquid is relatively clear when it reaches the

water table. The report further states the "practical effectiveness of this type of system depends on the attenuative characteristics of the soil and the volume and quality of wastewater."

One type of dry well that is potentially very hazardous, according to the Wyoming report, is the floor drain in a commercial or industrial facility which discharges to an open or damaged sump. These commonly are found at service stations and other facilities that perform vehicle maintenance or repair. Highly toxic compounds and heavy metals are likely to be contributed to the ground-water system. Because the usual location of such wells is in populated areas which frequently are not served by sewers or water districts, many nearby residents may obtain their water supplies from wells susceptible to contamination.

Some "injection wells" were constructed by excavating pits with a backhoe and backfilling them with gravel. No access is possible for these wells, and accurate records are not always available; thus, the dimensions of these "wells" could not always be determined.

Other types of construction also were found. Some wells were constructed of masonry. One well was found which consisted of an abandoned boxcar buried on end. Many sites were found to have leach fields and other waste disposal systems.

Industrial waste disposal wells generally do not use pressurized injection; industrial wastes are drained into these wells by gravity flow. Total depth is generally as shallow as practicable to provide discharge into a permeable zone. The injection zone is often above sensitive aquifers. The wells are typically sited in unsewered areas with commercial or industrial development. No State reports indicated injection into exempted aquifers.

Because of the nature of the siting and construction characteristics inherent to industrial disposal wells, unreported wells are likely to go unnoticed. Inspectors can easily overlook industrial disposal wells if casing does not rise above land surface.

Injected Fluids and Injection Zone Interactions

Injected Fluids. Industrial process water and waste disposal wells could potentially receive any fluid disposed by the various industries which use the wells. In New York, many industrial facilities are permitted to discharge wastes to the subsurface where all underlying aquifers are classified as sole source aquifers. Periodic monitoring of injection fluids from various industrial facilities is required for compliance with State Pollutant Discharge Elimination System permits. Monitored parameters, [illegible]

levels, are stored on a Permit Compliance System (PCS). The PCS data include facilities which are permitted and required to monitor specific parameters. However, some permitted facilities have not reported monitoring information.

For the purposes of this report, a copy of the PCS data, entitled, "Limits and Measurements Data for Nassau and Suffolk Facilities Discharging to Ground Water," was supplied to Engineering Enterprises, Inc. (EEI) by USEPA Region II. The data were stored in the EEI computer system in a format which allowed calculations and interpretations to be made. Calculation of "mass loading of contaminants per unit time" was one of the objectives of the study.

These PCS data included information on only those facilities which provided monitoring information. It should be noted that approximately 62 facilities are discharging wastewater from various sources including process waste, sanitary waste, non-contact cooling water, wastewater treatment plant effluent, etc.

In Nassau and Suffolk Counties, an average of 20 million gallons per day (MGD) of wastewater is injected into the subsurface by facilities listed on the PCS. Maximum volumes total nearly 21 MGD. Based on these volumes, calculations suggest that more than 190 grams of total dissolved solids (TDS) are entering the subsurface each second (190 g/sec). Converted to more familiar units, these data indicate that approximately 0.42 pounds of TDS are entering the subsurface each second, or 36 thousand pounds per day!

As illustrated in Figure 4-44, several inorganic contaminants are being injected into the subsurface. Injection rates range from 390 mg/sec of fluoride to as much as 5,900 mg/sec of nitrogen. Mass loadings per unit time for total sulfate and chloride fall in the intermediate range. It is not possible to calculate mass loadings for sulfide and sulfite due to lack of information on discharge rates.

Many EPA priority pollutants (heavy metals) and hazardous constituents identified by RCRA are being injected into the subsurface at a rate of nearly 120 mg/sec (Figures 4-45 and 4-46). Notable contaminant discharge rates include copper (125 mg/sec), iron (128 mg/sec) and nickel (151 mg/sec).

Hazardous organic constituents are injected into the subsurface at rates ranging from 4×10^{-6} mg/sec (xylene) to 680 mg/sec (1,1,1-Trichloroethane). (See Figure 4-47.) Discharge of additional hazardous organic elements has been permitted. Those elements include benzene, methylethyl ketone, trichloroethylene, tetrachloroethylene, trichlorofluoromethane, 1,1-dichloroethane, 1,2-transdichloroethylene, and vinyl chloride. It is not possible to calculate mass loadings per unit time for these

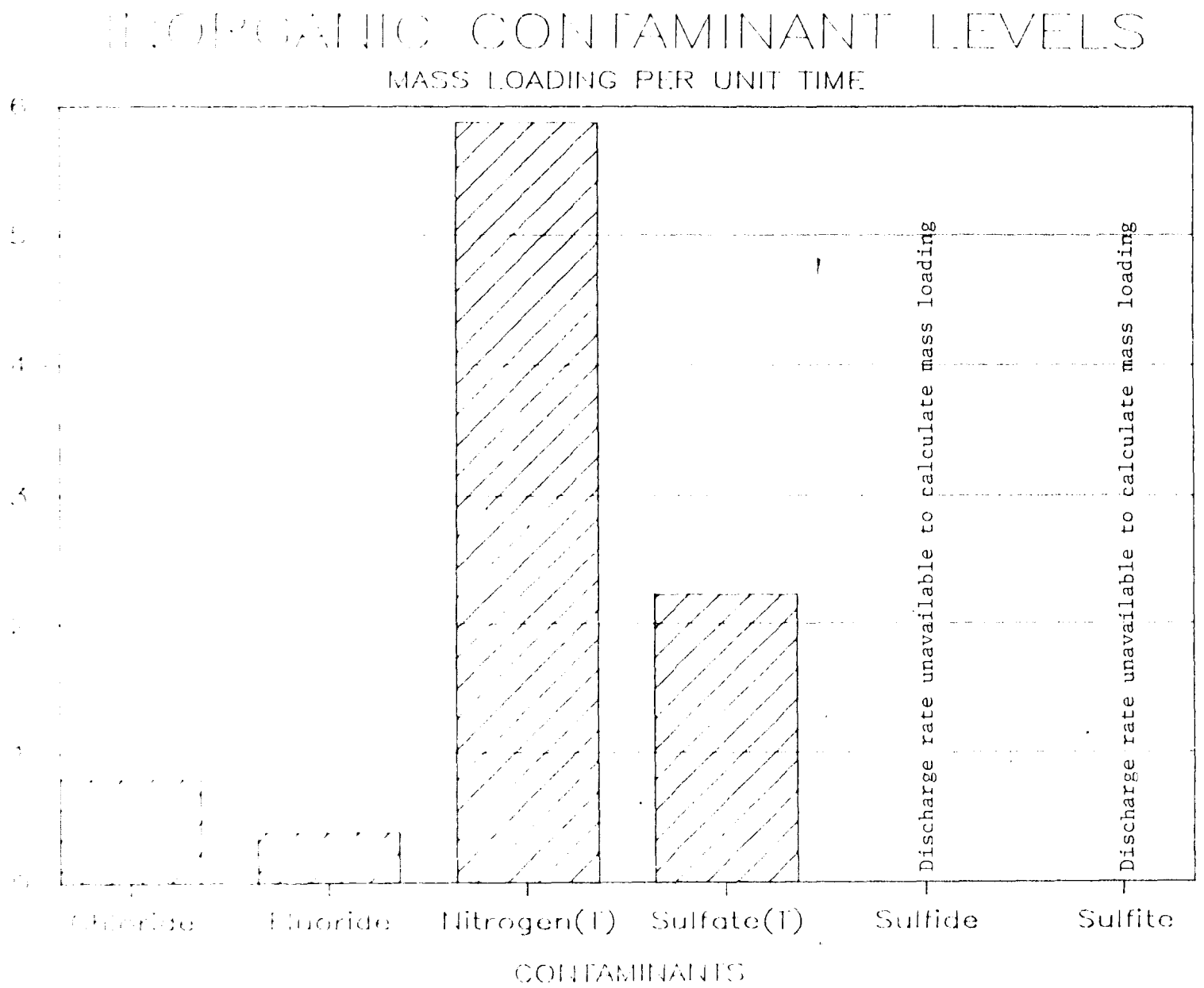


Figure 4-44. Mass loading of inorganic contaminants due to subsurface injection of industrial waste in Nassau and Suffolk Counties, New York (based on PCS data of the SPDES program).

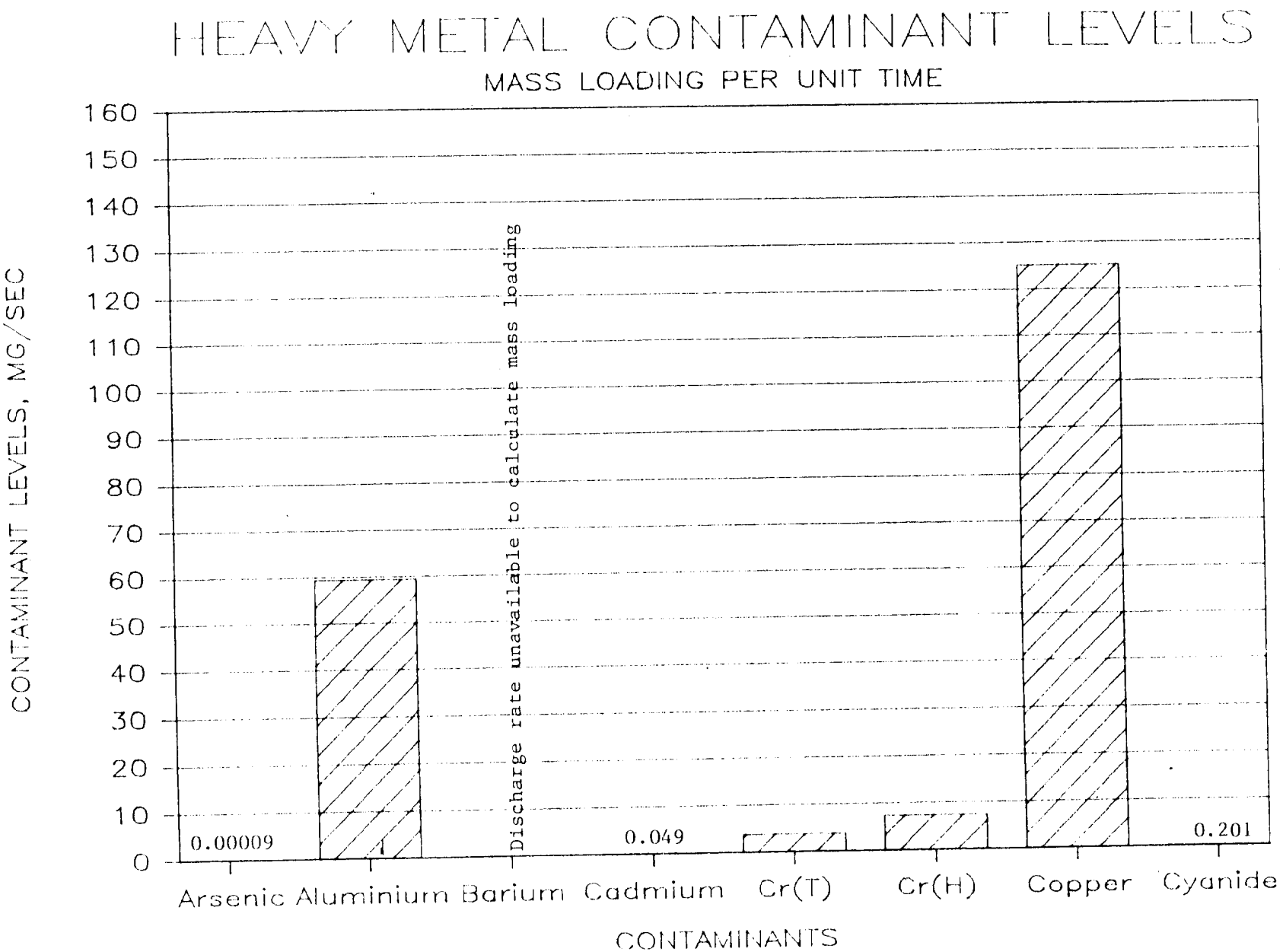


Figure 4-45. Mass loading of some heavy metal contaminants due to subsurface injection of industrial waste in Nassau and Suffolk Counties, New York (based on PCS data of the SPDES Program).

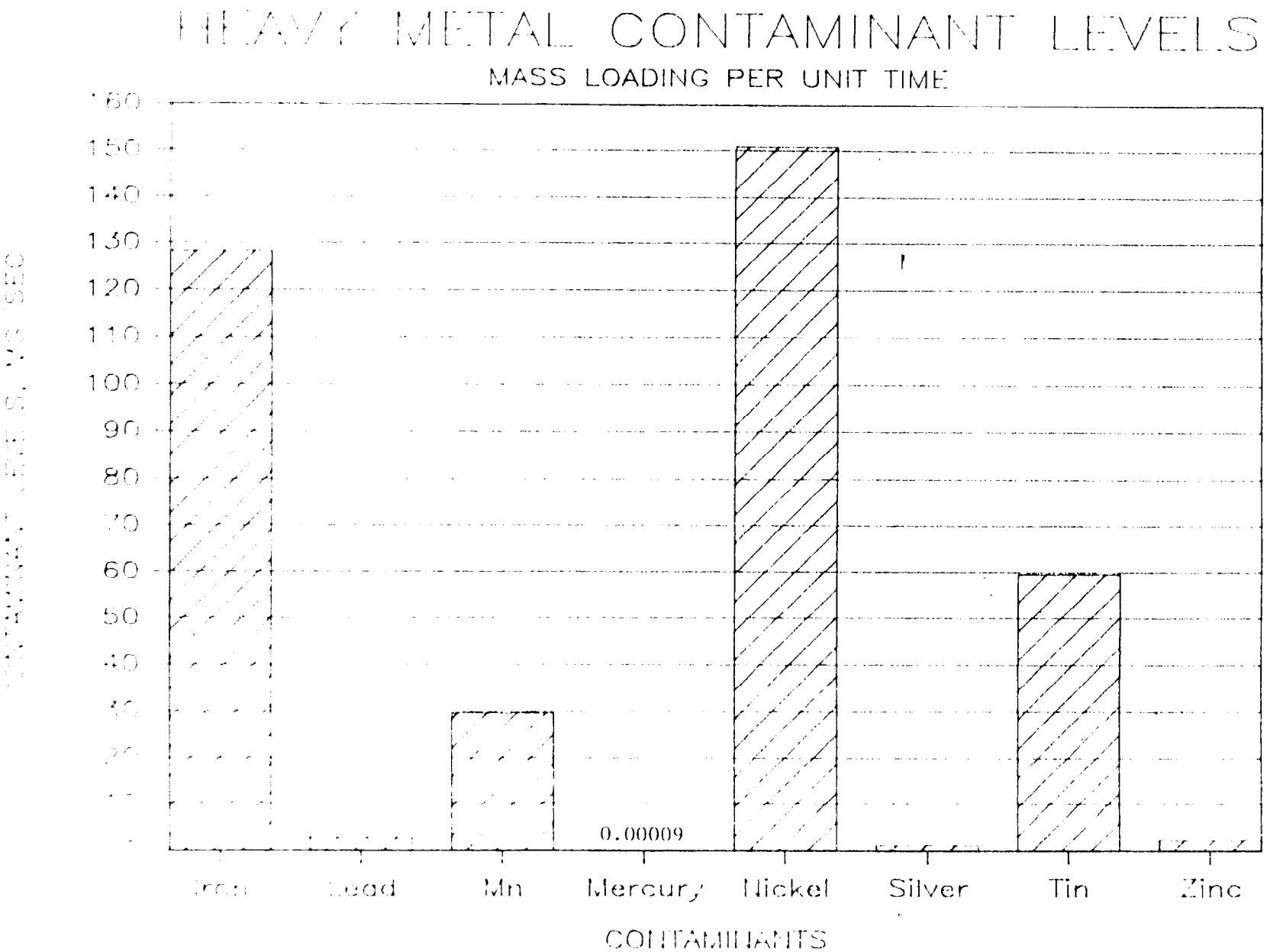


Figure 4-46. Mass loading of additional heavy metals contaminants due to subsurface injection of industrial waste in Nassau and Suffolk Counties, New York (based on PCS data of the SPDES Program).

