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:

- o Methods in common use that should be considered reasonably employed in public water treatment systems

- o 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

- o 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 <u>is</u> 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.

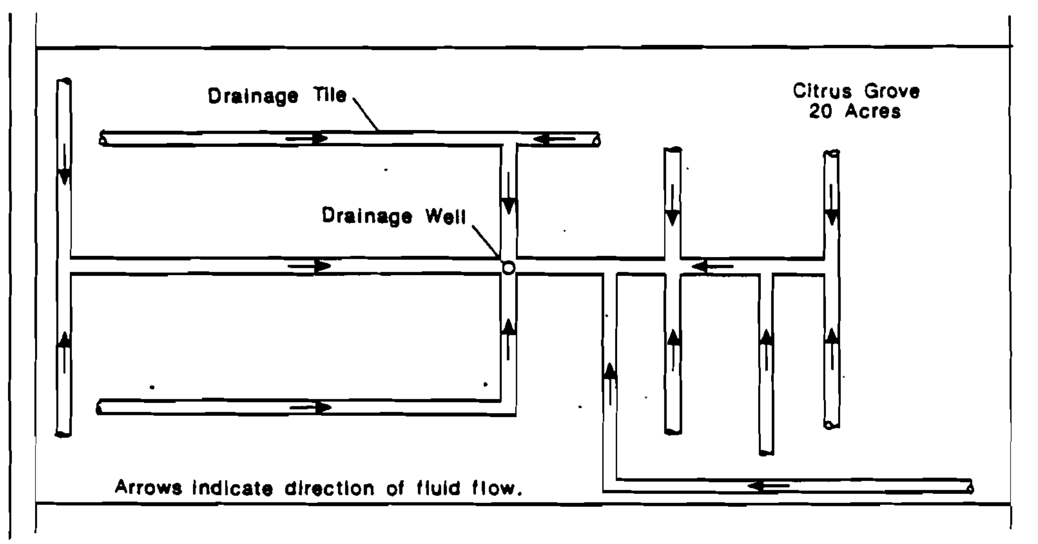
Well Construction, Operation, and Siting

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 4-1

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.

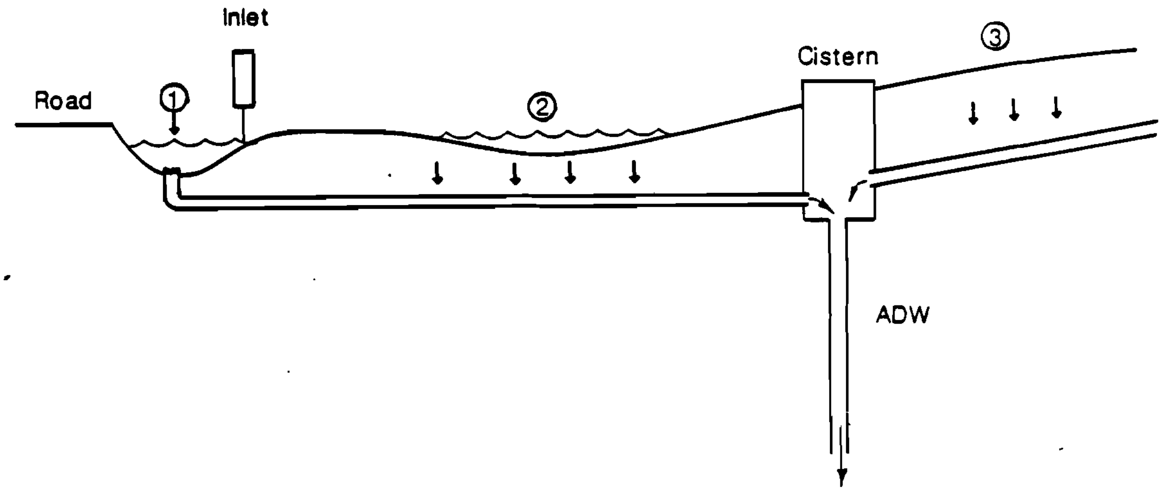
Generally, an agricultural drainage well system consists of a buried collection basin or cistern, one or more tile lines entering the cistern, and a drilled, or dug, cased well. The well may be a "dry well" (situated above the water table) or may be installed into a water bearing formation. Figure 4-3 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

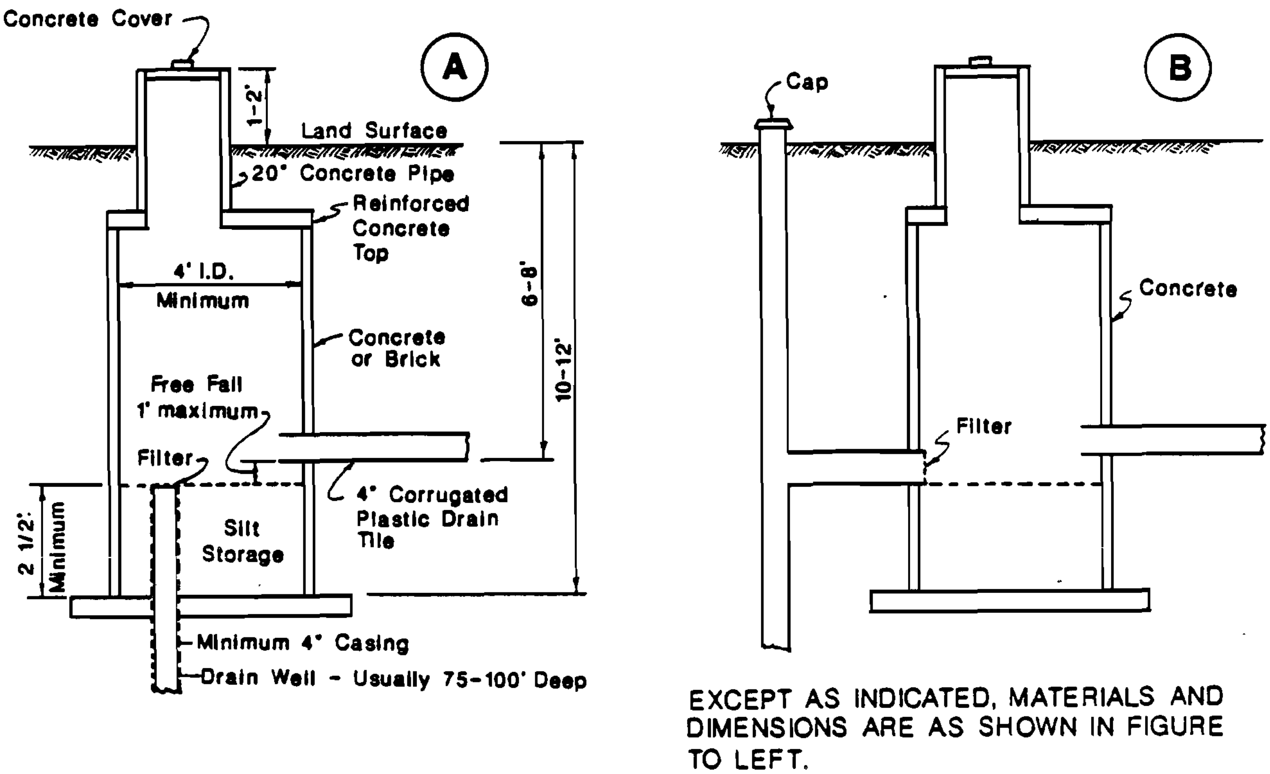
①Surface Flow

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 4-2



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)	4	—	—	<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

5F1

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	—	—	—

5F1

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)

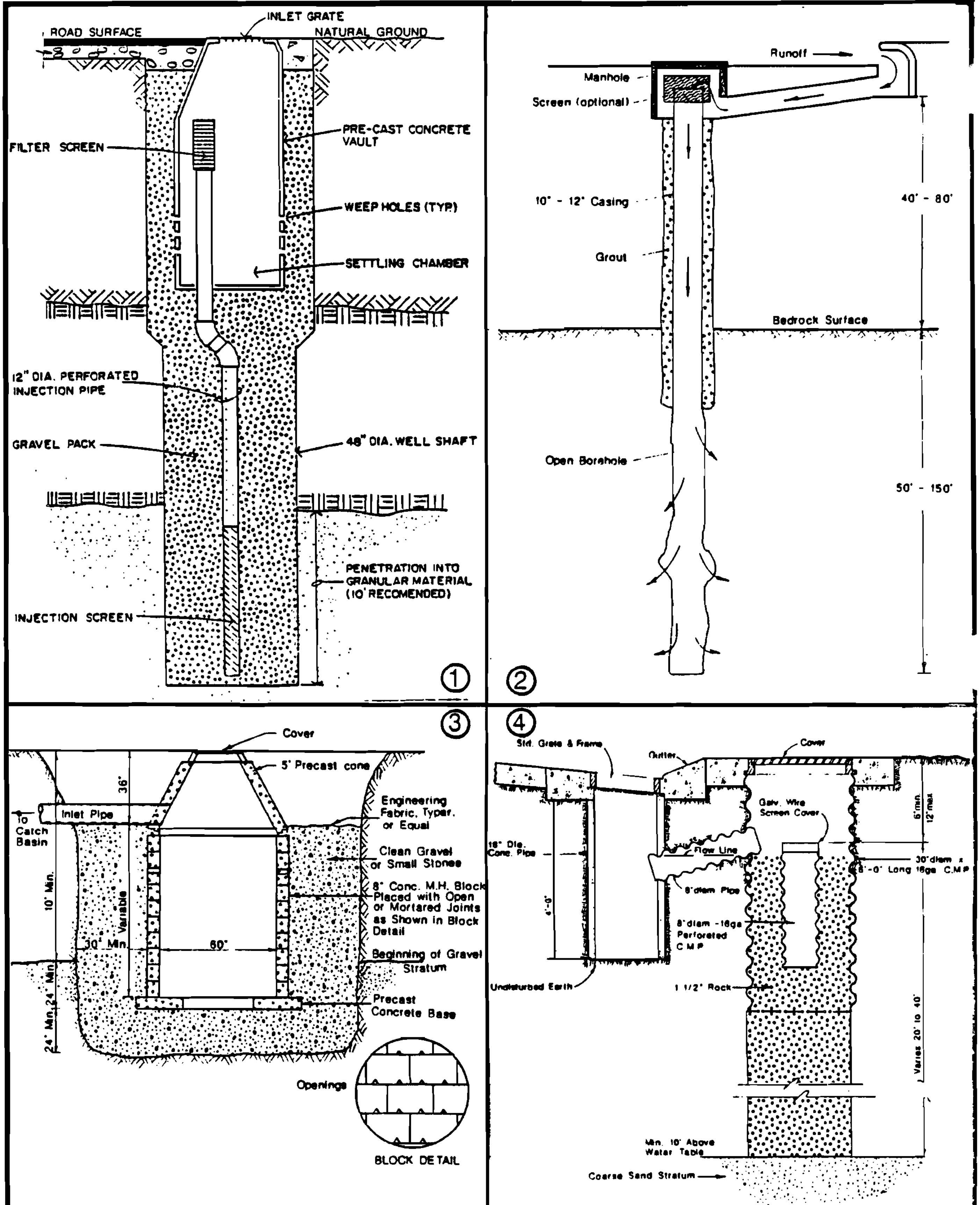
REGION & STATES	EPA REGION	Confirmed Presence Of Well Type	Regulatory System	Case Studies/ Info. available	Contamination Potential Rating
Connecticut	I	3 wells	PERMIT	NO	N/A
Maine	I	NO	N/A	NO	N/A
Massachusetts	I	19 WELLS	EXEMPT	YES	LOW
New Hampshire	I	NO	N/A	NO	N/A
Rhode Island	I	NO	N/A	NO	N/A
Vermont	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.

TABLE 4-5: SYNOPSIS OF STATE REPORTS FOR INDUSTRIAL DRAINAGE WELLS(5D4)

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	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	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 encountered. 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 indus trial 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.