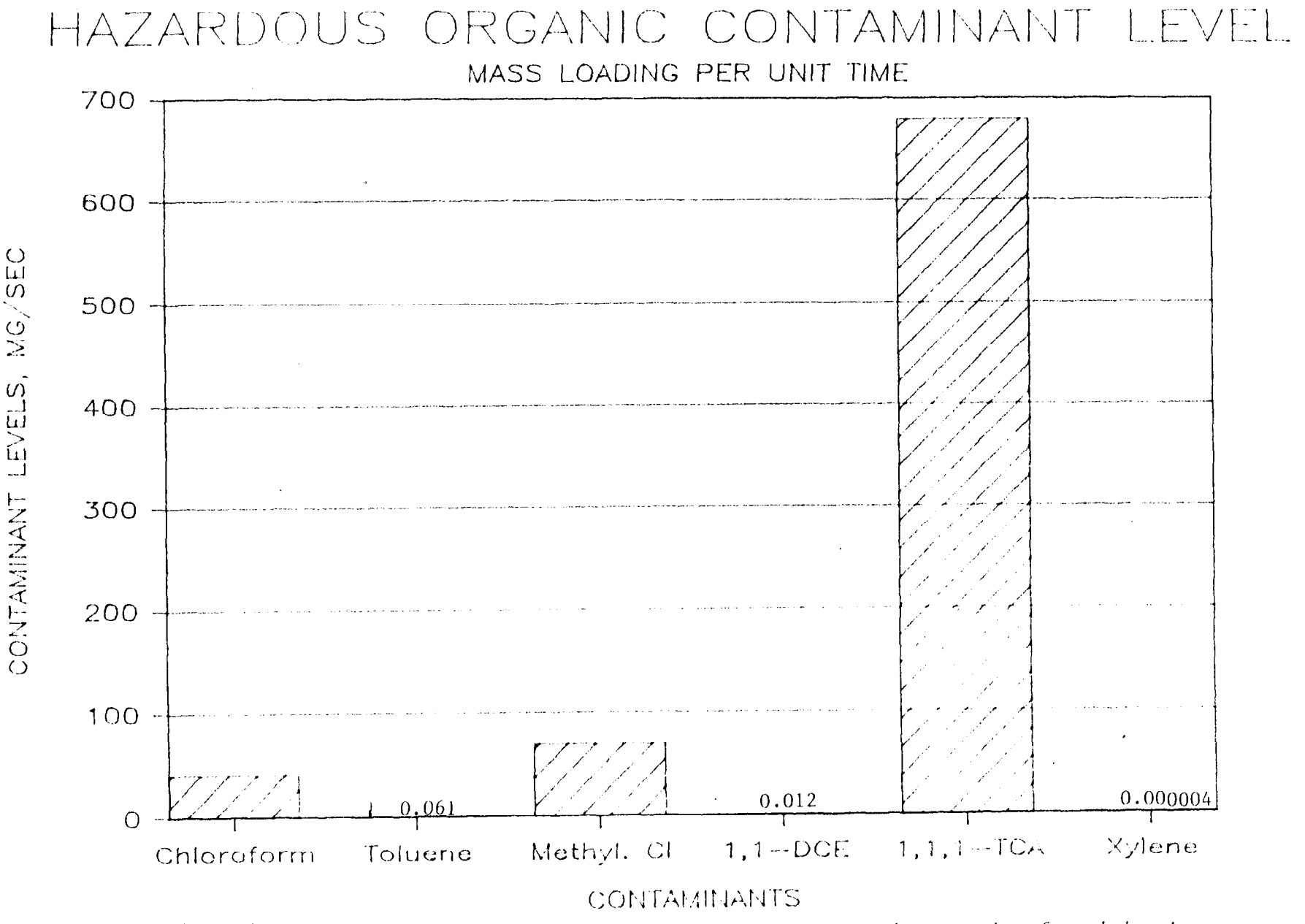


Figure 4-47. Mass loading of hazardous organic contaminants due to subsurface injection of industrial waste in Nassau and Suffolk Counties, New York (based on PCS data of the SPDES program).

contaminants because the permitted facilities did not provide discharge rates.

Some acids and related contaminants are discharged at a rate slightly below 22 mg/sec, as illustrated in Figure 4-48. Figure 4-49 indicates that other organic constituents are injected at rates ranging from 0.3 mg/sec to just under 200 mg/sec. Other biological and microbiological indicators, including carbonaceous biological oxygen demand (BOD(c)), chemical oxygen demand (COD), and carbonaceous oxygen demand (OD(c)), are injected at rates below 1,200 mg/sec. Coliform is injected at 130,000 #/sec (Figure 4-50).

In conclusion, many facilities in Nassau and Suffolk Counties are permitted to discharge as many as 65 organic and inorganic constituents to the subsurface. In some cases, fluids containing contaminant levels which exceed drinking water standards are injected. In other cases, fluids containing contaminant levels which are below drinking water standards are injected in excessive volumes (average 20 million gallons per day). These fluids typically percolate through the vadose zone to the water table. Some contaminants in the waste fluids may be attenuated by the vadose zone due to various physical, chemical, and biological processes. Nevertheless, contaminants have the potential to degrade ground water-quality. Contamination potential depends on volume, persistence, mobility, and toxicity of the injected constituents.

Although the information provided by New York was the most specific with respect to injectate quality, several other States provided general information on the composition of injected waste streams. For example, the California report identified waste streams which included waste laboratory chemicals, petroleum products, pesticides, pesticide and defoliant rinse waters, degreasing solvents, and industrial process chemicals. These wastes typically contain one or more of the compounds listed under 40 CFR Part 261 Subpart D (RCRA regulations). Further investigations should be conducted to determine whether these are Class IV facilities.

Alabama also provided data on the constituents of waste streams from various facilities. Tables 4-48 through 4-50 list a few of the substances identified.

It should be noted here that some wells which are classified as industrial disposal wells also may contain sanitary wastes which vary greatly depending on their origin. As discussed earlier, many facilities utilize septic systems to dispose of their industrial wastes. Sanitary wastes from those facilities are likely to be mixed in the waste stream. Section 4.2.1.2 discusses the characteristics of injected fluids discharged to septic systems.

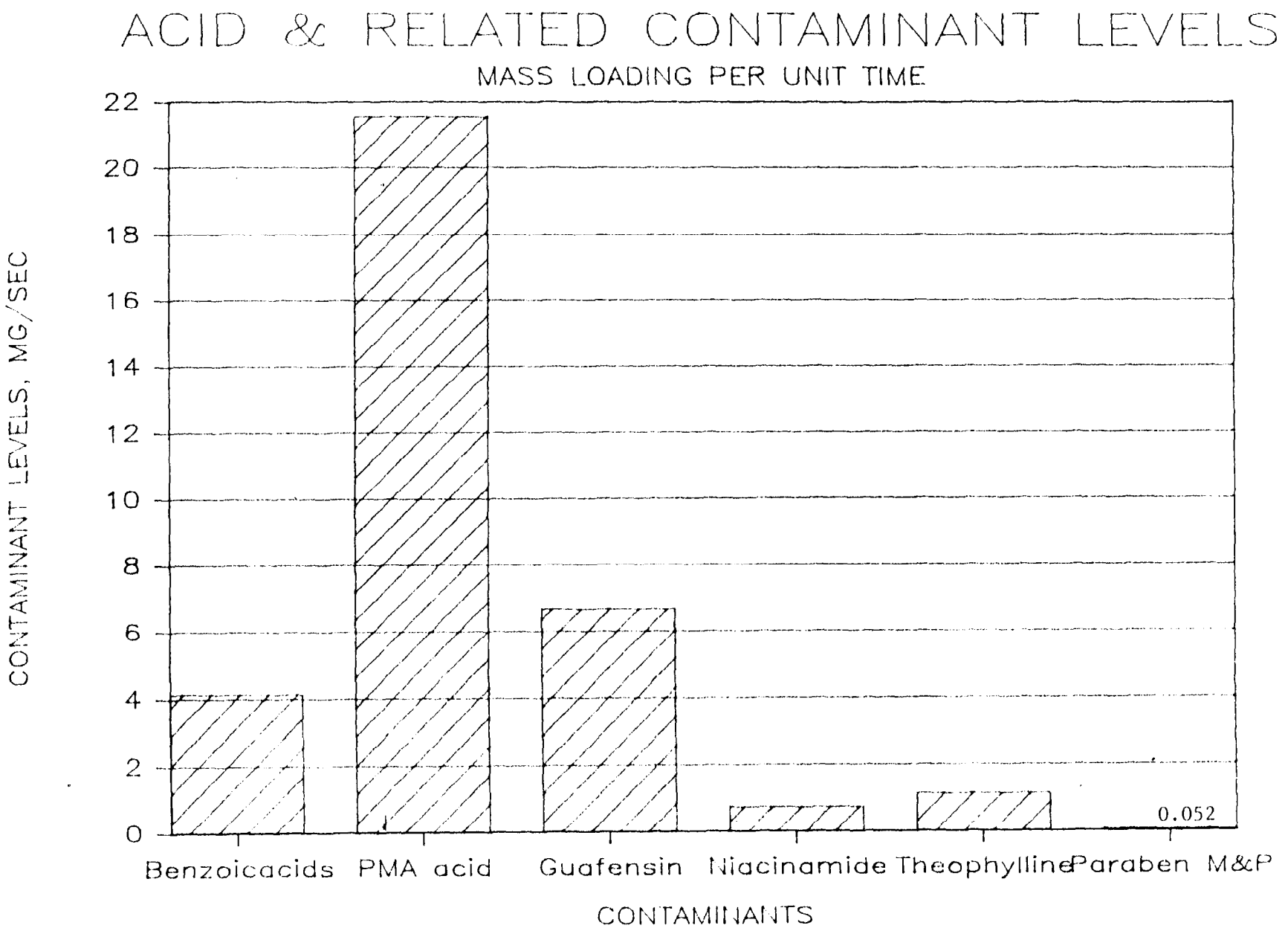


Figure 4-48 . Mass loading of acid and related contaminants due to subsurface injection of industrial waste in Nassau and Suffolk Counties, New York (based on PCS data of the SPDES Program).

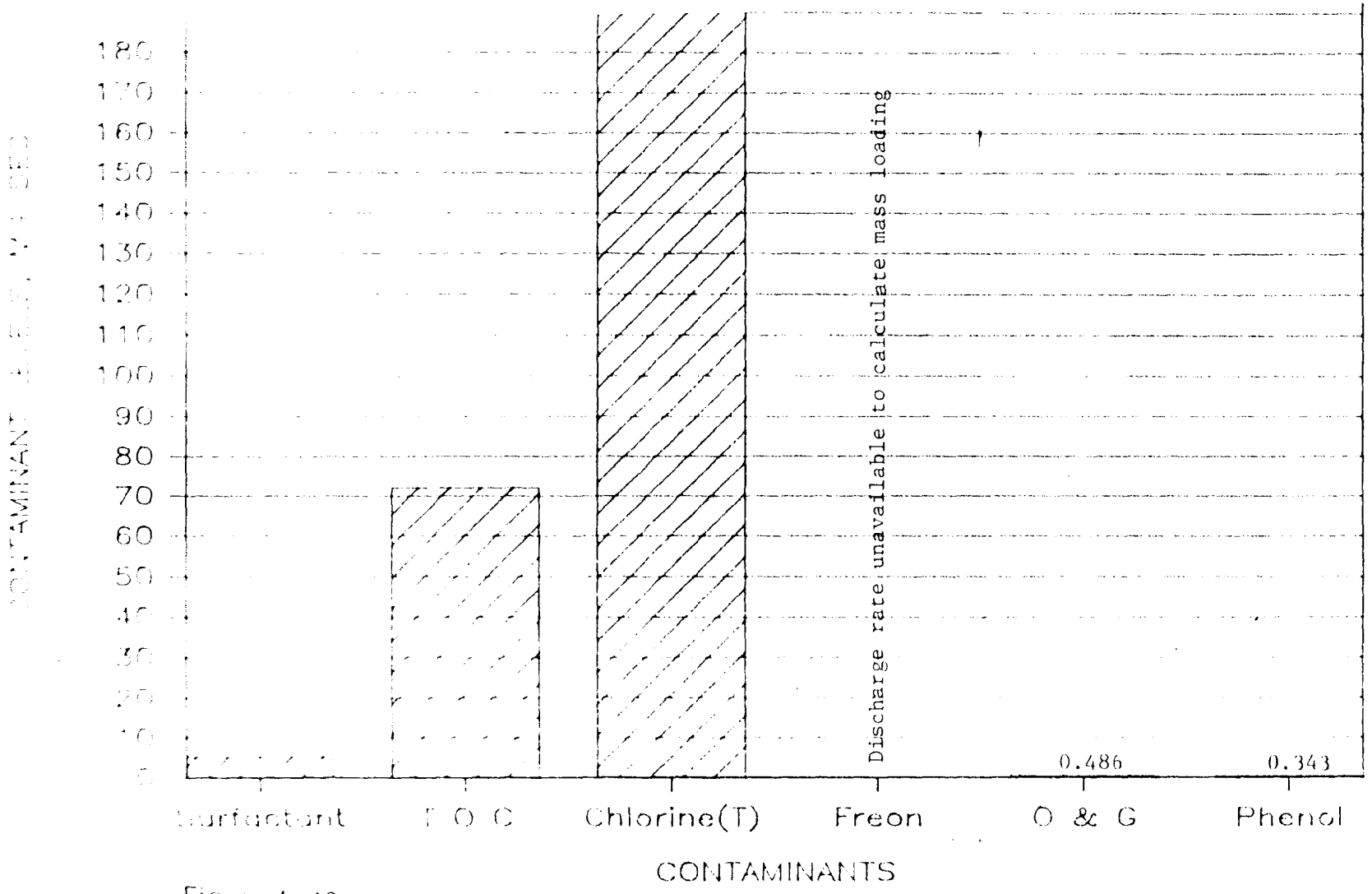


Figure 4-49. Mass loading of other organic contaminants due to subsurface injection of industrial waste in Nassau and Suffolk Counties, New York (based on PCS data of the SPDES Program).

MICROBIOLOGICAL CONTAMINANT LEVELS

MASS LOADING PER UNIT TIME

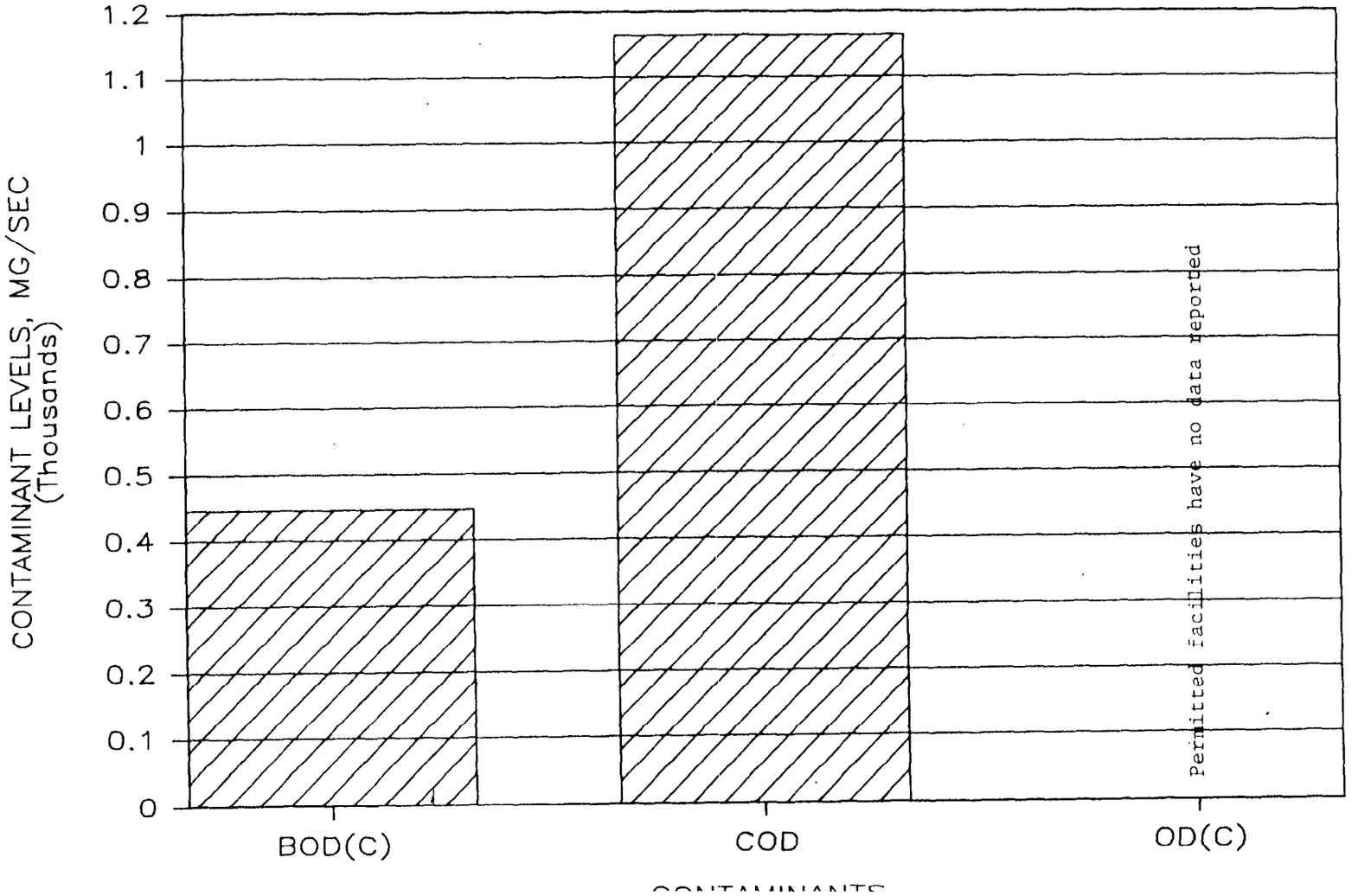


TABLE 4-48

FORMALDEHYDE DATA

Embalming Process Sample	
Lavender Funeral Home	195 mg/l
Rocko Funeral Home	750 mg/l
Septic Tank Sample	
O'Bryant Chapel	< .1 mg/l
Williams Funeral Home	.15 mg/l
Nichols Funeral Home	2.4 mg/l

TABLE 4-49

TYPICAL LAUNDERETTE WASTE

Substance	Range (mg/l)		
	Minimum	Average	Maximum
ABS	3.0	44.0	126.0
Suspended Solids	15.0	173.0	784.0
Dissolved Solids	104.0	812.0	2,064.0
COD	65.0	447.0	1,405.0
Alkalinity	61.0	182.0	398.0
Chlorides	52.0	57.0	185.0
Phosphates	1.4	148.0	430.0
pH	5.1	-	10.0
Nitrates	-	< 1.0	-
Free Ammonia	-	3.0	-
Sulfates	-	200.0	-

TABLE 4-50

TYPICAL POLLUTANT CONCENTRATIONS IN WASTEWATER
FROM SELF-SERVICE AUTO WASHES
(10 MONTH PERIOD)

Substance	Range (mg/l)		
	Minimum	Average	Maximum
Total Solids	729	2,[illegible]	3,334
Total Volatile Solids	207	455	871
Suspended Solids	95	[illegible]	840
Volatile Suspended Solids	25	[illegible]	11[illegible]
BOD (5)	15	[illegible]	166
Oil and Grease	38	[illegible]	2[illegible]

As stated previously, it is difficult to generalize about the quality of fluids injected into an industrial process water and waste disposal well. Fluid qualities vary with industrial processes. It is important to emphasize, however, that industrial wastes may contain "hazardous" constituents.

Injection Zone Interactions. Limited data are available concerning the interaction between industrial waste effluent and injection zones. More research is needed to determine the effects of the waste stream, particularly on the unsaturated zone. A study by Wilson (1983) indicated that very little attenuation of common organics and heavy metals occurs in the vadose zone during lateral migration. Due to design limitations, little data on attenuation during vertical migration were obtained during Wilson's study. It should be noted that the Wilson study dealt with concentrations expected in urban storm water runoff and not those expected from disposal of industrial wastes. Some of the constituents which made up the waste streams, however, were similar to those identified in several industrial facilities.

On a positive note, according to Wyoming, removal of contaminants may occur as a result of settling of solids, filtration, dilution, and chemical reactions in the saturated zone. However, if a perched water table is created, lateral flow of contaminants may increase. Metals and organics appear to be attenuated less by saturated lateral flow, the report notes, than do microorganisms.

In summary, interactions between injection zones and industrial waste effluent probably result from processes similar to those which occur in other well types. Chemical incompatibility between injected fluids and fluids inherent to the injection zones are likely to result in precipitation or dissolution of various minerals based on characteristics such as temperature, pressure, and pH. Injection of low quality fluids with respect to quality of the ground water may result in degradation of the ground water depending on volumes, rates, and constituents of the injected fluids.

Hydrogeology and Water Usage

Site specific hydrogeologic factors strongly influence the contamination potential posed to USDW by industrial waste disposal practices. Industrial disposal wells typically inject wastes above or into USDW. Hydrogeologic factors which significantly influence the contamination potential of industrial disposal wells include:

1. thickness of the vadose zone below the injection well;

2. physical and chemical properties of vadose zone sediments below the injection well; and

3. presence/absence of confining layers (aquicludes).

Thick vadose zones provide an increased sorptive surface area for dissolved industrial waste contaminants. As noted before, little research has been performed to determine the extent of adsorption/absorption processes which actually occur between wastewater contaminants and vadose zone sediments.

The permeability of vadose zone sediments is a second significant hydrogeologic determinant. Laterally continuous, low permeability silt or clay layers generally act as confining beds. Such strata existing above or below the injection zone can effectively restrict the migration of waste effluent to other zones which may contain drinking water.

Hydrogeologic factors contributed considerably to ground-water contamination at two facilities (reviewed for this report) where contamination was caused, in part, by industrial waste disposal wells. Industrial disposal wells at the Thompson Hayward Agricultural and Nutrition Company (THAN) in Bakersfield, California and at Mefford Field in Tulare, California were completed above shallow ground-water tables. Piezometric elevations reported at each site were less than 25 feet below land surface. Silty to coarse alluvium sands also were reported to comprise the vadose zones below each facility.

Industrial disposal wells described within each of the industrial disposal well case studies (Appendix E) injected waste waters above or into USDW. In two site studies, domestic water wells were located within 1/2 mile of the disposal wells. Domestic water wells downgradient of the THAN site in Fresno, California have been contaminated from disposal well operations at the facility (Kleinfelder and Associates, 1983). Water wells also have been contaminated from past operations of industrial disposal wells (septic tanks with wells) located in the eastern half of the San Fernando Valley (L.A. Department of Water and Power, 1983).

Industrial disposal wells in Arizona at both UniDynamics and Motorola Inc., 52nd Street Facility, were completed above shallow ground-water tables. Piezometric elevations at both sites were less than 100 feet below land surface. Permeable alluvial sands also were reported to comprise the vadose zones below each facility. (Ecology and Environment Inc., 1986; Gutierrez-Palmenberg, Inc., 1983). Groundwater contamination on-site has been documented downgradient of the wells at Unidynamics.

Some active industrial disposal wells reported in Arizona overlie the Salt River Valley. Aquifers in the valley are used for irrigation and public water supply (USGS, 1983). Waters tapped by municipal water purveyors are generally greater than 300 feet below land surface.

As illustrated by the case studies previously described, the usual location of industrial waste disposal wells is in populated areas which are frequently not served by sewers or local water districts. Many nearby residents may obtain their water supplies from shallow wells completed in aquifers which produce ground water that is susceptible to contamination.

Contamination Potential

Based on the rating system described in Section 4.1, industrial process water and waste disposal wells are assessed to pose a high potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Fluids may exhibit characteristics or contain constituents listed as hazardous as stated in the RCRA Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the Primary or Secondary Drinking Water Regulation parameters in ground water, or endanger human health or the environment beyond the facility perimeter or in a region studied on a group/area basis.

It is difficult to define "typical" scenarios for the criteria listed in the rating system because the industrial disposal well category is so diverse. In order to fairly assess the wells, they must be judged on a site specific basis. However, for the purposes of this study, the interest of groundwater protection mandates that worst-case scenarios are more heavily weighted.

As stated earlier, industrial disposal wells are likely to be located in populated areas which are frequently not served by sewer systems or water districts. Therefore, nearby residents may obtain their water supplies from wells. It is presumed that these wells produce water which meets drinking water quality standards. In other words, the ground water inherent to the injection zone is likely to belong to Class I or Class II of the Groundwater Classification System.

It is difficult to identify "typical" construction, operation, and maintenance features; therefore, worst-case

scenarios will be applied to this section of the rating system. In many cases previously described, wells showed no signs of casing, cement, tubing, packers, or wellhead assemblies. Furthermore, injection pressures, rates, and volumes "typically" are not monitored. The injected fluids are likely not to be analyzed, and many facilities are believed to be operating without permits. Under present operational procedures, there is a great potential for abuse, as illustrated by the case studies from Pennsylvania (Appendix E). Programs established to conduct mechanical integrity tests and to properly plug and abandon wells are rare. Based on these criteria, it is reasonable to assume that typical well construction, operation, and maintenance practices will allow injection or fluid migration into USDW.

Contaminants identified in wastewaters discharged to industrial disposal wells are numerous and site specific. Nevertheless, many waste streams may contain contaminants which are defined as "hazardous" per 40 CFR Part 261, Subparts C and D. Detailed investigation is needed to determine whether these wastes actually meet the "hazardous" criteria. Contaminants detected in some waste streams include TCE, xylene, benzene, and various pesticides, to name just a few.

Identifying injection volumes and rates is probably the most difficult parameter for which to determine a "typical" scenario. The reader is referred to the case studies (list provided in Appendix E) for evidence that injection of industrial wastes frequently occurs in sufficient volume or at a sufficient rate to cause an increase in concentration (above background levels) of the National Primarey or Secondary Drinking Water Regulation parameters in groundwater, or endanger human health or the environment either (a) beyond a facility's perimeter, or (b) in a region studied on a group/area basis.

Current Regulatory Approach

Industrial waste disposal wells are authorized by rule under Federally-administered UIC programs. Several available case studies suggest that 40 CFR 144.12 is possibly being violated. These requirements state:

> No owner or operator shall construct, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR Part 142 or may otherwise adversely affect the health of persons.

Unfortunately, many agenices with the authority to regulate these systems are under-staffed and are not able to inspect all systems, according to Utah. Limited State and local government resources make it easy for an operator to modify portions of his wastewater system (without being detected) to discharge to dry wells instead of to a municipal sewer. In States where well manufacturers and installers currently are unregulated and have no obligation to report their installations to local and State authorities, primary construction of facilities with industrial disposal wells may go unnoticed.

Furthermore, proving that injected waste is "hazardous" as described in 40 CFR 261 Subparts C and D is very difficult. Until these facilities can be proven to inject "hazardous" waste or are proven to be sources of contamination or to adversely affect public health, they may be classified as Class V wells.

Some questions have been raised concerning whether the RCRA program or the UIC program maintains jurisdiction over certain Class V wells when potentially "hazardous" wastes are involved. This problem is prevalent in regulating septic systems that receive industrial waste or toxic household waste. The following paragraphs summarize the RCRA regulations regarding household wastes and conditionally exempt small quantity generator (SQG) wastes. The information is excerpted from personal correspondence with the USEPA and indicates that the UIC program clearly maintains control over authorization of this type of injection well.

> Household wastes are defined in 40 CFR Part 261.4(b)(1) as "any material (including garbage, trash and sanitary wastes in septic tanks) derived from households (including single and multiple residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds, and day use recreation areas). It is conceivable that household wastes could contain toxic chemicals. Yet, under Part 261.4(b), these wastes are not considered RCRA hazardous wastes. Therefore, wells injecting household wastes for disposal purposes would fall under the Class V category rather than the Class IV category, even though these wastes may contain toxic chemicals.
>
> Small quantity generators of less than 100 kilograms per month are exempt from full RCRA regulations, under Part 261.5(g), provided that certain conditions are met. If the generator does meet the conditions, hazardous wastes may either be treated or disposed of in an on-site facility or an off-site storage, treatment, or disposal facility which is either:

1. permitted under Part 270; or

2. in interim status under Parts 270 and 265; or

3. authorized to manage hazardous waste by a State with a hazardous waste management program approved under Part 271; or

4. permitted, licensed, or registered by a State to manage municipal or industrial solid waste; or

5. a recycling or reclamation facility.

Thus, a Class V well that has been permitted, licensed, or registered as a facility by a State may inject RCRA hazardous wastes produced by conditionally exempt small quantity generators of less than 100 kilograms per month. In situations where this occurs, the well must be reclassified as Class IV. Since Class IV wells are prohibited, under 40 CFR 144.13, the well then must be properly plugged and abandoned in accordance with the requirements of Parts 144.14 and 144.23.