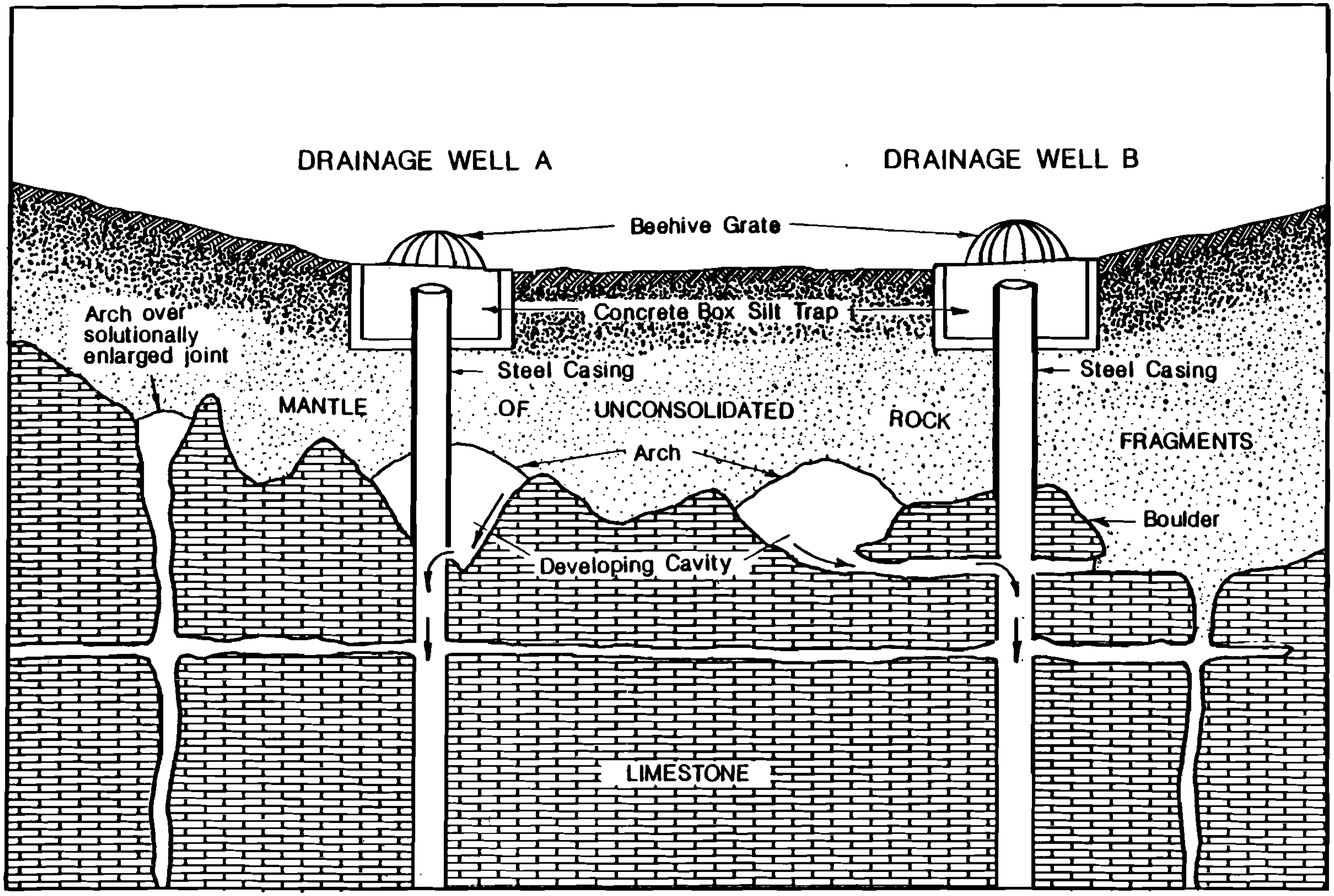
TABLE 4-6: SYNOPSIS OF STATE REPORTS FOR IMPROVED SINKHOLES(5D3)

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/B 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.

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)



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.

Figure 4-5

5D3

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 industrial 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 undér 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.

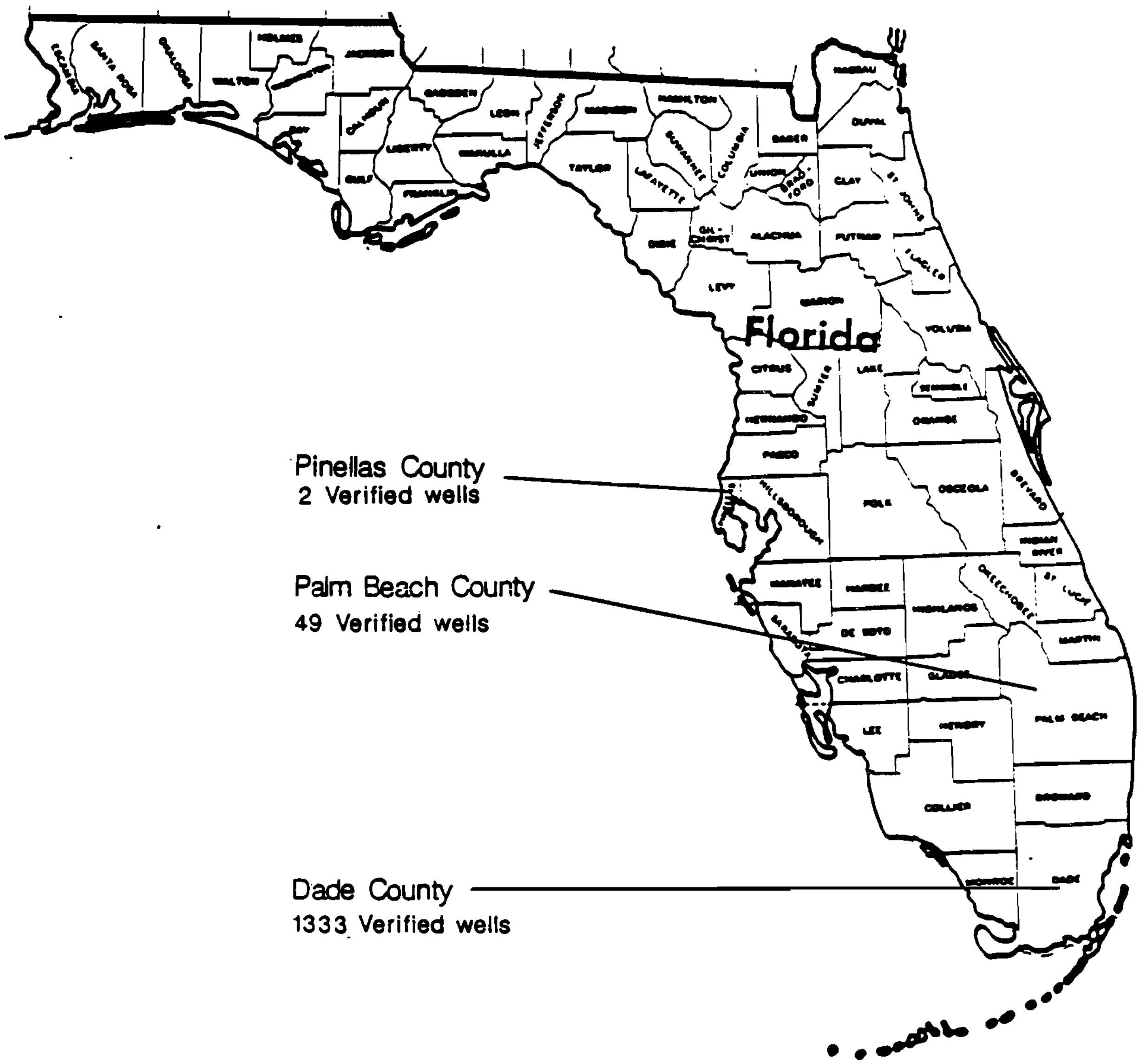
One special drainage well type was mentioned in the report from Louisiana. However, the report did not contain any details on this well type.

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.

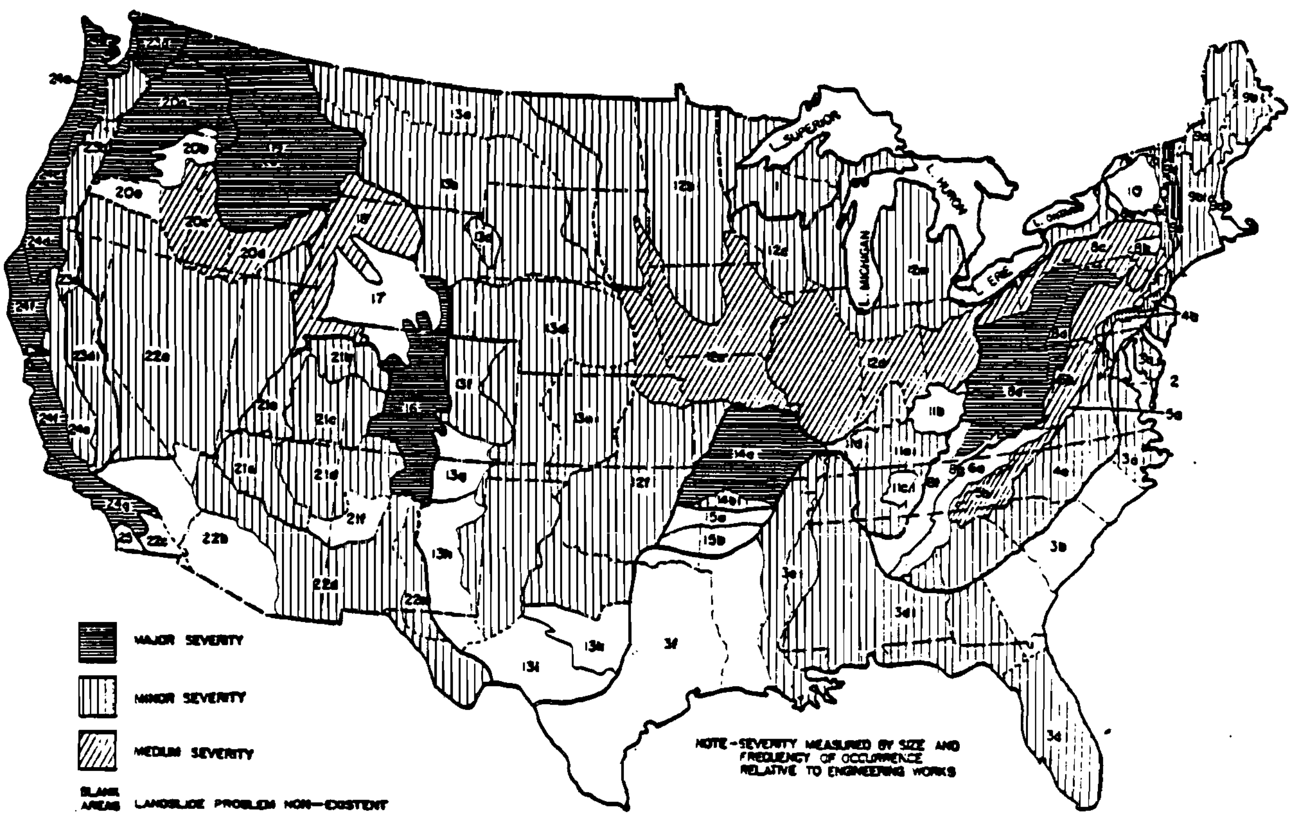
Well Construction, Operation, and Siting

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 Conemaugh; Monongahela; Dunkard	Fire clays
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	Nespelem silts; Astoria siltstone; Eocene shales	

(from Woods, Berry and Goetz, 1960)

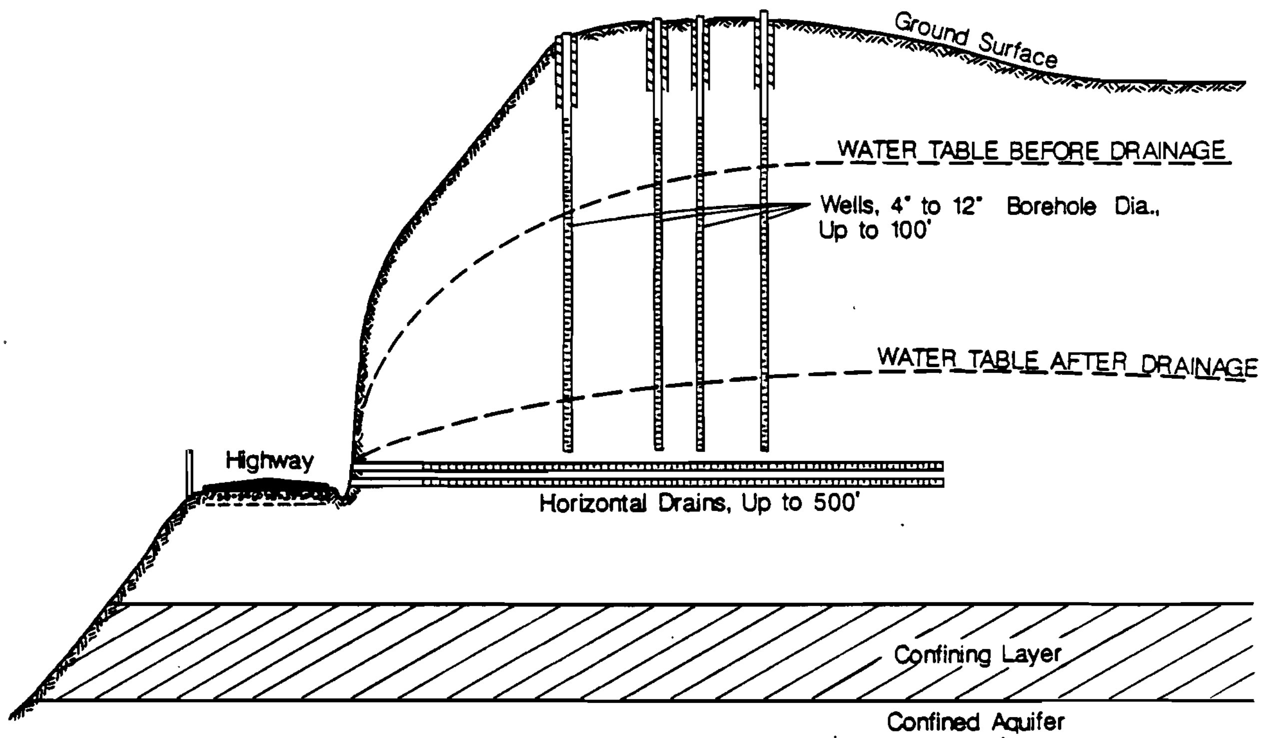
40 gallons/week while the discharge rate for the other two wells is unknown.