Several States implement stringent requirements for industrial process water and waste disposal wells. Table 4-47 indicates the regulatory systems described in each State report. Unfortunately, specific regulatory information provided in the State reports usually was very general or non-existent.

States with primacy approach the regulation of industrial waste disposal wells in many different ways. Some States require a permit prior to construction or operation while others authorize by rule. At least sixteen States have some type of permitting program in place which mandates a permit for the operation of industrial disposal wells. Some of these programs are conditional and require permits for injections in excess of set volumes or for certain system designs. Texas regulates industrial disposal wells as Class I injection wells. While regulations are diverse throughout States with primacy, most State reports recommend permitting systems which set minimum construction standards and monitoring requirements. In a few States, permitting systems and monitoring programs are part of the current regulatory program.

Several States quote applicable State regulations which, summarized, prohibit the injection of wastes which will degrade ground water. Examples include Indiana and North Carolina. Some States require general permits for operation of any type of injection well. Because the waste streams often contain potentially hazardous constituents, however, the trend in many States

seems to be moving toward individually permitting industrial disposal wells. States with individual permitting programs include New Jersey, Wisconsin, Alabama, Maryland, and Oregon. The regulatory systems of New Jersey, New York, and California are described in greater detail in the following paragraphs. These three systems were used as examples because information concerning the systems was readily available.

New Jersey. The following information is a direct excerpt from the New Jersey State Pollution Discharge Elimination System (NJSPDES) permit application package.

ADDITIONAL GENERAL CONDITIONS FOR INDUSTRIAL/COMMERCIAL DISCHARGES BY SUBSURFACE DISPOSAL

A. Monitoring Requirements

1. Flow measuring device(s) shall be installed in the waste stream(s) prior to discharge to the subsurface system such that the total daily flow can be measured on a continuous basis.

2. Flow shall be recorded and reported to the Department as required in the discharge monitoring requirements of this permit.

B. Maintenance Requirements

1. Septic Tanks

Septic tanks, if utilized, shall be inspected on at least a semi-annual basis to determine the level of sludge that has accumulated. When the level of the sludge reaches one-quarter (1/4) of the capacity of any septic tank within a single system, all tanks within that system shall be pumped.

The permittee shall also conduct an inspection of the following appurtenances on at least an annual basis:

Appurtenance	Inspection
Septic Tanks	Leaks, Baffle Corrosion
Conveyance Piping*	Leaks, Solids Accumulation Grade
Distribution Box	Leaks, Solids Accumulation Elevation

*Internal inspection to be performed only if readily accessable: otherwise inspection only for surface evidence of system failure.

The permittee shall maintain a record of all inspections performed and shall make the record of the inspections available to the Department upon request.

Prior to pumping any septic tank, the permittee shall arrange at his/her own expense for an EP Toxicity Test (or other such test as the Department may currently require to be performed on the sludge content. The results of the EP Toxicity Test (or other such test as the Department may currently require) shall be forwarded to the Bureau of Hazardous Waste Manifest and Classification of the Division of Waste Management for classification.

a. If the classification of the sludge is other than I.D. 73, appropriate disposal and any necessary manifesting and all applicable Waste Flow Rules shall be followed pursuant to the rules, regulations and requirements of the Division of Waste Management.

b. If the classification of the sludge is I.D. 73, the septic tank pumpings shall be disposed of pursuant to Section 18 (Residuals Management) of the General Conditions for all NJPDES Permits unless adopted Waste Flow Rules require otherwise.

2. Subsurface Disposal Area

a. The immediate and surrounding area of the subsurface disposal area shall be inspected on at least a monthly basis for evidence of malfunctioning. Said evidence shall include, but shall not be limited to breakout, ponding, wet areas, odors and an overabundance or loss of vegetative cover. A record of these inspections shall be maintained by the permittee and shall be made available to the Department upon request.

b. At the first indication of malfunctioning, the owner shall notify the Department pursuant to Section 14 (Reporting Noncompliance) in the General Conditions for All NJPDES Discharge Permits.

C. Operation Restrictions

1. The permittee shall comply with all provisions of Section 5.9, Additional Conditions Applicable to all UIC Permits, of the NJPDES regulations. N.J.A.C. 7:14A-1 et seo.

2. The operation of a subsurface disposal system shall at no time create an unpermitted discharge to any surface water of the State or a persistent standing, ponded, or flowing fluid condition.

3. When the Department has reason to believe that contamination of the ground waters is being caused by this facility, remedial measures shall be required to determine the extent of the suspected contamination and/or to correct the contaminated conditions. The remedial measures shall include, but shall not be restricted to, the installation of ground water monitoring wells, modification(s) of the treatment system (if any), installation of a treatment system and/or reduction of cessation or the discharge.

New York. In New York, the Department of Environmental Conservation (NYDEC) regulates the discharge of pollutants to both surface water and ground water under the State Pollutants Discharge Elimination System (SPDES) program. The SPDES program is operated based on the provision under Article 12 of NYDEC and the authority of the Federal Water Pollution Control Act. All facilities that discharge more than 1,000 gallons per day of wastewater to the subsurface are permitted through this program. The following discussion of the program concerns discharge to both the surface and subsurface.

The NYDEC has nine regional headquarters and several suboffices. The Division of Water at the Central office of the NYDEC in Albany, NY, coordinates all efforts through the regional headquarters. The regional headquarters, in turn, delegate responsibilities to respective suboffices and counties on a regional basis. The Division of Water of the central office issues Technical and Operational Guidance Service (TOGS) to establish priorities and procedures for the SPDES program.

According to TOGS (1985), the SPDES permitting is divided into two classes: Significant Permit Classes, and Non-Significant Classes.

Significant permit classes consist of all USEPA designated major* permits (NPDES Program?), plus the following non-major permits:

1. Municipal

2. Toxic Industrial

3. Non-Toxic Industrial

4. Private, Commercial and Institutional (PCI) (Regional Concern)

Non-Significant Classes consist of non-major PCI and other industrial permits less those designated for inclusion in the significant class under subpart 2, 3, and 4 above.

* (Most USEPA major permits in Long Island discharge to surface water.)

The regional offices have the authority to process all first time applications and issue permits complete with expiration date regardless of class. The permits are then classified as significant or non-significant based on certain guidelines. The potential for the discharge to create serious nuisance conditions, impact on water supply or bathing areas, and intense public concern are some items considered in this evaluation.

The Bureau of Wastewater Facilities Design (BWFD) sends renewal notices to dischargers in the significant class. The regional permit administrator, in turn, processes the applications and reissues permits as applicable. The BWFD sends renewal notices, also, to dischargers in the non-significant classes. However, the Bureau extends such permits indefinitely under the provision of the state administrative procedures. In any case, the permitees in the non-significant classes are required to monitor discharges as necessary and retain the analytical results for inspection by the Department or its designated agent.

The overall goal of the SPDES is to reduce severe contamination potential by closely monitoring all significant discharges while ensuring compliance of all nonsignificant permits by spot inspections. All monitoring data for significant classes are stored in the NYSEC's Permit Compliance System (PCS) data storage. Appropriate actions are taken on those facilities that discharge wastewater in excess of the water quality

regulations as specified in Title 6, Chapter X, Parts 700 - 705 of the New York State Codes, Rules and Regulations, (NYDEC, 1986). Most of the above discussion is based on TOGS (1985) reporting by the Division of Water of the NYDEC.

It is not clear whether other States have State regulatory systems similar to those of New York and New Jersey, but programs such as these are beneficial to the protection of ground water.

California. Little or no information is available in most State reports on local jurisdiction. The following excerpt is from the California report and illustrates how local agencies may be responsible for regulating industrial disposal wells.

> Class V industrial waste disposal wells (5W20) operating in California are regulated under the California State Health and Safety Code and the California State Water Code. Each code grants specific enforcement powers and responsibilities to two environmental regulatory branches:
>
> - the Department of Health Services
> - the State Water Resources Control Board and its nine Regional Water Quality Control Boards.
>
> The Department of Health Services (DOHS) and a California Regional Water Quality Control Board often coordinate actions at sites where regulatory jurisdictions overlap. This, however, is not true in all cases.
>
> Class V industrial waste disposal wells are regulated differently according to the type of wastes they dispose. Wells found to dispose of waste waters containing hazardous wastes (as defined in the State of California Health and Safety Code Chapter 6) are subject to stricter regulations recently passed under California Assembly Bill No. 2058. (The California Health and Safety Code was amended to contain the provisions of this bill in 1985.)
>
> Provisions under the bill prohibit:
>
>> any person on or after January 1, 1986, from discharging hazardous waste into an injection well which commenced operation on or after January 1, 1986, and prohibits such a discharge after January 1, 1988, into an injection well which commenced operation before January 1, 1986, unless the person has received a hazardous waste facilities permit for the well, the well is not within 1/2 mile of drinking water, and the injection well

> does not discharge hazardous waste into or above a specified formation, unless granted an exemption by the department (DOHS) pursuant to a specified procedure. (California AB 2058, 1985)

The bill also prohibits the DOHS from issuing a hazardous waste facilities permit unless a hydrogeologic assessment report for the industrial waste disposal well is reviewed and approved. Groundwater monitoring and injection zone requirements must also be stipulated by the DOHS before issuing a hazardous waste discharge permit. The bill further requires Regional Water Quality Boards to base waste discharge requirements which they issue for hazardous waste injection wells on hydrogeologic assessment reports. Hydrogeologic assessment reports (HAR) are carefully reviewed by Regional Water Quality Control Boards and the DOHS. Industrial disposal well owners are often required to submit extensive site specific hydrogeologic data within their HAR. (See "Industrial Disposal Well case Study, Kearney-KPF", Appendix E for an example of information required by state agencies within a HAR). In response to orders received from the DOHS and the Regional Water Quality Control Boards, a number of facilities are currently conducting hydrogeologic site investigations.

Class V wells not identified to discharge hazardous waste (as designated by the State) are regulated by the State and Regional Water Quality Control Boards. These Boards are empowered by the California State Water Code to require...

> any person ...who is discharging, or who proposes to discharge, wastes or fluid into an injection well, to furnish the State or Regional Board with a complete report on the condition and operation of the facility or injection well, or any other information that may be reasonable required to determine whether the injection well threatens to pollute the waters of the state. (Porter Cologne Water Quality Code, Sect. 13263.5a, 1985).

'When a report filed by any person pursuant to this section (California State Water Code, Section 13260(e) is not adequate in the judgement of the regional board, the board may require the person to supply the additional information which it deems necessary' (California State Water Code, Section 13260(e) as amended by AB 2058). Waste discharge requirements for industrial disposal wells are set by the Regional Board on a case by case basis. These requirements can specify the

design, location and type of construction among other requirements which must be complied with by the injection well owner in a lawful manner. Shallow industrial waste disposal wells discovered by the Regional Boards to have operated without waste discharge permits have been closed by the Boards in most cases. These wells can reopen if, after reviewing the waste discharge report, a Regional Board judges that the shallow industrial disposal well will not threaten regional groundwaters.

Based on information provided in State reports, it is likely that the local regulatory system utilized by California is more stringent than systems in other States.

Recommendations

Recommendations provided by State reports are summarized on the State Report Summaries in Appendix A. While some States provided only general recommendations for continuation of the UIC program as a whole, other States provided recommendations for specific well types. The following list of recommendations includes most of the topics addressed in the State reports. State reports which contain specific recommendations are identified in parentheses.

Inventory.

1. Inventory efforts should be continued with a high priority given to identifying industrial disposal facilities (PR, IN, WI, AK, WY).

2. Assume that all industrial waste disposal practices have deleterious effects on USDW, thus warranting immediate attention. Then conduct site investigations to assess the true contamination potential (PA).

3. The NPDES program could be more effective in helping the UIC program by requiring sewer improvement districts to inventory all industrial users of their systems and to review details of each user's waste streams(s) (NY).

4. The issue of the reluctance of operators to report their wells can be overcome by presenting a coordinated program (about waste streams that are allowed) through a multi-media approach. The

multi-media approach should encourage public participation at the State and local levels (States in Region V).

Hydrogeological Evaluations.

1. "Extensive groundwater evaluation studies should be completed in order to identify areas which would be vulnerable to contamination due to industrial waste disposal. Standard criteria should be developed to define in precise terms the criteria that constitute vulnerability," (PR, AS).

2. "Drainage areas surrounding industrial facilities should be studied and all possible pollution sources noted," (KS).

Permits.

1. "Industrial disposal wells should be permitted only when the injectate contains less than 10,000 mg/l TDS," (FL).

2. These wells can be detected and managed by local building code, environmental, or sewage protection programs (UT).

Inspections.

1. Inspection of industrial waste disposal facilities should be continued (PR).

2. "Inspection teams should be reinforced by chemical or industrial engineers whose familiarity with the industrial processes would render a more objective assessment of the impact industry might have on the environment," (PR).

3. Inspection of well construction practices should be mandatory along with annual inspections to ensure adherence to appropriate regulations (MD, KS).

Monitoring.

1. "Request all industries to conduct monitoring programs," (PR).

2. "Tighten up sampling requirements to assure their being representative of material reaching the injection well," (PR).

3. "If USDW is/are present above the injection zone, monitoring should be required which is capable of detecting the migration of effluent in the direction of the USDW," (WI).

4. Ground-water monitoring should be conducted using a minimum of one upgradient and two downgradient wells, (AZ).

5. Existing State regulations should be reviewed and revised to provide more prudent control of injection and monitoring requirements (HI).

6. All nonhazardous industrial process water and waste disposal wells shown to have a high contamination potential should be phased out. These wells should be required to inject below USDW as Class I wells in the future. Other 5W20 wells should be periodically checked for injection rate and fluid quality (States in Region V).

Alternative Methods.

1. The practice of injecting industrial process water and waste should be discouraged, and wastes should be routed to on-site treatment facilities or municipal sanitary sewer systems where possible, (FL, UT).

2. "Discharge of industrial process wastes to septic systems should be discouraged due to the fact that septic tank systems are not designed to adequately treat this waste type," (NE).

3. "Septic tanks were designed to treat domestic (kitchen and toilet) wastes only. The septic tank really has no place in industry except to treat wastes generated exclusively by a mess hall (cafeteria) and sanitary facilities. Even very small amounts of some industrial wastes can render a tank useless for the stabilization of domestic waste," (PR).

4. Alternative methods for disposal of industrial process water and waste should be considered (MD).

5. The policy of prohibiting the installation of septic tank/drainfields for treating embalming fluids (current practice requires holding facilities and periodic removal and proper disposal) should be continued (SC).

6. Until additional data is at hand to define the fate of industrial wastes in the saturated zone, it is prudent to take extraordinary precautions to minimize the potential for aquifer degradation via injection of highly toxic substances (WA).

7. Alternatives to land disposal such as recycling or resource recovery, reduction of wastes generated through process modification, and improved methods of hazardous waste neutralization should be actively pursued (WA).

Supporting Data

Appendix E lists 27 case studies of industrial process water and waste disposal facilities used in preparing this assessment. Also listed in Appendix E are three tables which illustrate varying construction features and injectate constituents of several industrial disposal wells in California.

4.2.6.3 Automobile Service Station Disposal Wells (5X28)

Well Purpose

Wastewater comprised of waste antifreeze fluids, waste petroleum products (oil, grease, etc.), floor washings (including detergents, sediments, etc.), and miscellaneous wastes originates from service bays at gas stations and auto dealerships. This type of wastewater will be called Service Bay Wastewater (SBW) in the following discussion. SBW typically is disposed of by three general methods: discharge to sanitary sewers, discharge to the subsurface by injection, and riddance by other methods such as storage or hauling of waste to an off-site disposal or recycling facility. (See Figure 4-51.)

Of particular concern is the injection of wastes to the subsurface brought about through one or a combination of methods. One method of waste injection involves discharge of wastewater through disposal wells or dry wells which exclusively receive wastewater from service bay drains. For the purpose of identification in the following sections, these wells will be called single purpose wells. The other method of injection involves discharge of SBW through cesspools, septic tank systems, or storm water drainage wells. These discharge systems will be called multi-purpose disposal systems as they receive wastes both from service bay drains and sewage or storm water runoff. In the event that the SBW is disposed through septic tank systems, the waste may be finally discharged to the subsurface through cesspools, dry or disposal wells, drainfields or other disposal methods. Hence, SBW may be injected to the subsurface through any of the above mentioned disposal methods, all of which are regulated under the UIC regulations.

Inventory and Location

Some States like Connecticut, Idaho, Illinois, Indiana, Michigan, New Jersey, New York, and Utah have conducted area-specific investigations to identify and assess the impact of the

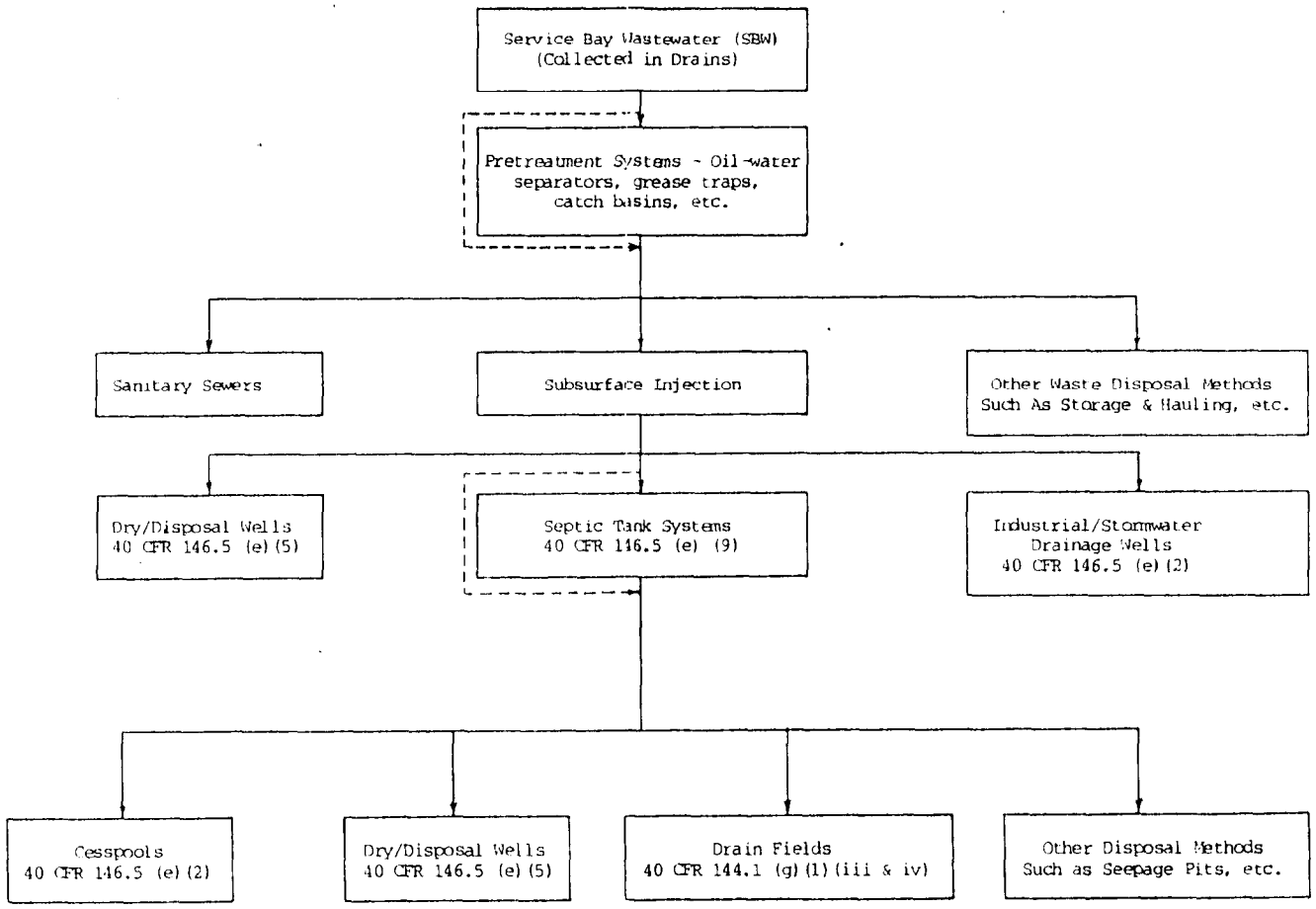


Figure 4-51
Typical disposal methods employed by gasoline service stations and car dealerships that discharge service bay wastewater (SBW)

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injection to the subsurface. Appropriate corrective actions are now being implemented based on the findings of these investigations.

A nationwide inventory has not been conducted for gasoline station service bay disposal wells. By and large, such an inventory has not been conducted because most States are not aware of such injection practices. Meanwhile, those States that are aware sometimes misinterpret the Class V definition and identify certain disposal techniques as septic tank systems or storm water drainage wells.

The USEPA Region II conducted several field trips in New York and New Jersey and identified some automobile service stations that were suspected of injecting service bay wastewater to the subsurface. (Engineering Enterprises, Inc. (EEI) was contracted to sample and analyze some of these injection wells in Long Island, New York. The preliminary investigation in Long Island, New York, revealed that three out of eight gasoline service stations investigated discharge SBW to the subsurface through single purpose and multipurpose wells. It was not possible to identify the disposal method at the rest of the sites. Missing plumbing records and site plans, modifications to old plumbing, and lack of information exchange during transfer of ownerships were some of the many elements that affected proper identification of a disposal method at these five sites.

In Connecticut, an inventory has not been completed because SBW disposal methods are identified and regulated only on a case-by-case basis as they are reported or identified during routine inspection. In New Jersey, the New Jersey Department of Environmental Protection (NJDEP) reported 18 service station disposal wells of which 11 non-filer facilities are undergoing enforcement actions, one facility is closed, and the others are either permitted or under investigation. In other words, there is no extensive program setup to inventory or regulate such disposal methods.

Under all of these circumstances it was not possible to obtain a complete inventory either on a State level or national level. Table 4-51 is a synopsis of the inventory data given by the states.

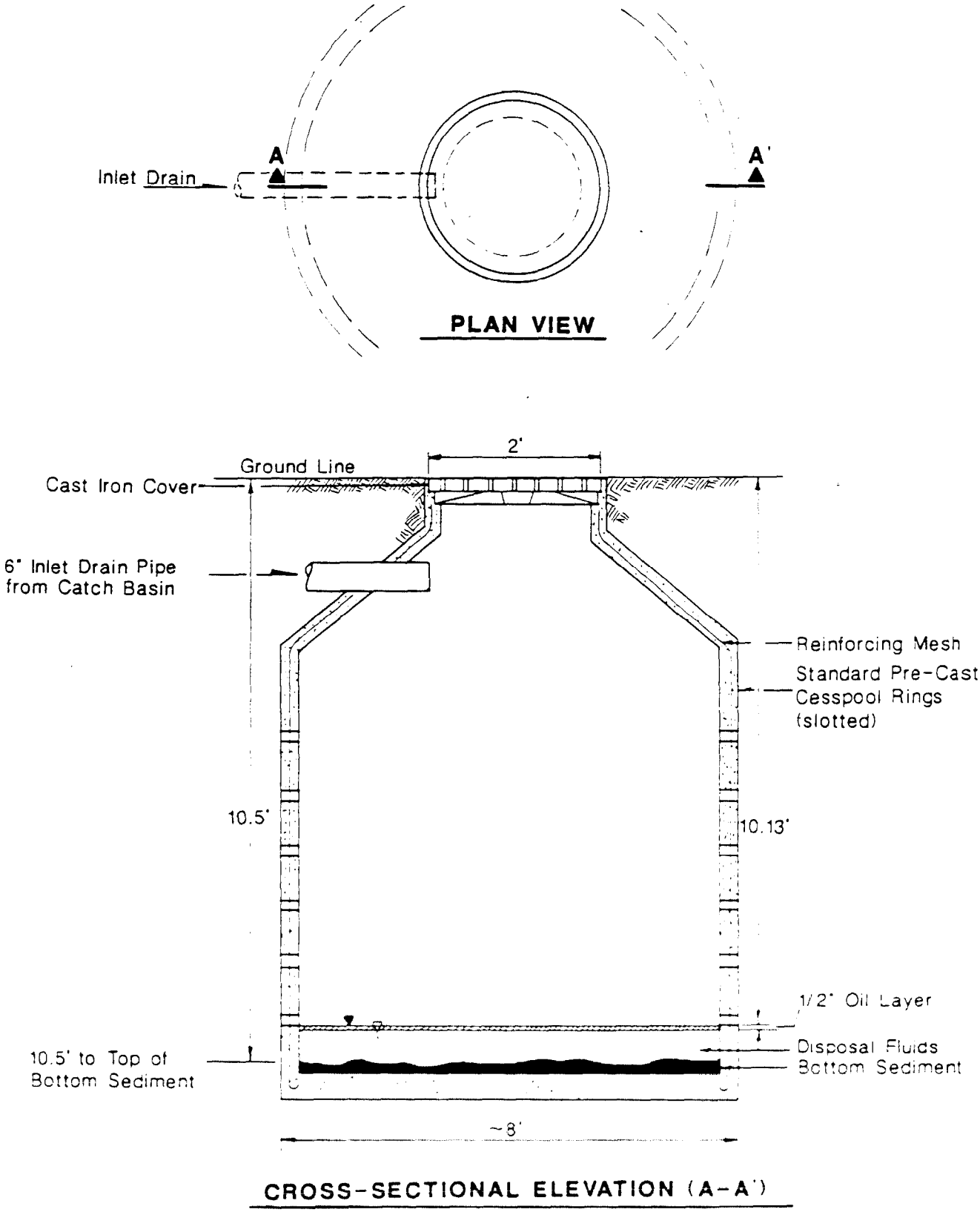
Well Construction, Operation, and Siting

As discussed before, wastewater from service bays may be discharged through single purpose or multipurpose wells. Construction of multipurpose wells is similar to constructions discussed under septic tank systems or storm water drainage wells. Single purpose wells designed to discharge only service bay wastewater are typically completed at shallow depths using standard precast cesspool rings as illustrated in Figure 4-[illegible]. At some sites, depending on the volume of waste discharged to

TABLE 4-51: SYNOPSIS OF STATE REPORTS FOR AUTOMOBILE SERVICE STATION WASTE DISPOSAL WELLS(5X28)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	1 WELL	PERMIT	YES	HIGH
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	3 WELLS	N/A	YES	LOW
Vermont	I	10 WELLS	N/A	YES	MODERATE/HIGH
New Jersey	II	18 WELLS	NJPDES PERMIT	YES	N/A
New York	II	3 WELLS	PERMIT	YES	HIGH
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	1 WELL	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	YES	PERMIT	NO	N/A
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	5 WELLS	RULE	NO	N/A
Indiana	V	2 WELLS	N/A	NO	N/A
Michigan	V	27 WELLS	N/A	NO	N/A
Minnesota	V	NO	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	YES	N/A	NO	N/A
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	NO	N/A	NO	N/A
Iowa	VII	1 WELL	N/A	NO	HIGH
Kansas	VII	NO	N/A	NO	N/A
Missouri	VII	5 WELLS	N/A	NO	UNKNOWN
Nebraska	VII	NO	RULE	NO	N/A
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	2 WELLS	BANNED	NO	6 (7=HIGHEST)
Wyoming	VIII	NO	N/A	NO	N/A
Arizona	IX	NO	N/A	NO	N/A
California	IX	NO	N/A	NO	N/A
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	YES	N/A	NO	HIGH
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	21 WELLS	RULE	NO	4TH HIGHEST/14 TYPES
Oregon	X	NO	N/A	NO	N/A
Washington	X	NO	N/A	NO	N/A

NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.



DETAIL OF A DRY DISPOSAL WELL
SAMPLED AT A GASOLINE SERVICE STATION
LONG ISLAND, NEW YORK

Figure 4-52

the geology, a series of standby wells may also be constructed as the situation warrants.

Wastewater effluent originating from service bays may pass through a pretreatment system before being discharged into a disposal well. Such pretreatment systems include grease pits, oil water separators, or catch basins. Figure 4-53 is an illustration of a catch basin sampled in New York. Injection takes place by simple gravity flow from the pretreatment system to the subsurface disposal facility.

Injected Fluids and Injection Zone Interactions

Typically, wastewater from service bay drains may include waste oil, antifreeze, floor washings (including detergents, organics, and inorganic sediment), and other petroleum products. Hence, wastewater of this nature may contain highly toxic organics and heavy metal priority pollutants along with other organic and inorganic compounds that may eventually migrate to the ground water. Many of these contaminants may be absorbed or adsorbed to the organic and inorganic suspended sediments and settleable sediments.

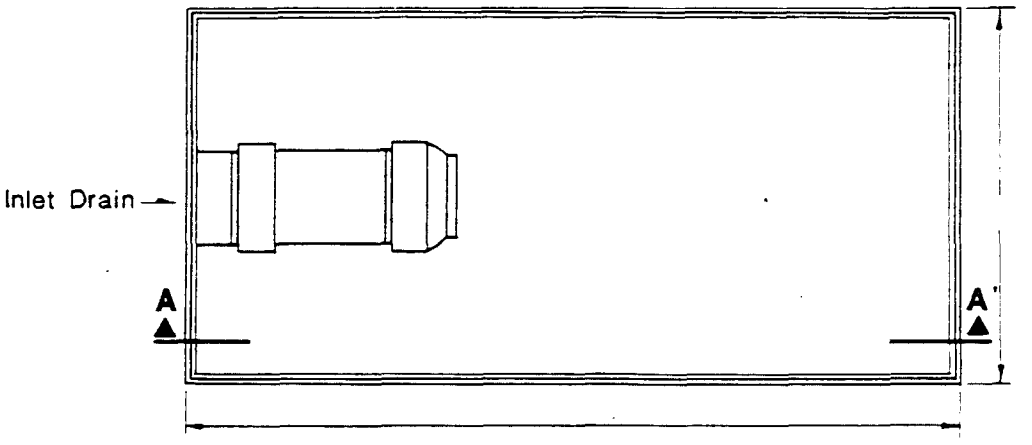
Samples obtained at some gas stations during the preliminary investigations in Long Island, New York showed contaminant levels highly in excess of drinking water standards. High levels of heavy metals (total), ethylene glycol, and volatile organics were detected in the wastewater samples collected in the investigation.