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 land-sliding in active slide areas.

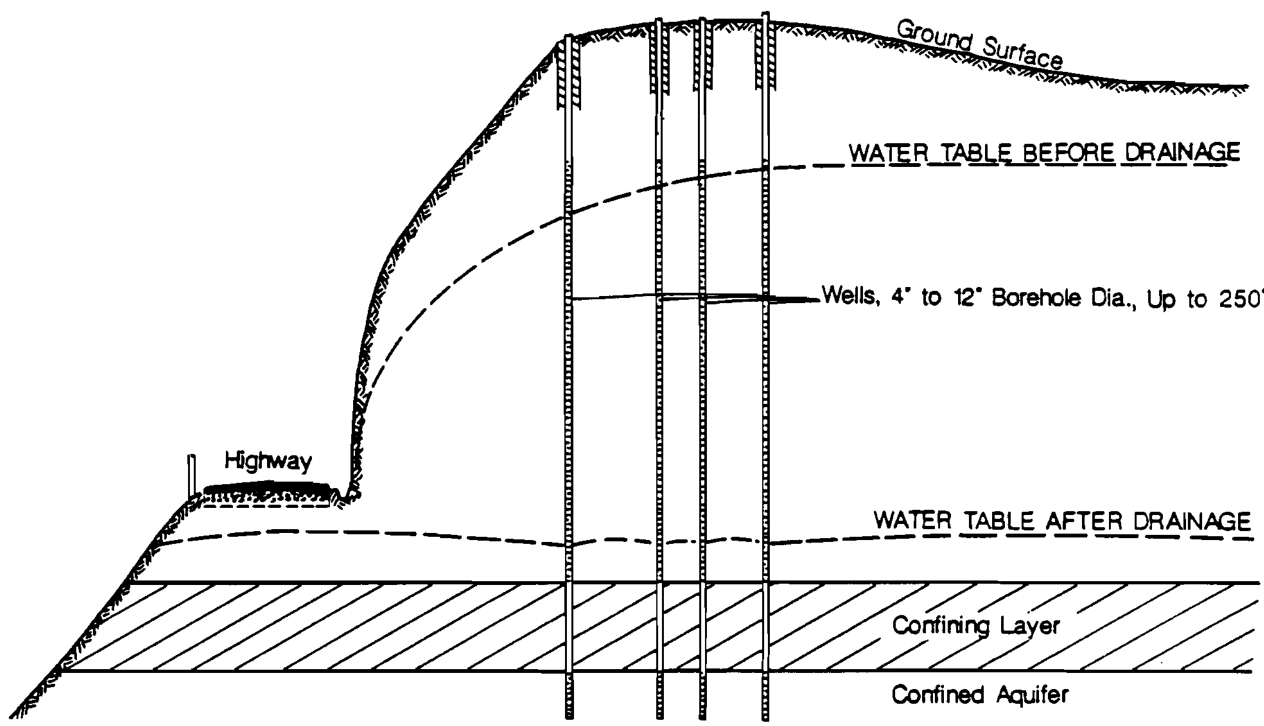
Two kinds of vertical drainage systems are employed to dewater slide areas. One method involves installation of a combination of vertical drainage wells and horizontal/subhorizontal drains. At the Craig and Lewistown sites, vertical drainage galleries, consisting of clusters of wells, are installed in 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-



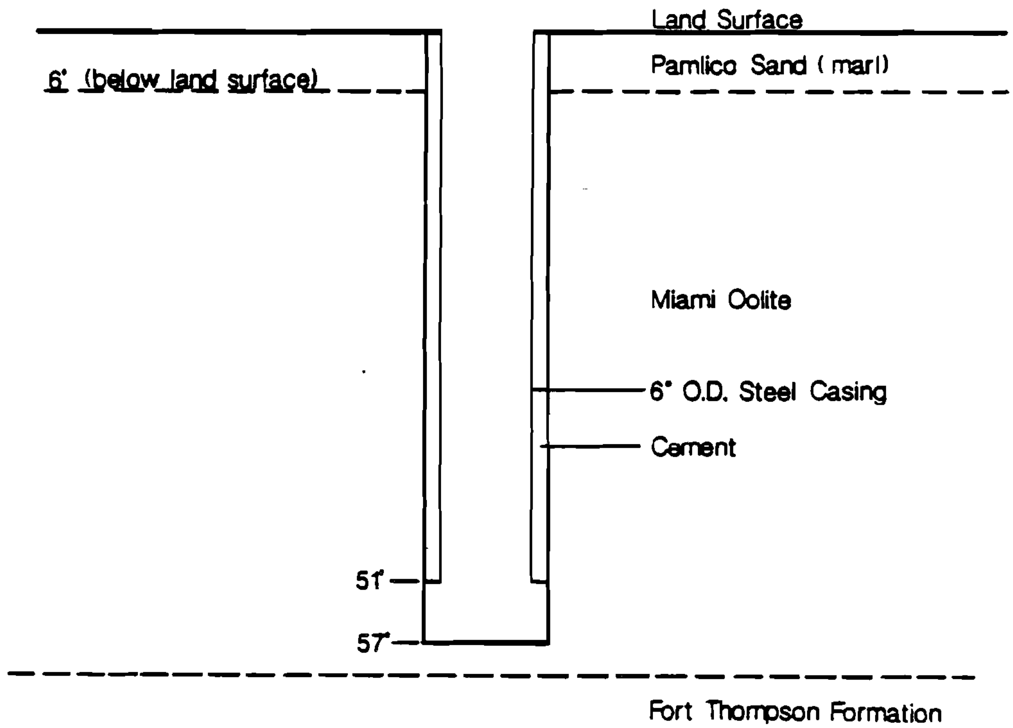
A. Combination of Vertical and Horizontal Drainage (employed in Lewiston & Craig, Montana)



B. Vertical Drainage (employed in Dillon, Montana)

METHODS EMPLOYED TO DEWATER LANDSLIDE PRONE AREAS

Figure 4-8



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.

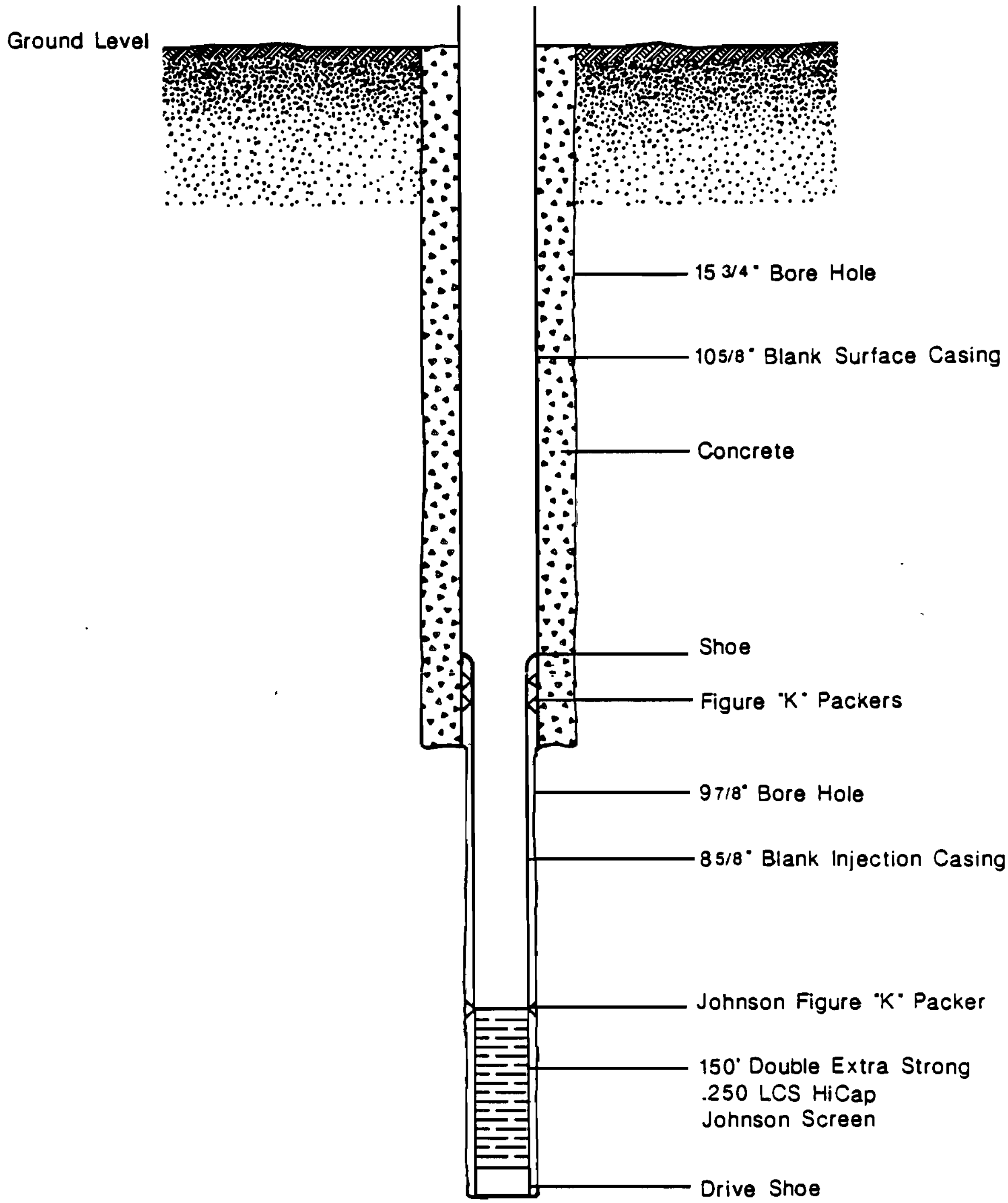
Direct Space Heating

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.

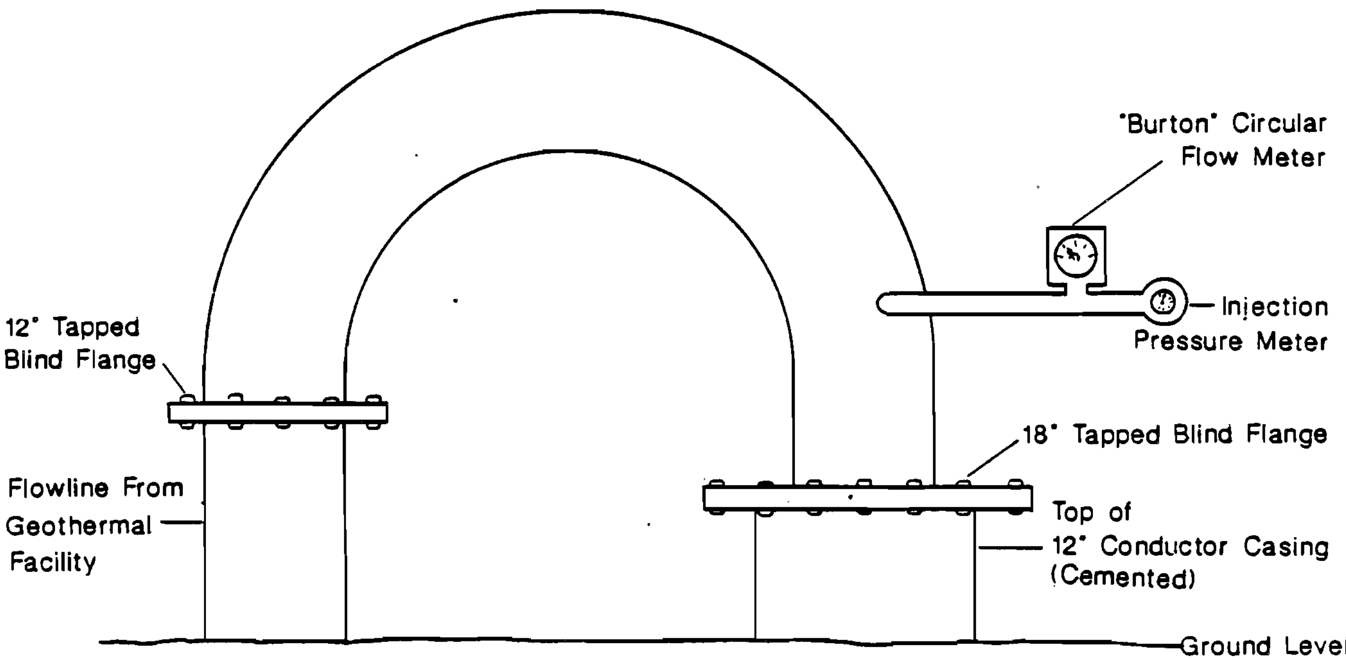
Present construction designs for these wells must address corrosive problems associated with cooled geothermal fluids. Casing made of low carbon steel with minimum .25 inch sidewall thickness is optimum. The casing should be cemented with a slurry consisting of approximately twenty percent bentonite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

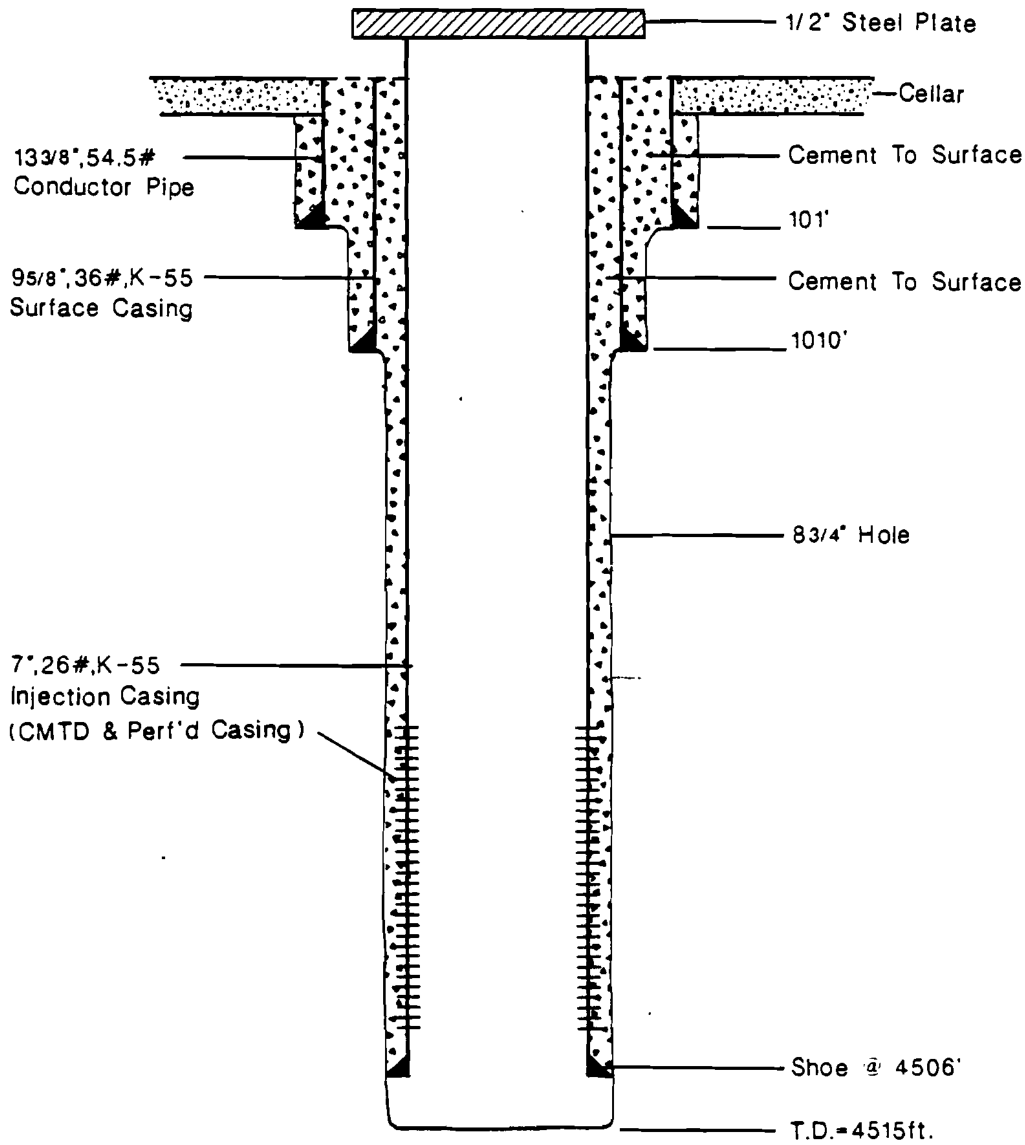
The design in Figure 4-12 features conductor casing that typically is not found with direct space heating facilities. The purpose of the conductor casing is to prevent shallow unconsolidated sediments from collapsing into the wellbore during



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 4-12

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.

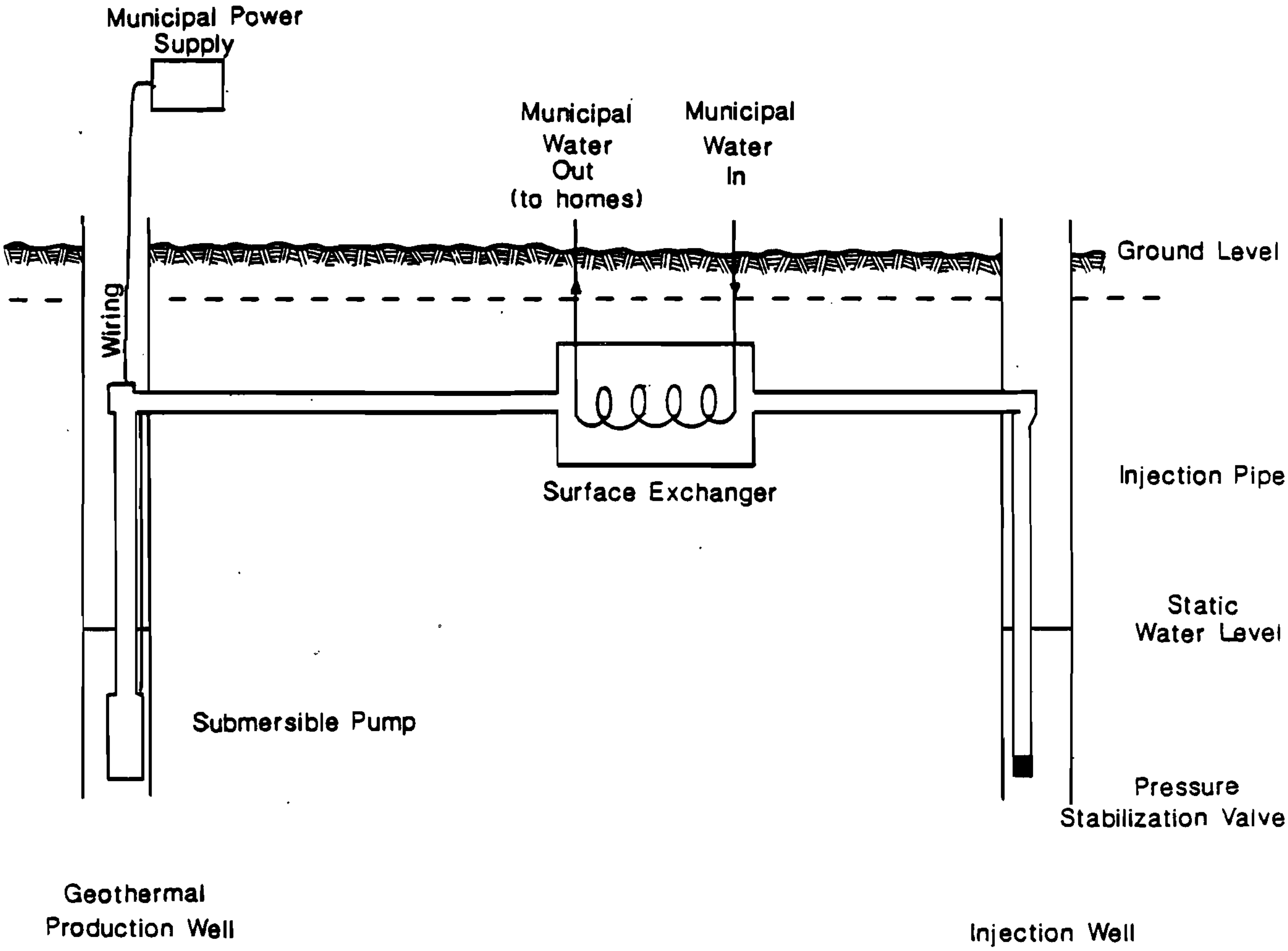
Both downhole and surface heat exchangers are used for direct space heating. Warren Estates, a new housing subdivision in Reno, Nevada, employs a centralized surface heat exchanger. This system is schematically presented in Figure 4-13. This system is ideal when a single, high volume production well 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.

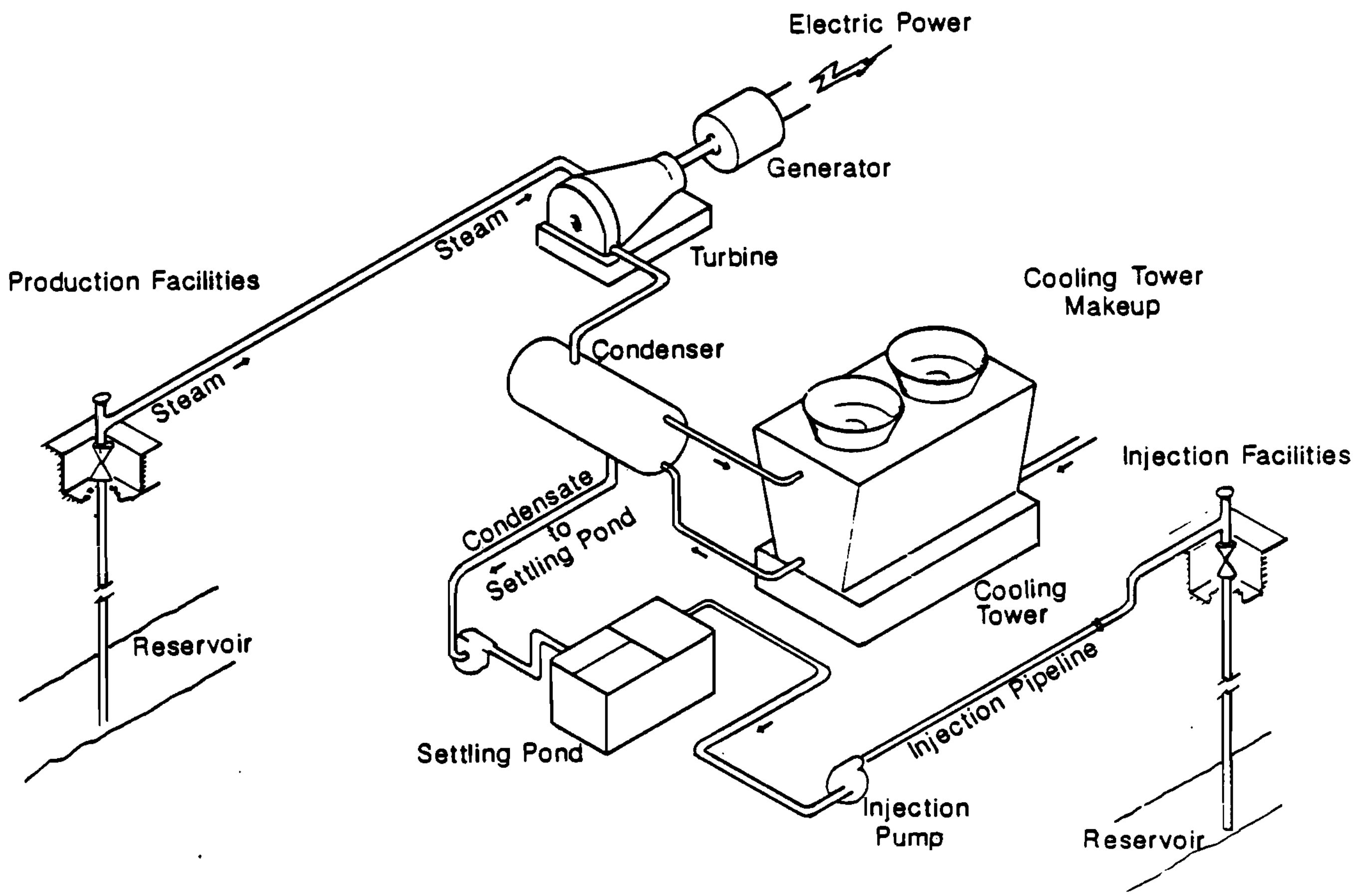
Dual phase systems are being used in California and Nevada. This system, diagrammatically represented in Figure 4-15, makes use of geothermal resources comprised partly of steam and partially of hot water (300 - 400°F).