During the investigation in New York and a separate investigation in Utah, it was estimated that some wells had up to two feet of oily residue in the wells, and the entire inside of the wells was coated with black oily films. Case studies are listed in Appendix E.

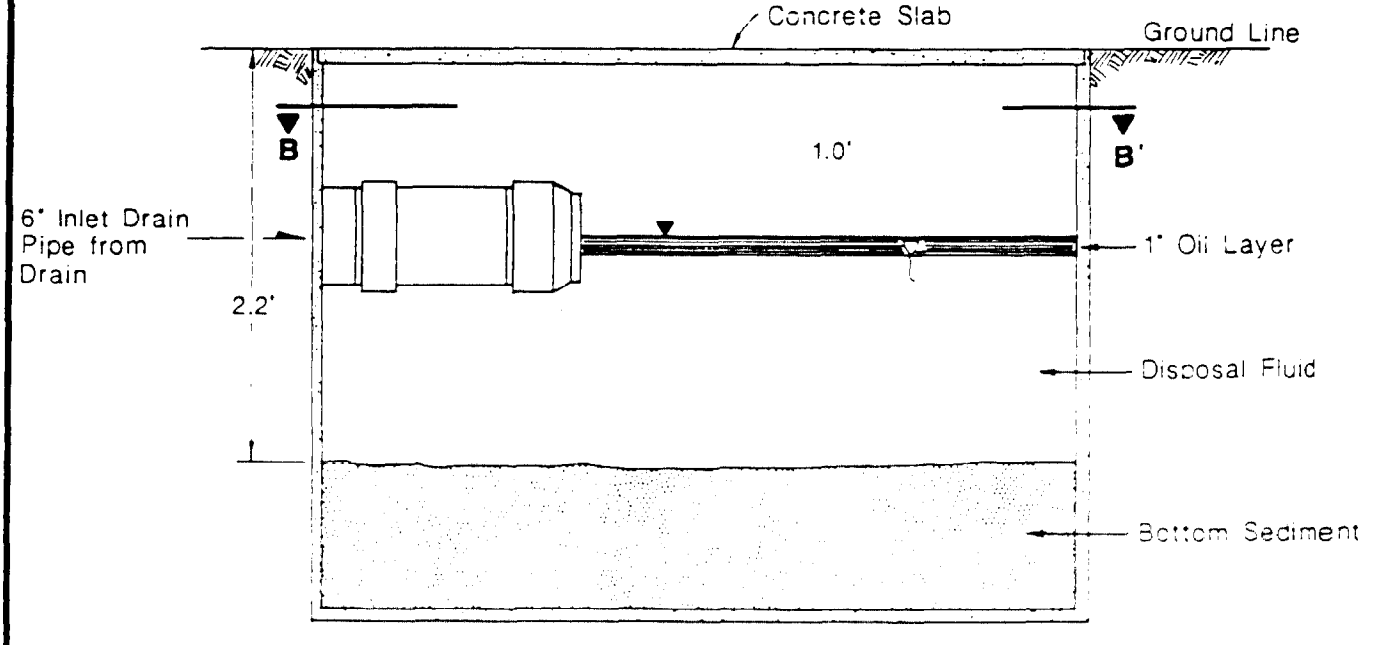
At most sites, waste fluids enter the unsaturated subsurface zone by gravity flow, seeping through slots and openings of the disposal well. Waste fluids migrate vertically downward in the unsaturated (vadose) zone by force of gravity. In this process, the fluids may leave behind residual contamination in the wells and in the flow path through the vadose zone, due to adsorption or absorption. The residue potentially may leach or desorb contaminants to the subsurface for long periods of time.

Hydrogeology and Water Use

Wastewater from service bays typically is injected into the shallow subsurface (within 20 to 30 feet of land surface). Consequently, at many sites, shallow aquifers may be in or near such discharge zones. Shallow aquifers are highly vulnerable to contamination regardless of their location with respect to injec-



PLAN VIEW (B-B')



CROSS-SECTIONAL VIEW (A-A')

DETAIL OF A CATCH BASIN
SAMPLED AT A GASOLINE SERVICE STATION
LONG ISLAND, NEW YORK

Figure 4-53

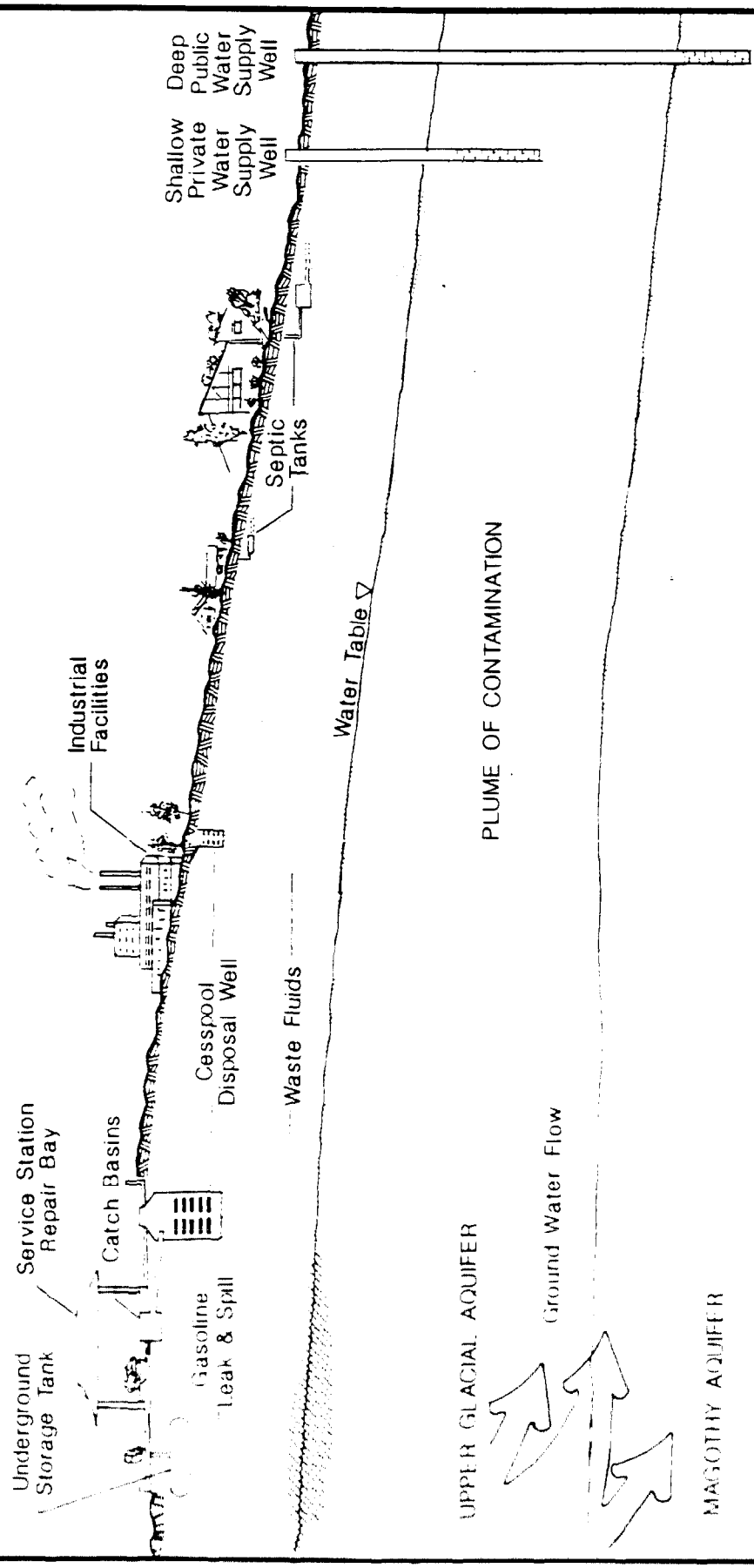
tion zones since contaminants in SBW may eventually reach the aquifer. Incidentally, most gas station service bays are located in populated areas that may have many additional sources of pollution (See Figure 4-54). Some residents in the area may obtain their drinking water from wells completed in shallow aquifers in the general area. Contaminants entering the shallow aquifers may migrate through the ground water and, eventually, contaminate drinking water wells in the vicinity.

In some areas where shallow aquifers are non-potable, water wells may be completed in deeper aquifers. Contaminants from SBW disposal wells may still migrate down to the deeper aquifer, depending on the hydrogeological connection between the upper shallow aquifer and the deeper aquifer. Improperly abandoned or poorly constructed and maintained water wells may also contribute to connectivity of shallow and deep aquifers.

Contamination Potential

Based on the rating system described in Section 4.1, automobile service station waste disposal wells are assessed to pose a high potential to contaminate USDW. These wells typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance would allow fluid injection or migration into unintended zones. Injection fluids typically have concentrations of constituents exceeding standards set by the National Primary or Secondary Drinking Water Regulations. Furthermore, many of the fluids are likely to exhibit characteristics or contain constituents listed as hazardous as stated in the RCRA Regulations. Based on injectate characteristics and possibilities for attenuation and dilution, injection does occur in sufficient volumes or at sufficient rates to cause an increase in concentration (above background levels) of the National Primary or Secondary Drinking Water Regulation parameters in groundwater, or endanger human health or the environment beyond the facility perimeter or in a region studied on a group/area basis.

When SBW is disposed by subsurface injection, it usually is discharged to a shallow zone. The waste is injected into the subsurface in populated areas that depend, in many instances, on ground water as a source of drinking water. Hence, in most cases, the injection zones are underlain by USDW. Also, the construction, operation, and maintenance of many subsurface injection methods allow contaminants to migrate into unintended zones in the subsurface. The injection fluids commonly contain toxic organics and heavy metal priority pollutants in excess of drinking water standards. Finally, injected fluids are very likely to cause degradation of ground-water quality beyond the facility perimeter. Based on the above findings and the rating systems developed and discussed at the beginning of Section Four, it can be concluded that subsurface discharge of SBW presents a high potential to contaminate USDW in the vicinity. This



NOT TO SCALE

HYPOTHETICAL VIEW OF VARIOUS SOURCES OF CONTAMINATION AND TRANSPORT OF TOXICS IN THE SUBSURFACE (EEI, 1986)

Figure 4-54

conclusion is reaffirmed by some state reports, including New York, Utah, and Iowa, that rate these disposal methods as those that pose a high contamination potential.

As discussed above, discharge of such contaminants to the subsurface has an immediate or potential impact on the ground-water quality and, thereby, poses a threat to human health and the environment. The impact ground-water quality is influenced by the transport and fate of the injected fluids in the subsurface.

As mentioned by Keeley, Piwoni, and Wilson (1986), there are many natural processes that affect the transport and fate of pollutants (Table 4-52). They are divided into physical, chemical, and biological processes. These processes may, in many instances, reduce the contamination potential. Nevertheless, these contaminants have the ability to eventually degrade the ground-water quality depending on the volume, persistence, mobility, and toxicity of the injected fluid. Investigations that study the transport and fate of contaminants can be both costly and time consuming but are essential. Such investigations become more complicated (especially in densely populated residential and industrial areas as in the case of the Long Island, New York study) as different sources of contamination contribute to the gross contamination plume.

A thorough investigation of the various factors mentioned above is necessary to understand the full impact and contamination potential of service bay waste water injection on USDW.

Current Regulatory Approach

Automobile service station waste disposal wells are authorized by rule under Federally-administered UIC progrmas (see Section 1). Currently, gasoline station disposal wells are not actively regulated by the USEPA or by many State systems. One reason is that some States do not believe that such disposal practices exist. Also, many other States are confused and misled, believing that multipurpose wells like septic tank systems and storm water/industrial drainage wells (that also discharge waste from service bays) do not meet the definition (in UIC Regulations) of "Automobile Service Station Disposal Wells."

Some States, however, are beginning to recognize the impact of these injection practices. For instance, according to Patton (1987), Connecticut has barred any discharge of wastewater to the subsurface from gasoline station service bays. All facilities, old and new, are now required to dispose of such wastewater only through the sewer system or other means where the waste is removed from the area. Operators are required to obtain necessary permits in this regard. Facilities that do not follow these requirements have been asked to immediately seal off such drains.

TABLE 4-52
NATURAL PROCESSES THAT AFFECT SUBSURFACE CONTAMINANT TRANSPORT. (KELLEY, PIWONI AND WILSON, 1986)

Physical processes
Advection (porous media velocity)
Hydrodynamic dispersion
Molecular diffusion
Density stratification
Immiscible phase flow
Fractured media flow
Chemical processes
Oxidation-reduction reactions
Radionuclide decay
Ion-exchange
Complexation
Co-solvation
Immiscible phase partitioning
Sorption
Biological processes
Microbial population dynamics
Substrate utilization
Biotransformation
Adaptation
Co-metabolism

Other States, including Wyoming, Wisconsin, New Jersey, and New York, are taking effective steps to mitigate these injection practices. Some States, like Texas, are now requiring permits for these discharges, and have classified the wells as Class I wells (Musick, 1986).

The USEPA Region II recently sampled catch basins and disposal wells at eight gas stations in Long Island, New York. Results (though inconclusive) show that many USEPA priority pollutants and other toxic compounds in the injection fluid may be highly in excess of the drinking water standards. USEPA Region II is currently sending out Class V well inventory/investigation forms to new car dealers in New York.

Another type of facility that discharges service bay wastewater is car dealerships which maintain service bays. A USEPA investigation in New Jersey revealed that a foreign car dealer was operating a Class IV well and injecting hazardous waste that contained trichloroethane (used for degreasing). Effective actions were taken and, consequently, the Director of the New York Class V UIC program sent nearly 1,400 permit applications to new car dealers (since the probability of injection practices similar to New Jersey were anticipated to be occurring in New York). Based on the monitoring information required for permit compliance, the State Director hopes to determine whether there is current injection of potentially hazardous or otherwise toxic wastes. Local governments do not regulate subsurface discharge of service bay wastewater at the present time.

Recommendations

As discussed previously, subsurface injection or discharge of potentially hazardous and toxic fluids from service bays at gasoline stations and car dealerships is a threat to human health and the environment.

An inventory of SBW disposal systems on a state level and, eventually, on a national basis is vital (New York, Puerto Rico, Idaho). This information can be employed in making an assessment of the contaminant mass loading and detrimental effects on the subsurface water quality. Unsewered areas, such as in some areas of Long Island, New York, may have large concentrations of SBW subsurface disposal facilities. Therefore, it may be appropriate to begin inventories in these unsewered areas and gradually work outward.

Iowa suggests requiring a permit to operate which includes information on construction features, a plan to utilize separators and holding tanks, and a plan to sample and analyze the injected fluids.

The following three recommendations are excerpts from Utah's report on Class V injection wells (1987):

A. These wells can be corrected by providing underground holding tanks (total containment) for the waste oils/fluids. These tanks would require regular off-loading to waste oil reclaimers. In Utah, there is economic incentive for a service station to sell waste oil to a reclaimer. The management of these wells would be accomplished at the local government level because they already enforce their building and sewer ordinances. Any inspections by state or federal staff would be a duplication of effort.

B. Communities with a water reclamation system commonly prohibit oil and grease discharges to their sewer. Consequently, some operators opt to discharge to dry wells as a "loophole" to the environmental regulations. Local building code and sewer pretreatment inspection should be able to locate and manage these wells.

C. The UIC program has not been effective in controlling this problem, but local government has. The UIC program can be more effective by educating those local government staff who conduct building and environmental inspections. This training will help locate these violators and hopefully solve the problem.

4.2.7 RECHARGE WELLS

4.2.7.1 Aquifer Recharge Wells (5R21)

Well Purpose

Artificial recharge is used primarily as a water resource management tool. The main objective of artificial recharge is to increase the amount of water entering an aquifer, thereby allowing a greater rate of ground-water withdrawal. This may be conducted during periods of excess surface water during rainy seasons, or it may involve importation of water from nearby areas.

During natural recharge through stratified soils, water collects or perches on less permeable subsurface layers. If recharge continues over a long period of time over a large area, perched water may approach the land surface and cause ponding. Under these conditions, recharge wells are very effective because they bypass the impermeable sublayer restrictions to vertical flow (Bianchi, et al., 1978) and inject directly into UDW.

In addition to water storage, artificial recharge through wells may be used for other reasons. Other applications include prevention of salt water intrusion into fresh water aquifers

(Section 4.2.7.2), disposal of wastewater treatment effluent (4.2.3.3), subsidence control (4.2.7.3), disposal of urban and agricultural runoff (4.2.1.2, 4.2.1.1), and aquifer remediation (4.2.8.3). This section will cover recharge wells which have been reported to serve the primary purpose of augmenting underground water supplies.

Inventory and Location

The inventory data collected by each State, Territory, and Possession account for a total of approximately 3,558 aquifer recharge wells (See Table 4-53). The wells included in this category have been limited to those which have been reported as recharge wells. New York has reported 3,000 recharge basins which have been included in the inventory as requested by the State of New York; however, it is unlikely that these would qualify as Class V facilities unless wells were installed to enhance basin drainage. The distinction between recharge well types and drainage well types is oftentimes difficult. Recharge wells may serve secondary purposes, such as drainage. Likewise, a secondary purpose of drainage wells may be aquifer recharge. This sometimes leads to a conflict of interest which, in turn, may increase contamination potential to some underground sources of drinking water.

Inventory information from other sources has been compiled by the Environmental and Ground Water Institute at the University of Oklahoma (O'Hare et al., 1986). Figures 4-55 and 4-56 reflect information from this source. See Appendix E for the reference to a list of facilities represented on Figure 4-56.

Many other recharge projects probably exist throughout the United States, its territories, and possessions. One would expect to find recharge wells in areas where populations are heavily dependent upon ground-water supplies for irrigation and domestic use, where evapotranspiration and extraction of water exceeds recharge, and in areas with restrictive subsurface layers which impede natural recharge.

Construction, Siting, and Operation

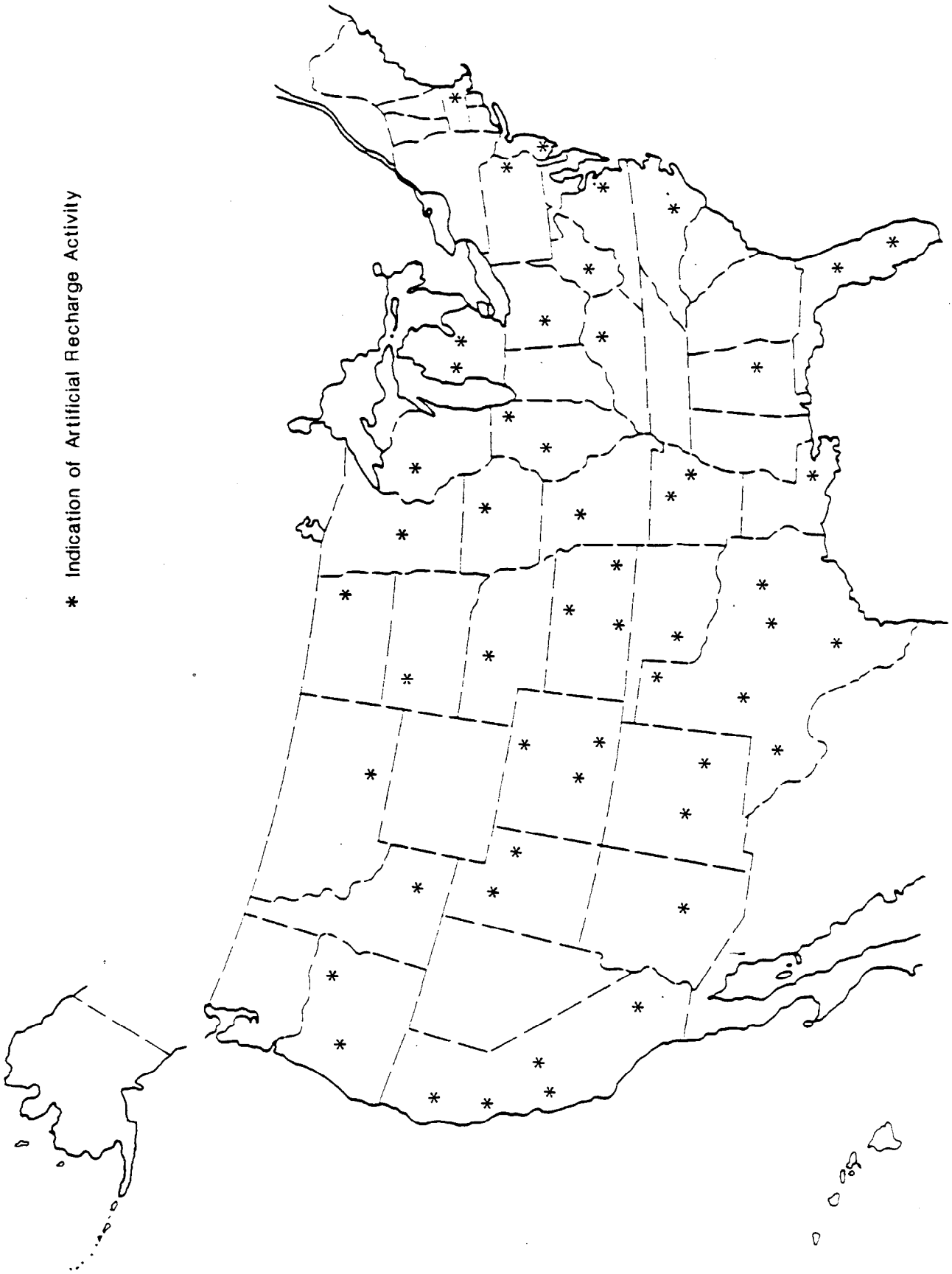
There are several methods of artificial recharge in widespread use. These include surface spreading, infiltration pits and basins, and wells or shafts. Surface spreading and infiltration basins recharge through surface seepage. Wells may be utilized in areas where existence of impermeable strata between the surface and the aquifer makes recharge by surface infiltration impractical. Wells are also used in urban areas where sufficient land for surface spreading is not available.

Construction, siting, and operation of recharge wells will depend on whether the well serves a secondary purpose. Aquifer recharge wells inventoried include some wells that also serve as

TABLE 4-53: SYNOPSIS OF STATE REPORTS FOR AQUIFER RECHARGE WELLS(5R21)

REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	NO	N/A	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	NO	N/A	NO	N/A
New Hampshire	I	1 WELL	N/A	YES	LOW
Rhode Island	I	NO	N/A	NO	N/A
Vermont	I	NO	N/A	NO	N/A
New Jersey	II	NO	RULE/PERMIT	NO	N/A
New York	II	3000 BASINS	N/A	NO	N/A
Puerto Rico	II	NO	N/A	NO	N/A
Virgin Islands	II	NO	N/A	NO	N/A
Delaware	III	NO	N/A	NO	N/A
Maryland	III	NO	N/A	NO	N/A
Pennsylvania	III	NO	N/A	NO	N/A
Virginia	III	NO	N/A	NO	N/A
West Virginia	III	NO	N/A	NO	N/A
Alabama	IV	NO	N/A	NO	N/A
Florida	IV	349 WELLS	PERMIT	YES	3RD HIGHEST/8 TYPES
Georgia	IV	NO	N/A	NO	N/A
Kentucky	IV	NO	N/A	NO	N/A
Mississippi	IV	NO	N/A	NO	N/A
North Carolina	IV	NO	N/A	NO	N/A
South Carolina	IV	NO	N/A	NO	N/A
Tennessee	IV	NO	N/A	NO	N/A
Illinois	V	1 WELL	RULE	NO	N/A
Indiana	V	NO	N/A	NO	N/A
Michigan	V	NO	N/A	NO	N/A
Minnesota	V	1 WELL	N/A	NO	N/A
Ohio	V	NO	N/A	NO	N/A
Wisconsin	V	NO	N/A	NO	N/A
Arkansas	VI	NO	N/A	NO	N/A
Louisiana	VI	NO	N/A	NO	N/A
New Mexico	VI	30 WELLS	REGISTRATION	NO	LOW
Oklahoma	VI	NO	N/A	NO	N/A
Texas	VI	44 WELLS	PERMIT +	YES	V LOW X
Iowa	VII	NO	N/A	NO	N/A
Kansas	VII	4 WELLS	N/A	NO	POSSIBLE
Missouri	VII	NO	N/A	NO	N/A
Nebraska	VII	4 WELLS	RULE	NO	VARIABLE
Colorado	VIII	NO	N/A	NO	N/A
Montana	VIII	NO	N/A	NO	N/A
North Dakota	VIII	NO	N/A	NO	N/A
South Dakota	VIII	NO	N/A	NO	N/A
Utah	VIII	NO	RULE/PERMIT	NO	N/A
Wyoming	VIII	7 WELLS	PERMIT	YES	6TH HIGHEST/10 TYPES
Arizona	IX	51 WELLS	PERMIT	YES	LOW +
California	IX	52 WELLS	PERMIT	YES	UNKNOWN
Hawaii	IX	NO	N/A	NO	N/A
Nevada	IX	NO	N/A	NO	N/A
American Samoa	IX	NO	N/A	NO	N/A
Tr. Terr. of P	IX	NO	N/A	NO	N/A
Guam	IX	NO	N/A	NO	N/A
CNMI	IX	NO	N/A	NO	N/A
Alaska	X	NO	N/A	NO	N/A
Idaho	X	7 WELLS	PERMIT 18 FT	YES	7TH HIGHEST/14 TYPES
Oregon	X	NO	N/A	NO	N/A
Washington	X	7 WELLS	N/A	NO	N/A

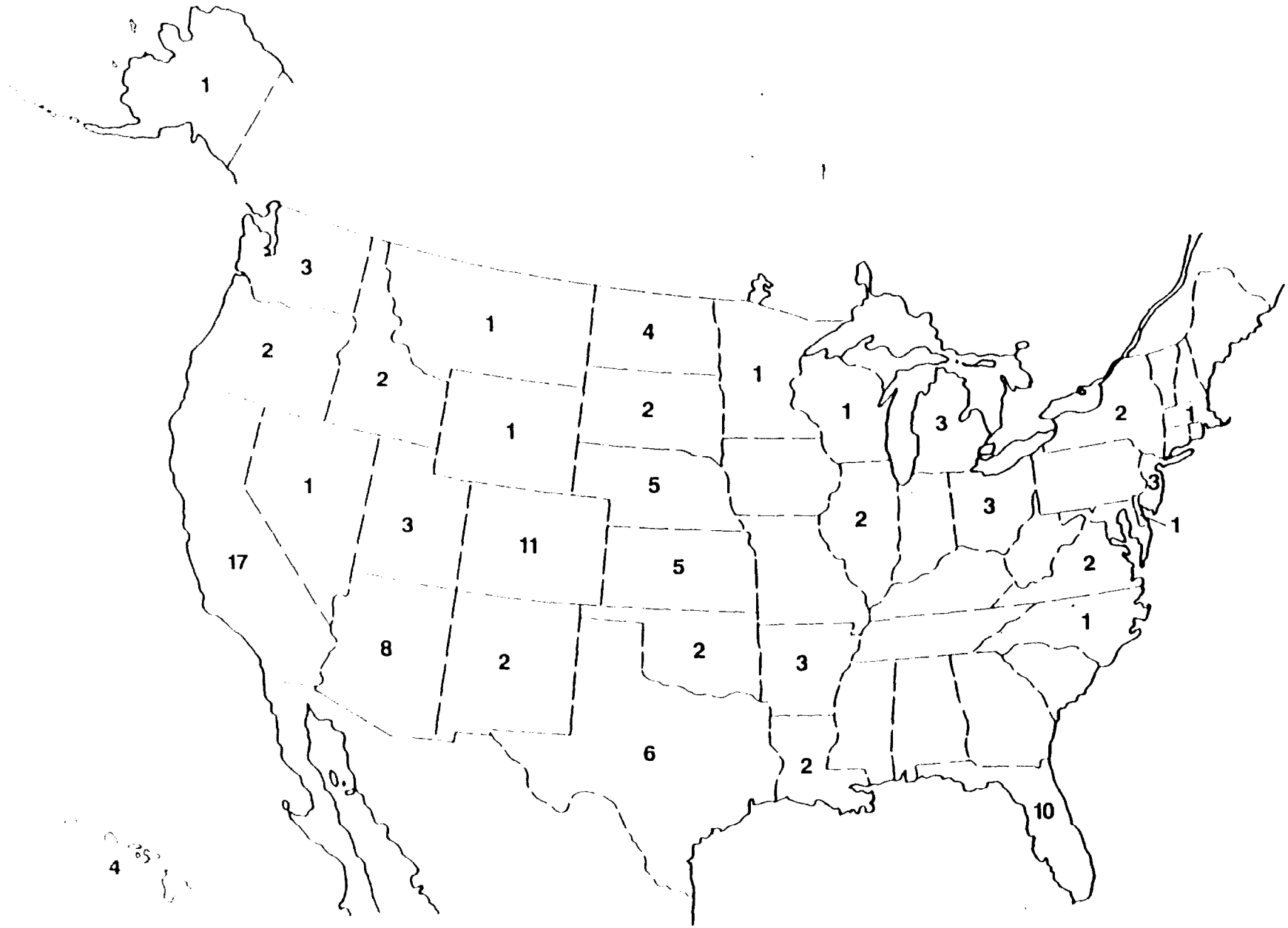
NOTE: SOME NUMBERS IN THIS TABLE ARE ESTIMATES.
* WHERE UNDERGROUND WATER DISTRICTS HAVE BEEN ESTABLISHED
X PROVIDED POLLUTANTS ARE KEPT OUT OF RECHARGE WATER
+ PROVIDED PROPER DESIGN, CONSTRUCTION AND OPERATION