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.

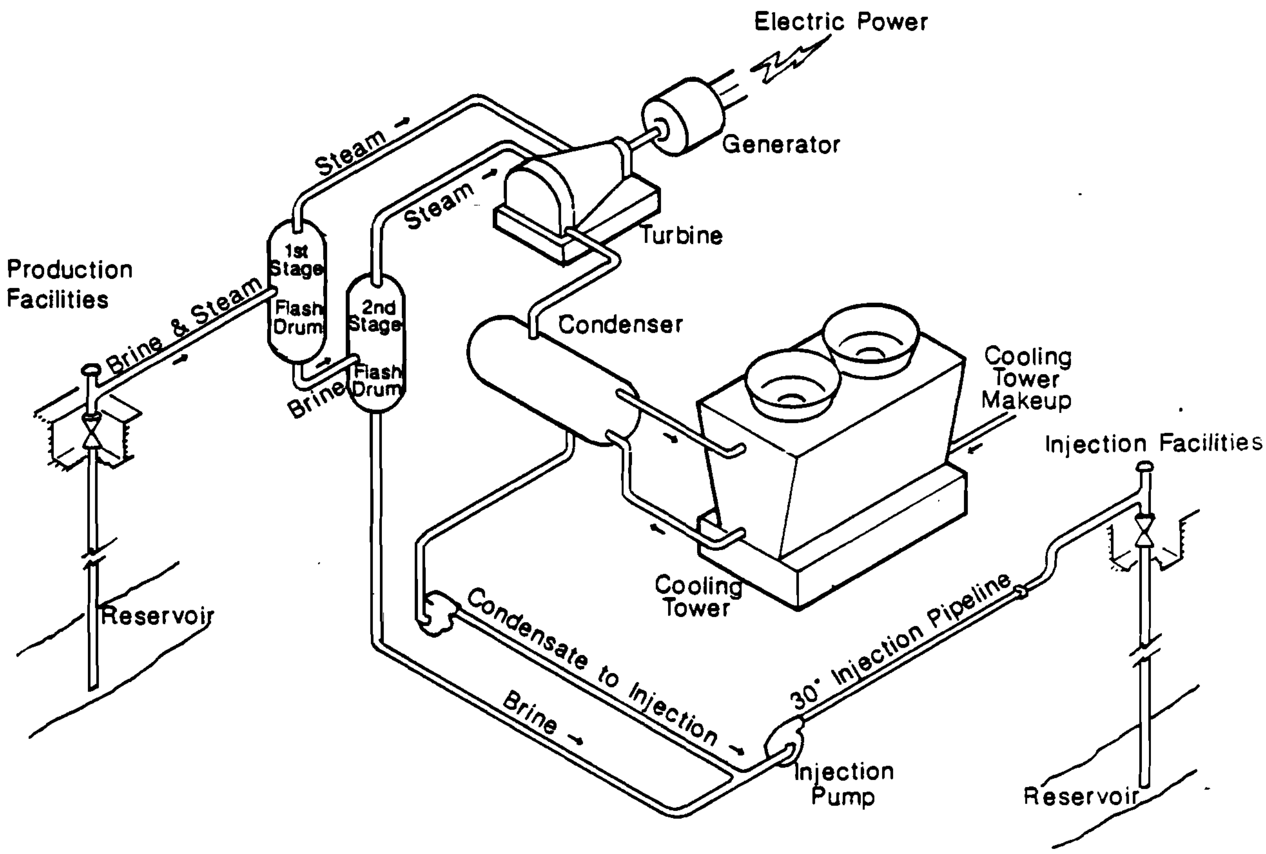
Several facilities using the Binary Method of electric power generation also are located in California and Nevada. A binary facility schematic is presented in Figure 4-16. This type of system is truly "closed." It is designed so that one hundred percent of the produced fluid is reinjected into the geothermal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



TYPICAL DRY STEAM ELECTRICAL POWER
GENERATION FACILITY

(after a figure provided by Chevron Geothermal)

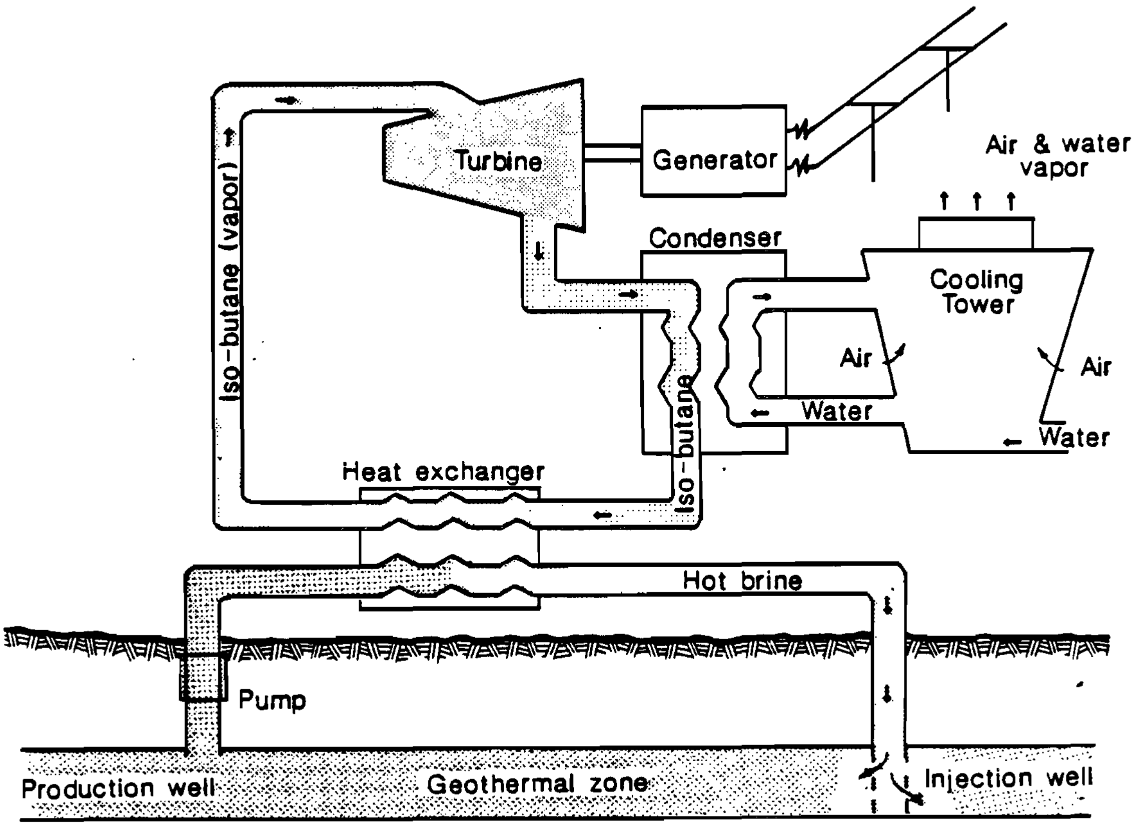
Figure 4-14



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, 1986
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/l)
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

5A5,6

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/l)
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 ($<150^{o}C$) 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^{O}F (120^{O}C). These fluids are considered ground-water resources and are the property of the public trust. Thermal fluids 250^{O}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.

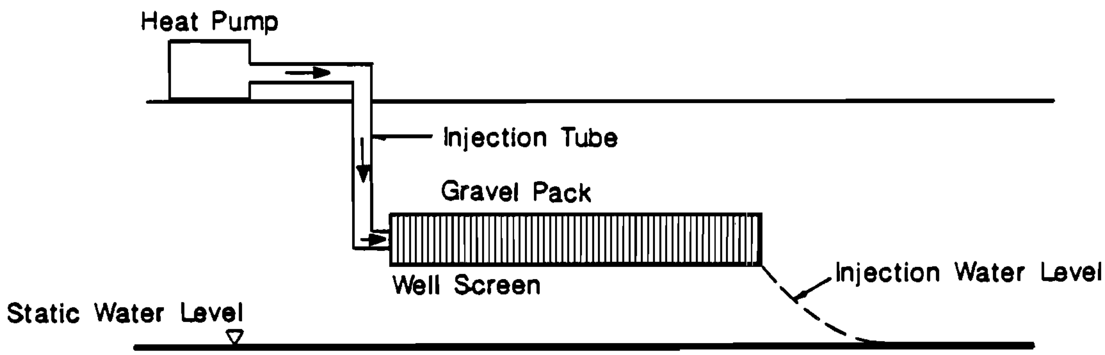
Well Construction, Operation, and Siting

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

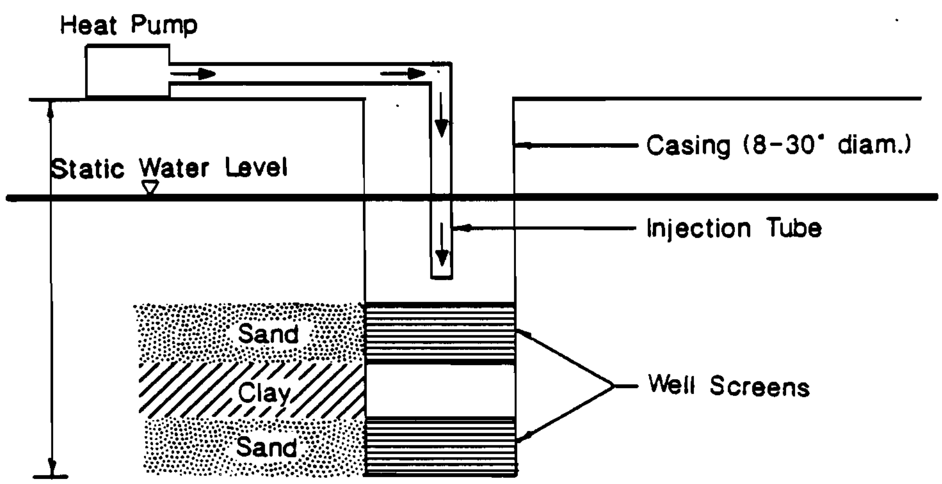
TABLE 4-24: SYNOPSIS OF STATE REPORTS FOR HEAT PUMP/AIR CONDITIONING RETURN FLOW WELLS(5A7)

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.