INDICATION OF ARTIFICIAL RECHARGE ACTIVITY FROM LITERATURE AND/OR VERBAL COMMUNICATION WITH VARIOUS AGENCIES

(from O'Hare et al, 1986)

Figure 4-55



NATIONAL ARTIFICIAL RECHARGE ACTIVITY
PAST AND PRESENT PROJECTS, DEMONSTRATIONS,
PILOT PROJECTS, EXPERIMENTS AND STUDIES

Figure 4-56

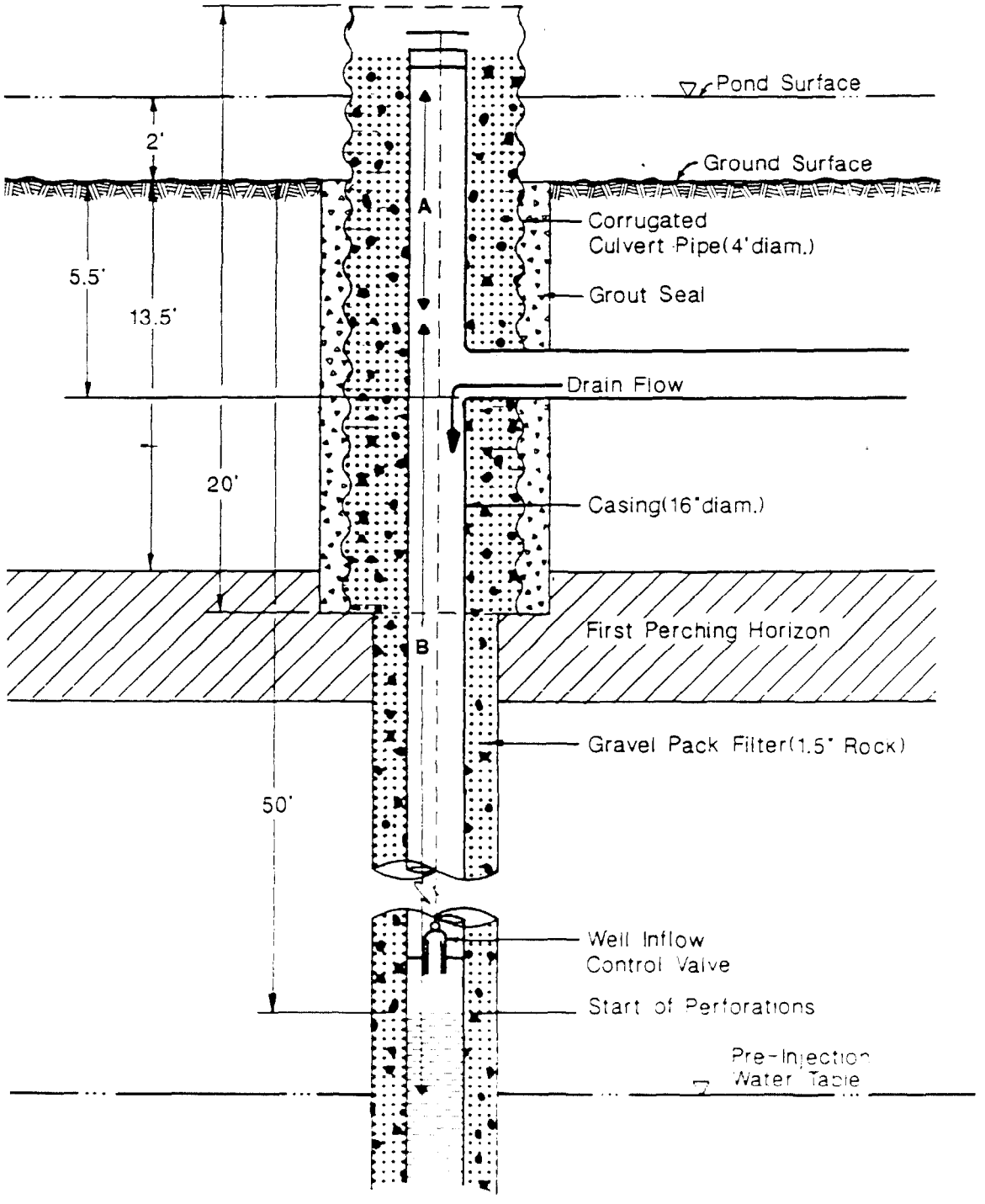
drainage and disposal wells. This can often pose a potential threat to the receiving aquifer, especially when the injection zone is a drinking water supply aquifer.

The subsurface drain collector - deep well recharge system known as Leaky Acres Recharge Project in Fresno, California illustrates construction specifics of a recharge well used exclusively for the purpose of aquifer recharge. The well was constructed using a reverse rotary rig to bore a 34-inch diameter hole. The injection casing is 16 inches in diameter. A 4-foot diameter corrugated culvert was used as conductor pipe to isolate the upper drain collector zone of the soil profile from the deeper aquifers. The conductor was grouted from ground surface to a depth of 20 feet into the first horizon perching zone. The casing perforations start at a depth of 50 feet and extend to full depth of the 250 foot borehole (Figure 4-57). The recharge well is located at the center of a 10-acre ponding basin. Injected water is diverted from an areal canal, filtered through surface soils, and collected through a subsurface tile drain system for injection.

Many of the reported recharge wells from Florida are actually "connector" wells which are also used to dewater phosphate mining areas. These wells are constructed through an impermeable perching layer of strata close to the surface, thereby draining the perched water to a deeper water supply aquifer. This results in recharge of the deep aquifer through the constructed well, which "connects" the deep aquifer to the shallow perched aquifer. These wells are typically 12 inches or greater in diameter and approximately 200-300 feet deep. Wells are usually cased with PVC pipe from the surface to the injection zone. The PVC pipe is slotted and screened at the "intake" zone within the surficial aquifer. Water in this zone drains into the slotted casing and cascades through the pipe into the deeper injection zone.

Many of the reported recharge wells from Texas are "dual purpose" wells which alternately produce ground water for irrigation and inject agricultural surface runoff into the supply aquifer. Texas also reports recharge wells northeast of El Paso, sited at a domestic wastewater treatment plant. The El Paso area wells serve the secondary purpose of treated waste disposal for the treatment plant. Plant recharge/disposal wells are constructed to a depth of approximately 800 feet (See Figure 4-58.) The Teton Village Wastewater Treatment Plant in Wyoming also utilizes injection wells for recharge and waste disposal. Construction, siting, and operation variations exist throughout the United States. The variables are determined by local hydrogeologic conditions and any secondary purposes of wells. The above examples provide a representative sampling of wells which illustrate the diversity of aquifer recharge application.

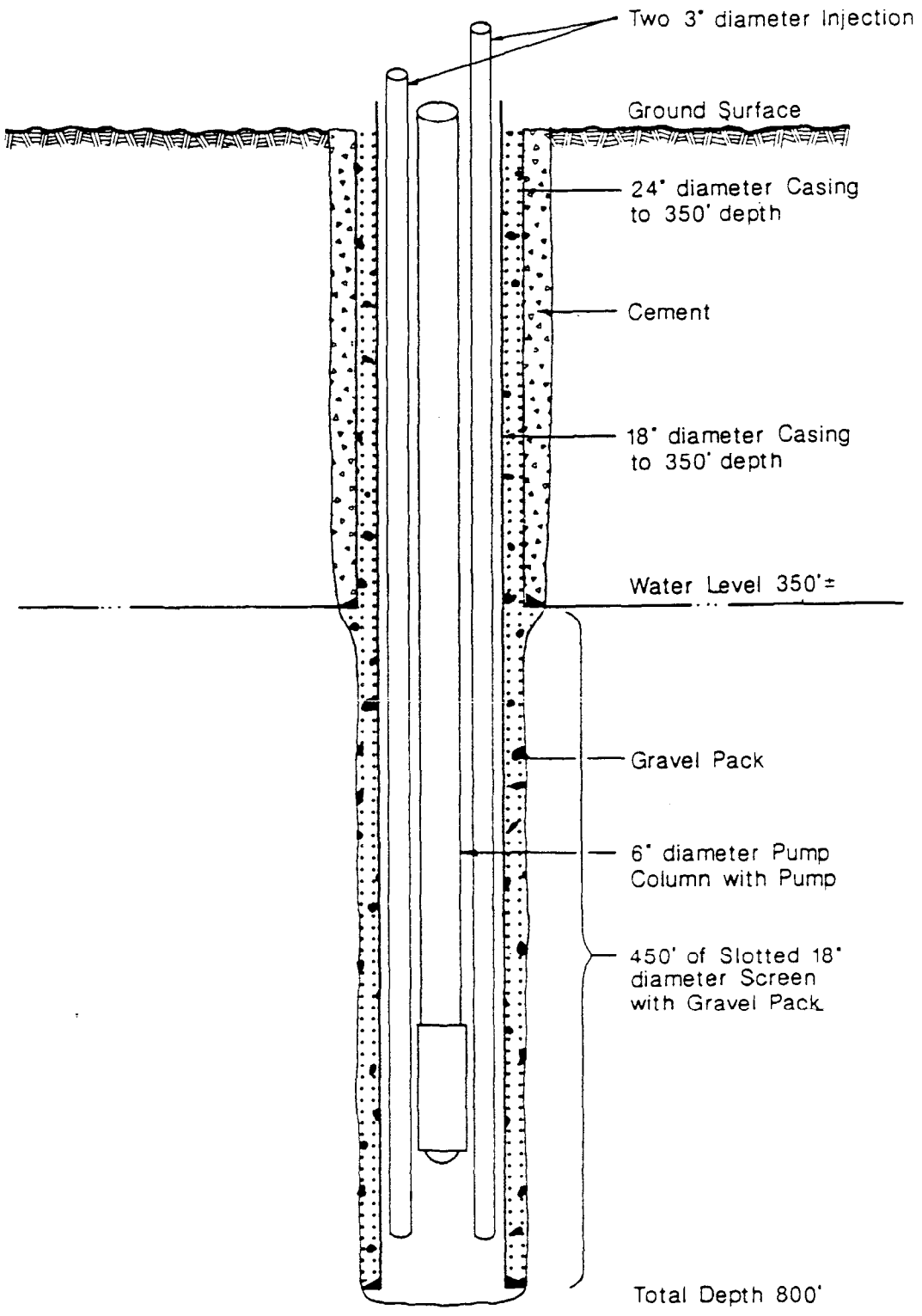
One of the major operational problems with recharge injection wells is clogging. During extended periods of injection, some clogging generally occurs near the borehole due to accumula-



lection Head
ximum Injection Head

MATIC OF FRESNO
ARGE WELL CONSTRUCTION

Figure 4-57



Scale: None

DIAGRAM OF RECHARGE/DOMESTIC
WASTE DISPOSAL WELL
IN EL PASO, TEXAS

(after Texas DWR, 1986)

tion of suspended solids. Design of a recharge well to allow redevelopment or removal of the clogged aquifer interface near the borehole is possible. Redevelopment procedures for wells at the Leaky Acres Project in Fresno, California involve shifting of a coarse, well-rounded gravel pack at the injection zone. This movement dislodges the sand and clogging fines from the aquifer, thus creating a clean injection face. Dislodged material is pumped out of the well during redevelopment procedures.

Other redevelopment practices include cleaning of the injection zone through methods such as flush pumping, surging, and jetting. The injection wells at El Paso utilize a downhole pump (Figure 4-58) to redevelop the well by surging and pumping. This is a common redevelopment procedure. Clogging may also result from biological activity, chemical incompatibility, and entrained air. Injection zone interactions will be discussed further in the following section.

Injected Fluids and Injection Zone Interactions

Injection fluid characteristics will vary depending on the source of injection waters. Water quality transformations that might occur during passage of injected water through an aquifer include adsorption, ion exchange, precipitation and dissolution, chemical oxidation, biological nitrification and denitrification, aerobic or anaerobic degradation of organic substrates, mechanical dispersion, and filtration.

Field experience has shown that recharge wells lose capacity with time, even with refined surface water pretreatment, because of gradual penetration of clogging materials. Pretreatment methods include the use of settling basins and soil filtration before injection. These procedures are effective in removing much of the clogging material. Attempts have been made to chemically disperse deeply-trapped sediment and move it more deeply into the aquifer, but concern about effects of this approach on water quality and producing wells in the area has limited this technique. Sodium Hexametaphosphate is one chemical that is sometimes added for clay particle dispersal. Periodic cleaning of the well will also decrease clogging caused by suspended solids.

In addition to suspended solids, clogging may result from the presence of air bubbles in recharge water, bacteria growth, and chemical reactions between the receiving aquifer water and injection water. These problems can be remedied by injecting chemically and thermally compatible, well filtered water, and preventing turbulence from cascading water during injection.

Mechanical jamming from rearrangement of grains in the aquifer reduces pore volume and may result from alternatively pumping and injecting fluids through the same well. This is generally not a major problem with properly designed and constructed wells.

Some types of recharge wells inject into the vadose or unsaturated zone above the aquifer. These wells allow the injectate to bypass a significant portion of materials between the surface and the injection zone, but injected fluids must pass through some material before reaching the saturated zone. Passage through part of the unsaturated zone will allow attenuation of some constituents before water reaches an aquifer.

The major advantages of direct aquifer injection through wells are the immediate response of aquifer water levels and a relatively high rate of recharge. Disadvantages of direct aquifer injection include: 1) direct introduction of water and any chemical or biological contaminants that may be present in the recharge water, 2) recharge using pressurized injection could result in extensive formation fracturing, and 3) introduction of suspended solids may cause local clogging of the aquifer and contamination due to adsorption and transportation of pollutants. The solids of greatest concern are the colloidal clays, because they resist most forms of settling and filtration and are, therefore, difficult to remove from waters prior to injection (Dvoracek, 1971).

Hydrogeology and Water Use

A thorough and detailed knowledge of hydrogeologic features is necessary for adequately selecting a recharge site. Some parameters to be considered include geologic and hydraulic boundaries, tectonic boundaries, inflow and outflow of water, porosity, hydraulic conductivity, transmissivity, storage capacity, water resources available for recharge, natural recharge, water balance, lithology, and depth of the aquifer. Special attention is required for karstic regions, where injected water may rapidly discharge to the surface through underground caverns. In some areas, injection below karstic discharge outlets can minimize volume of discharge after recharge (U.N., D.E.S.A., 1975).

Populations in arid climates are generally more dependent upon ground water, as surface water is usually not readily available. Heavy ground-water demands in these areas may cause depletion in the supply aquifer. Irrigated agricultural areas of California and Arizona are prime examples of depletion resulting from heavy ground-water demand.

Contamination Potential

Based on the rating system described in Section 4.1, aquifer recharge wells are assessed to pose a high to low potential to contaminate USDW. These facilities typically do inject into or above Class I or Class II USDW. Typical well construction, operation, and maintenance vary considerably but ideally would not allow fluid injection or migration into unintended zones. Injec-