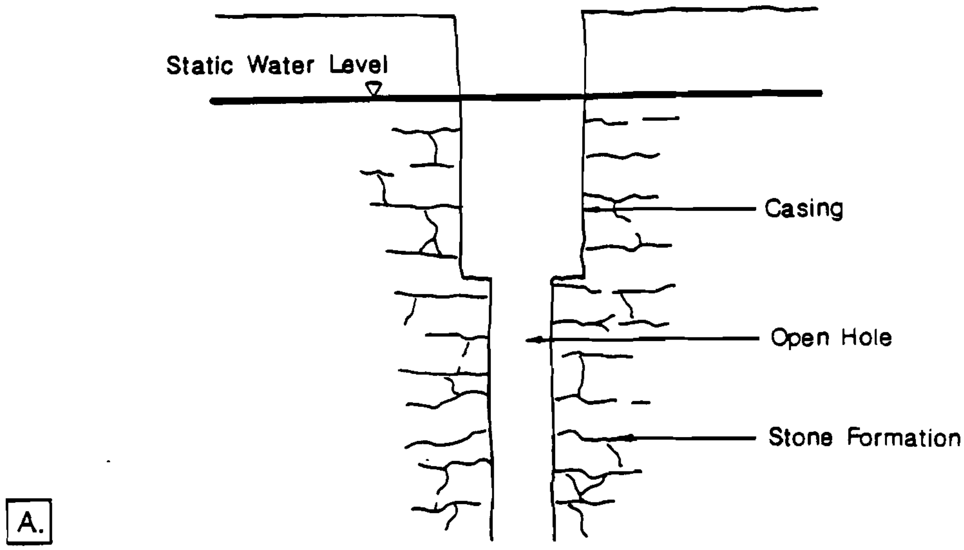


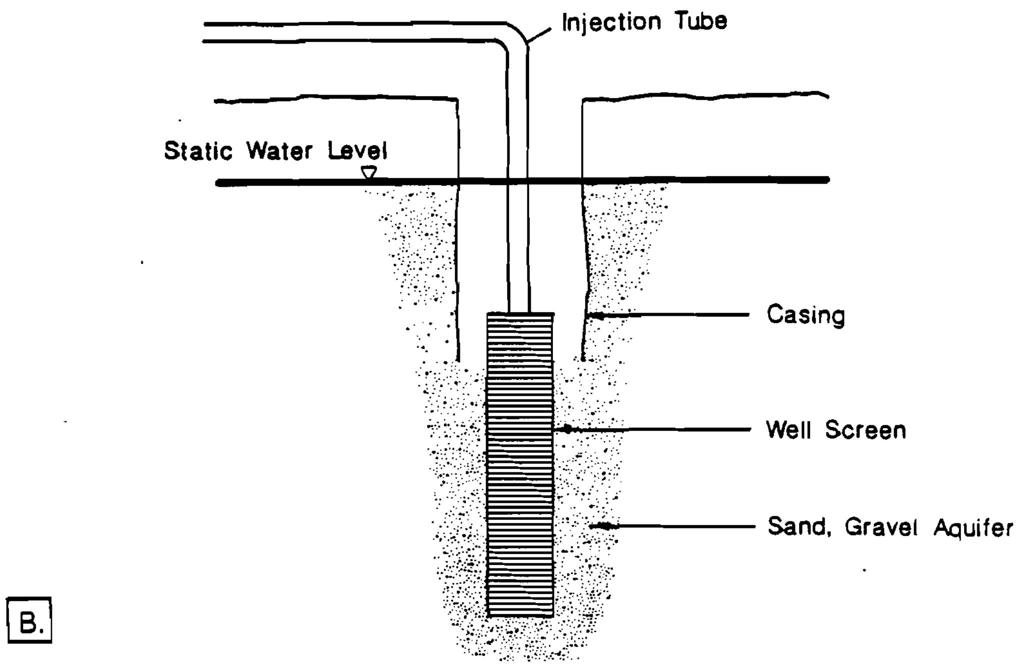
B.

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 4-18

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

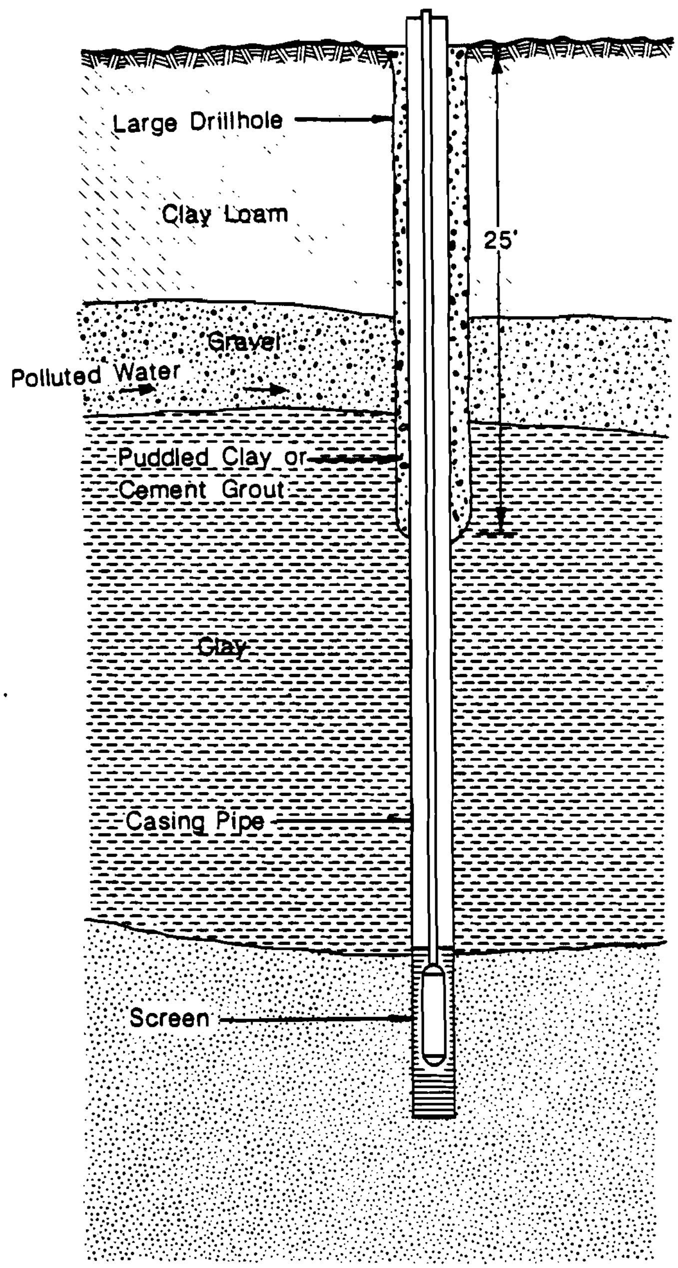
Operation. Although the most common operation of heat pump/air conditioning return flow wells is through gravity flow, this is not always possible. In aquifers with low permeabilities, return flow waters may need to be pressurized to produce sufficient infiltration rates. Also, most aquifers will not 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 ground-water 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

5A7

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.

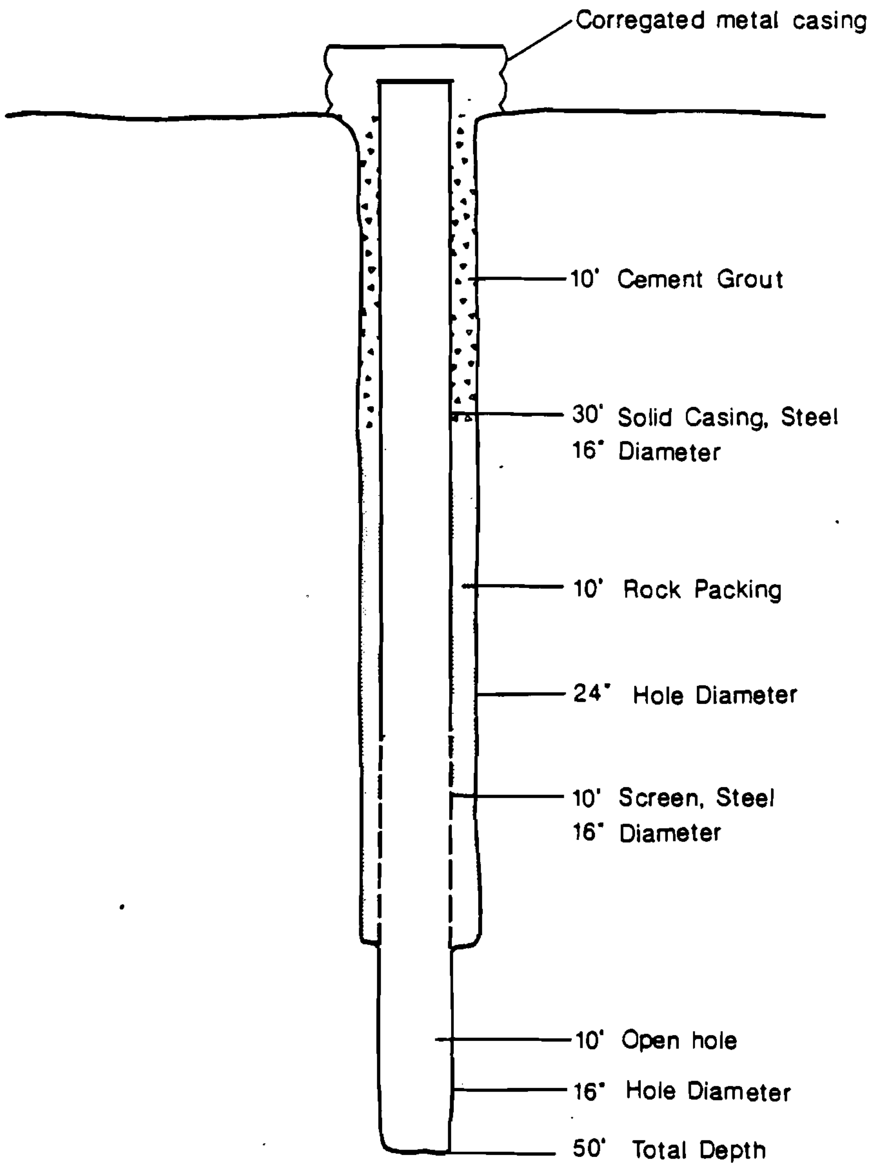
Some problems associated with reinjection of aquaculture wastewater include:

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 4-20

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.

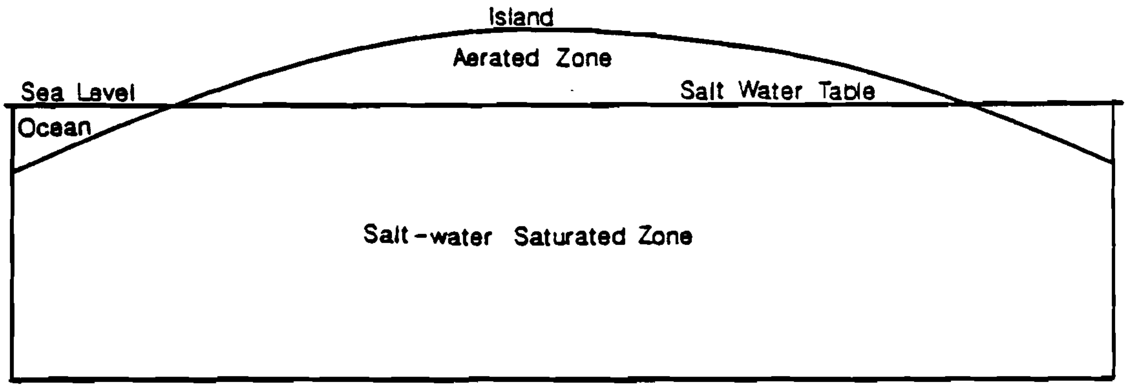
On the island of Hawaii, the proposed injection wells will be located at Keahole Point near Kailua-Kona, along the western island margin. The principal aquifer within this region is an unconfined sequence of basaltic lava flows. In general, the aquifer is highly permeable. This aquifer is the injection 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.

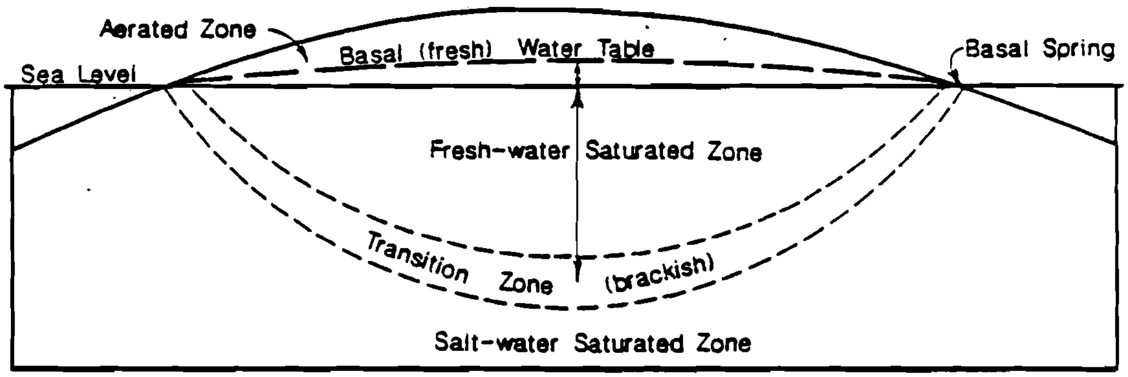
With the exception of rift zones and volcanoes, virtually all of the Hawaiian islands are saturated with sea water below sea level (Macdonald et al, 1983). Fresh ground water occurs in the form of a huge lens floating on sea water (Driscoll, 1986). Fresh basal water floating on salt water presses down 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

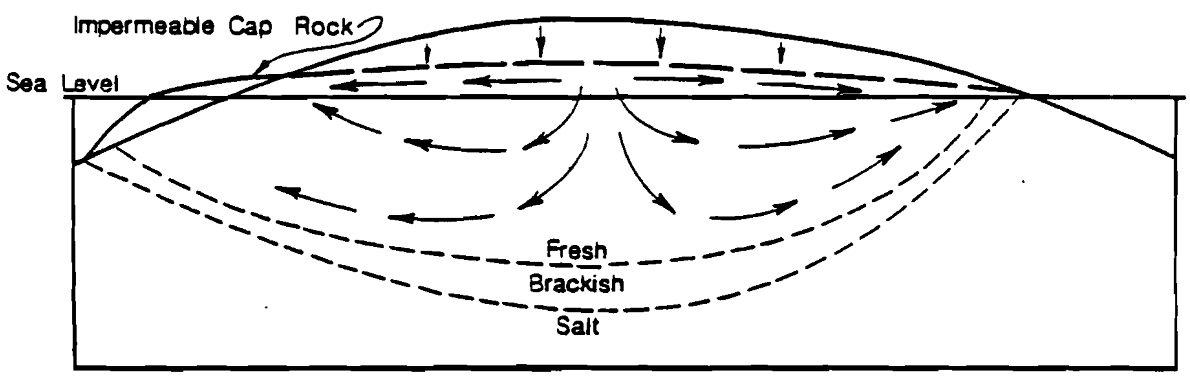
Based on the rating system described in Section 4.1, aquaculture return flow wells are assessed to pose a moderate potential to contaminate USDW. These facilities may or may not inject or above USDW (Class I and/or Class II). Typical well construction, operation, and maintenance would not allow fluid 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 4-21

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 construction 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;
   d. 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 overlie 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 1949 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>1K 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

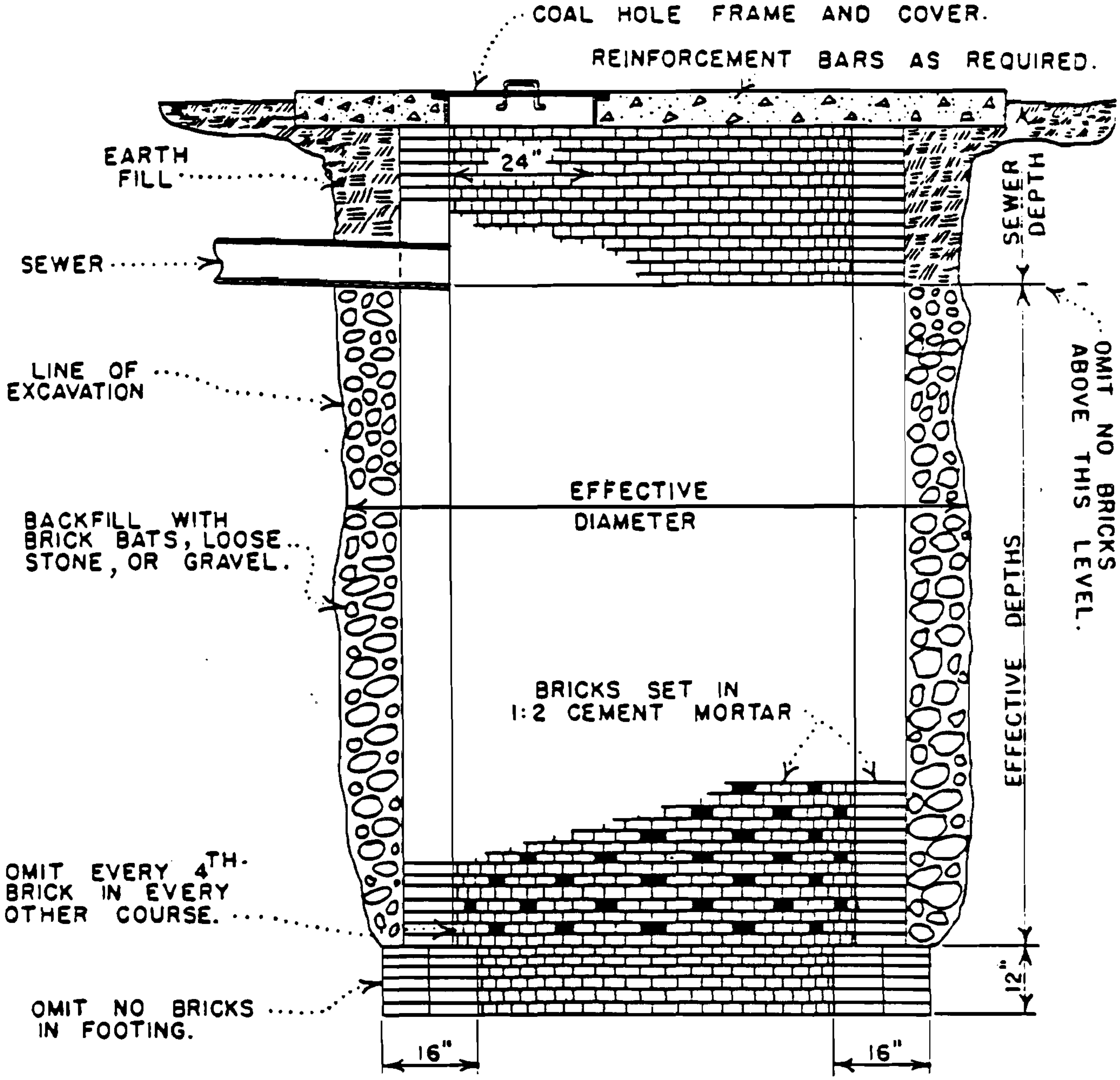
Injected Fluids. The quality of injected wastewaters discharged (by gravity) from Class V cesspools and raw sewage waste disposal wells is poor. These wells receive domestic sewage from individual homes, recreational facilities (i.e. campgrounds) and businesses. Sewage generated from these sources consists 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	150	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 6,000 Class V cesspools in Oregon inject raw sewage into water-bearing zones currently or potentially useable as drinking water sources. Shallow ground water tapped by 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 treatment is limited. In these areas lot size 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>18 FT	NO	6TH 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.

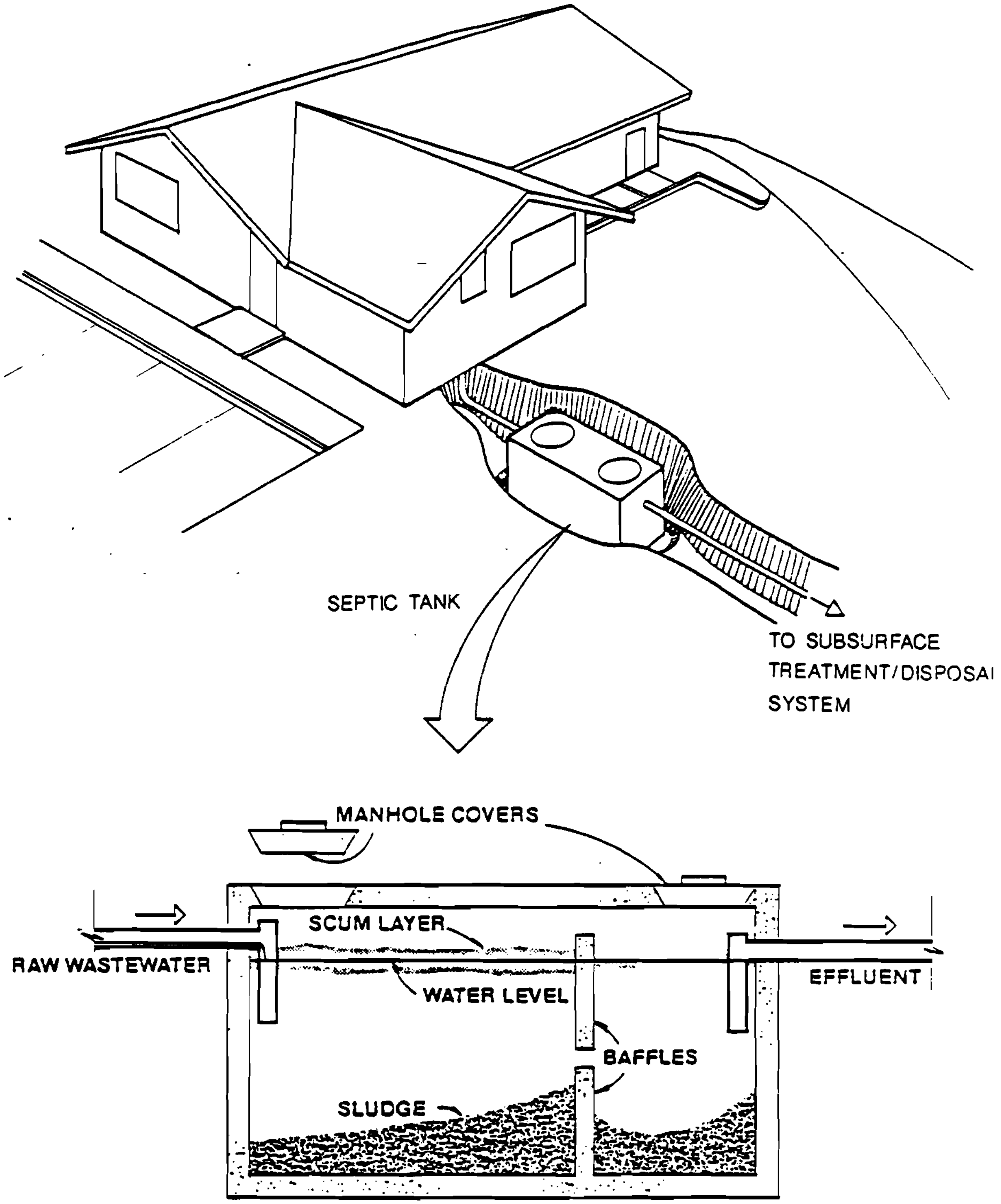
Construction, Siting and Operation

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).

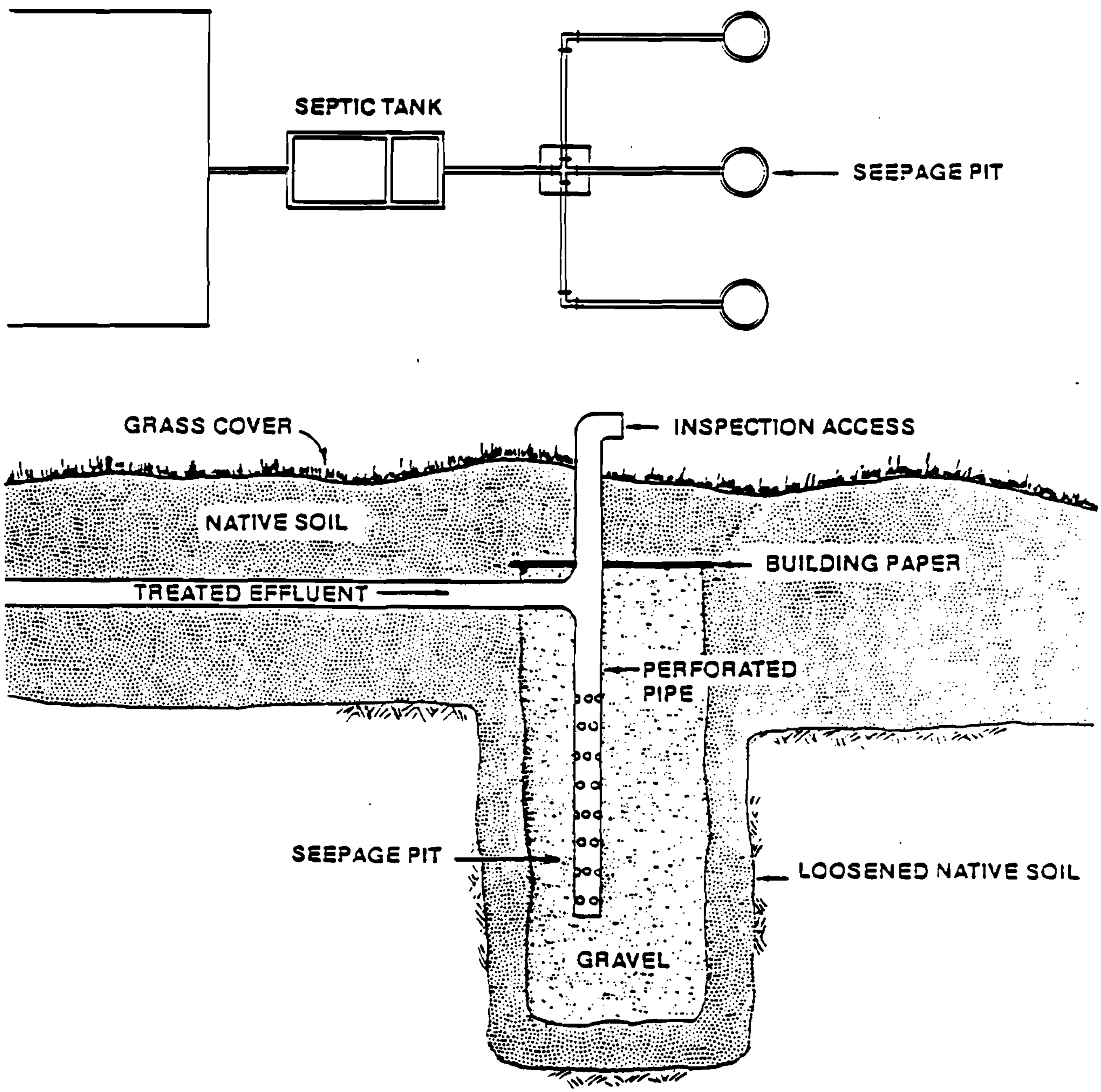
Configurations of drainfields include the conventional drainfield and the absorption mound system. Conventional drainfields consist of a series of perforated distribution pipelines (Figure 4-25) placed in trenches or shallow seepage beds. The perforated pipe is placed in the trench or bed at a slight 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

(adapted from James M. Montgomery, Consulting Engineers, 1979)

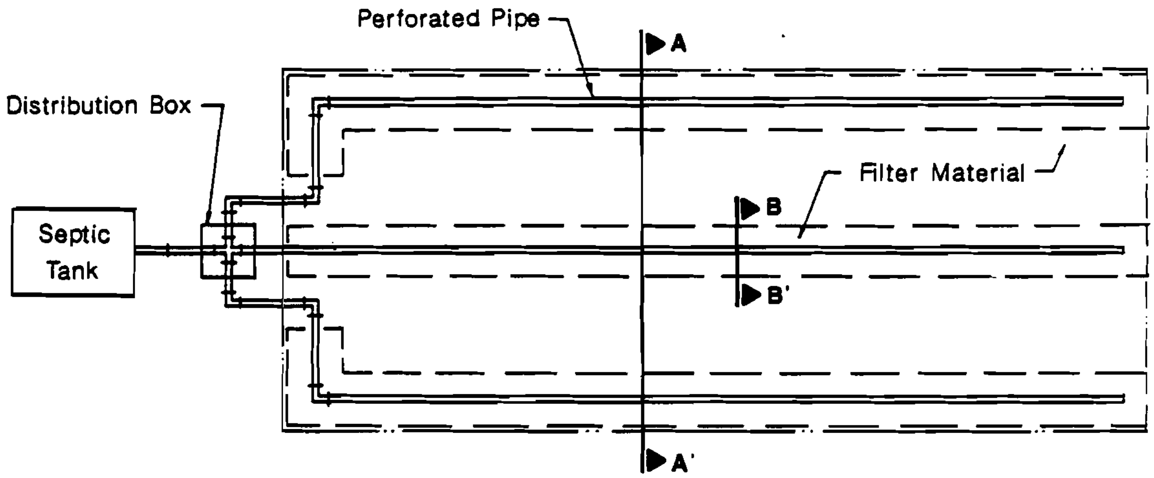
Figure 4-23



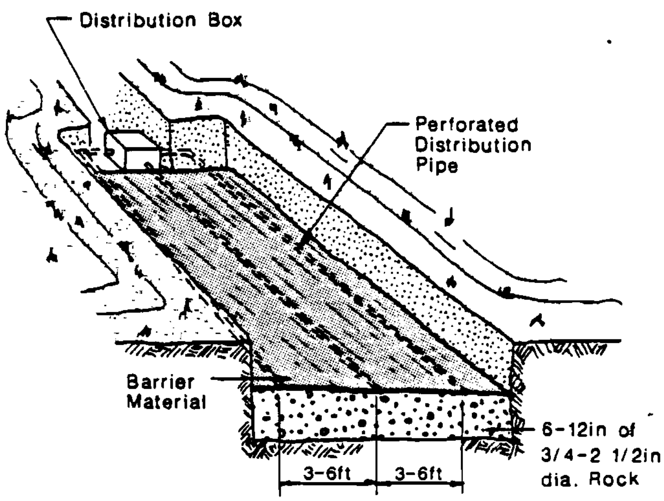
SEEPAGE PIT DISPOSAL SYSTEM

(from James M. Montgomery, Consulting Engineers, 1979)

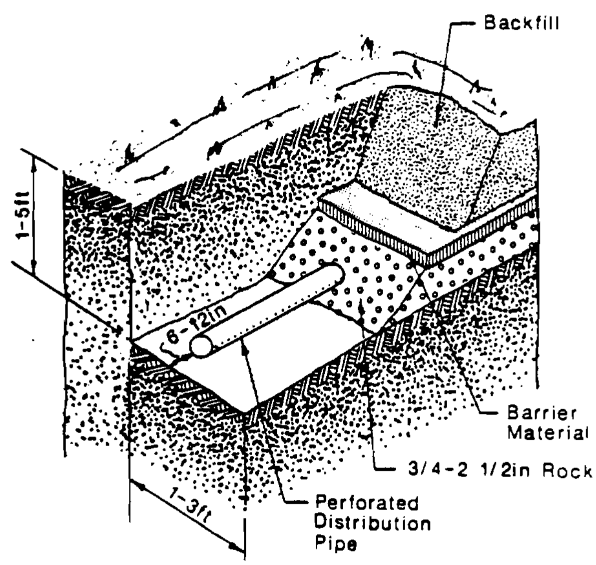
Figure 4-24



PLAN VIEW



SEEPAGE BED DESIGN SECTION A-A'



TRENCH DESIGN SECTION B-B'

CONVENTIONAL DRAIN FIELD DISPOSAL SYSTEMS

(from USEPA, October 1980 and James M. Montgomery, Consulting Engineers, 1979)

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

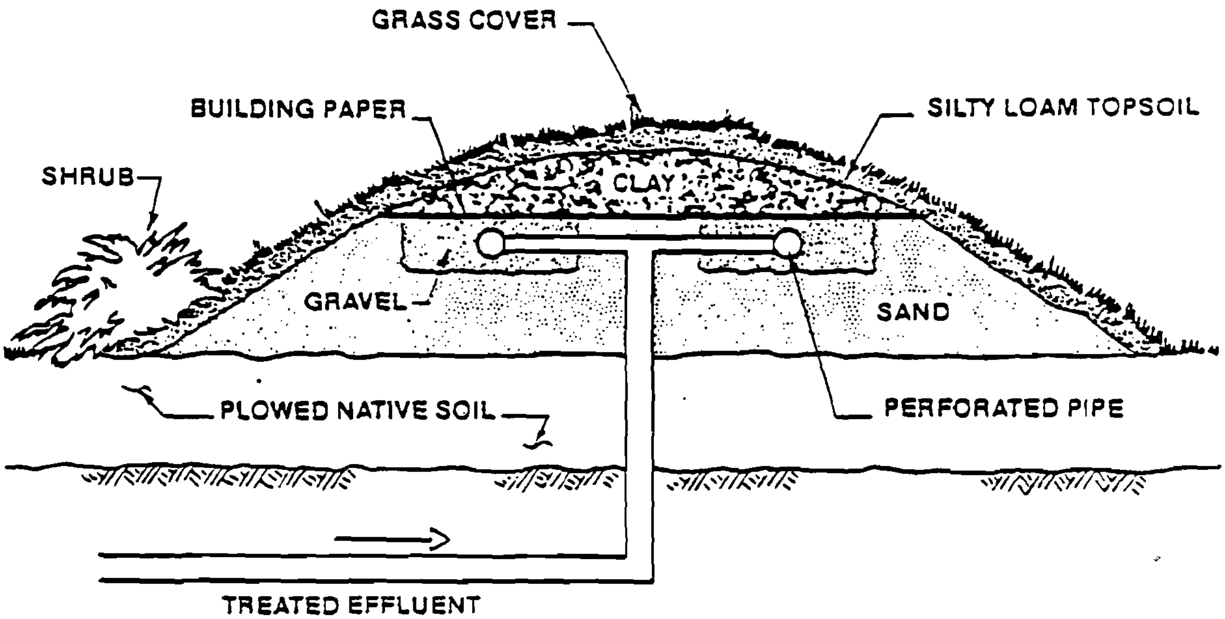
Domestic sewage from individual homes and large residential developments consists of approximately 99.9 percent water (by weight) and 0.03 percent suspended solids. Ranges of constituent concentrations found in domestic sewage are presented in Table 4-30 in the cesspool and raw sewage well assessment 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

(from James M. Montgomery, Consulting Engineers, 1979)

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. Viruses, in only rare instances, have been detected up to 400 meters in

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.

DWA 11,31,32

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 vadose zones.

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) because there are few such wells identified. Massachusetts rates them low because they are permitted, and permit conditions limit both injection and siting. South Carolina reports over 200 and rates them as low based upon the permitting system in place.

Other States such as Nevada, Alaska, Ohio, Nebraska, and Montana rate these same sub-types as having high pollution potential. This presents a dilemma in providing a national generic assessment. It seems clear that the best approach is to rate these injection practices by their unregulated potential. Therefore, all septic systems are assessed as having a high contamination potential.

Septic Systems (Well Disposal Method 5W31). In general, septic systems are used in residential areas. Very often they are found in combination with private or public water supply wells completed into the surficial aquifer. Class V septic systems are located in areas which are not publicly sewered or lack sufficient capacity to service rapid residential development.

Properly designed, constructed, and operated septic systems prvide an adequate method of treatment and renovation of human waste and biodegradable domestic waste. However, evidence is growing that systems often do not operate as designed. Septic systems treat nitrogen, microorganisms, and total solids to varying degrees. Synthetic organic compounds potentially present in wastewater are not treated. As a result, septic tank effluent has been found to contain contaminants which exceed MCLs (maximum contaminant levels) or are "hazardous". This effluent drains into a well which may inject directly into an USDW.

Septic Systems (Drainfield Disposal Method, 5W32). The discussion on the nature of the injectate applies equally to this sub-class of well. In fact, systems lacking the septic tank, consisting of a drain field only have been reported being used for the disposal of industrial wastes. These are rated in Section 4.2.6.2, later in the report.

The design advantage of a septic tank followed by a drainfield is that a properly designed and operated system can provide treatment and renovation for sanitary wastes. Such a system can be a very practical solution to the disposal of sanitary wastes in unsewered areas. However, in view of the nature of modern domestic waste and the wide spread potential for abuse, including the often reported dual use of residential systems to include industrial and commercial wastes, such wells should be rated as having a high contamination potential. The potential seems even higher when it is recalled that the abuse of septic systems may destroy the treatment of pathogens and the biological processes in the tank and drainage field. The result is the subsurface emplacement of untreated liquid wastes which endanger USDW.

Current Regulatory Approach

Class V septic systems are authorized by rule under Federally-administered UIC programs (see Section 1). Many States regulate discharges of sanitary sewage to ground water by flow rate categories. In Massachusetts for example,

> Domestic discharges greater than 15,000 GPD require a permit and are regulated under the Groundwater Discharge Permit Program... Discharges into structures or pits that are deeper than they are wide qualify as underground injection control facilities. Those UIC facilities (which are not exempted) are required to obtain a groundwater discharge permit.

Many States report that no records are kept of single family septic systems. These may be registered with a local jurisdiction, and approved by a sanitarian, but those records may not be available to the State.

South Carolina gives a good description of the relationship of State Agencies.

> In South Carolina, wastewater disposal systems comprised of septic tank/absorption fields are regulated by two permitting programs within the South Carolina Department of Health and Environmental Control. The Bureau of Environmental Sanitation issues permits for facilities involving restaurants, laundromats, car washes and individual residential systems. The Bureau of Water Pollution Control issues construction and operating permits for all other industrial and sanitary land disposal systems, including septic tank/tile field systems.
>
> The permitting program of each Bureau issues a permit of approval or denial for tile field disposal only after a rigid assessment of the overall potential environmental impact from the proposed system. The site specific assessment includes an investigation of potential impact to the shallow aquifer system and takes into consideration wastewater characteristics, hydrogeological conditions of the proposed site, and any existing and/or potential ground-water use in the area. Hydrogeological site assessments are performed by staff hydrogeologists of the Groundwater Protection Division for systems regulated by the Bureau of Water Pollution Control. Soil classifiers (sanitarians) perform preliminary site assessments for the Bureau of Environmental Sanitation. On occasion, a hydrogeologist from the Groundwater Protection Division 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.