~~EER~~W1 82-

EER-WP.12.821

ENGINEERING & ECONOMICS RESEARCH, INC.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

~~EER 82~~

EERWP-12-821

THE IMPLICATIONS OF UIC AND NPDES REGULATIONS
ON SELECTION OF DISPOSAL OPTIONS
FOR SPENT GEOTHERMAL BRINE

July 1982

Prepared For:

Geothermal and Hydropower Technologies Division
U.S. Department of Energy

Project Officer:
Leon Lehr
R. Costello

Prepared By:

Engineering and Economics Research, Inc.
1951 Kidwell Drive, Suite 201
Vienna, VA 22180

Contract No. DE-AC-01-81RA-50415
EER Project No. ET23I

TABLE OF CONTENTS

	<u>Page</u>
LIST OF EXHIBITS	iv
SUMMARY	S-1
1.0 CONCLUSION AND RECOMMENDATIONS	1-1
2.0 INTRODUCTION	2-1
2.1 Background	2-1
2.2 Purpose	2-2
2.3 Scope	2-3
3.0 REGULATORY REQUIREMENTS	3-1
3.1 Legislative History of the Regulations	3-1
3.1.1 The Consolidated Permitting Process	3-2
3.1.2 The States' Role in Drinking Water Regulation Enforcement	3-3
3.2 The Safe Drinking Water Act	3-4
3.2.1 Legislative Background	3-4
3.2.2 Underground Injection Control	3-4
3.3 The Clean Water Act	3-9
3.3.1 Legislative Background	3-9
3.3.2 National Pollutant Discharge Elimination System Regulations	3-9
3.3.2.1 Definitions	3-11
3.3.2.2 Emissions Criteria	3-12
4.0 WASTE CHARACTERIZATION	4-1
4.1 Quantity of Wastewater	4-4
4.2 Quality of Wastewater	4-6
5.0 TREATMENT AND DISPOSAL OPTIONS	5-1
5.1 Surface Disposal Systems	5-1
5.1.1 Direct Release to Surface Waters	5-1
5.1.2 Chemical Treatment and Disposal	5-2
5.1.3 Evaporation and Ponding	5-4
5.1.4 Land Application	5-5
5.1.5 Cascading Use	5-5
5.2 Subsurface Disposal	5-7

TABLE OF CONTENTS (Concluded)

	<u>Page</u>
6.0 EVALUATION OF TREATMENT/DISPOSAL OPTIONS	6-1
6.1 Regulatory Implications	6-1
6.2 Technological Readiness	6-9
6.2.1 Surface Disposal	6-9
6.2.2 Subsurface Disposal	6-13
6.3 Economics	6-15
6.3.1 Surface Disposal	6-15
6.3.1.1 Direct Discharge	6-16
6.3.1.2 Zero Discharge	6-17
6.3.2 Subsurface Disposal	6-23
6.3.2.1 Capital Costs of Injecting	6-23
6.3.2.2 Operations and Maintenance Costs of Injecting	6-27
6.4 Environmental Considerations	6-29
6.4.1 Surface Disposal	6-29
6.4.2 Subsurface Disposal	6-29

LIST OF EXHIBITS

<u>Exhibit</u>	<u>Page</u>
3.1 State with the Greatest Potential for Moderate- to High-Temperature Geothermal Resources	3-5
3.2 Overview of Class III vs. Class V Injection Wells	3-8
3.3 EPA-Designated Primary Industries Which Are Most Likely to Utilize Geothermal Energy	3-14
3.4 Temperature Requirements of Geothermal Applications on the EPA NPDES Industrial List	3-15
3.5 Pollutants Cited by NPDES Regulations Most Likely to be Present in Geothermal Waste Stream	3-16
4.1 Simplified Flow Diagram of a Binary Cycle Geothermal Power Plant	4-2
4.2 Comparison of the Wastewater Discharge of Fossil-Fuel Power Plant and Geothermal Power Plant (Millions of Gallons/Day)	4-5
4.3 Common Chemical Species Found in Geothermal Fluids and Their Concentration (ppm)	4-7
4.4 List of Chemical Additives Used for Scale Control in Geothermal Power Plants	4-9
4.5 Chemical Species and Their Concentrations (ppm) Present in Cooling Tower Blowdown	4-11
5.1 Simplified Process Flow Diagram for the Removal of Solids	5-3
5.2 Multipond Surface Evaporation System	5-6
5.3 Common Injection Rate of Geothermal Power Plants and Other Industrial Waste Disposal Systems	5-8
6.1 EPA Quality Criteria for Water	6-3
6.2 Pollutants Limited by Water Quality Standards in States With Geothermal Potential	6-8
6.3 Wastewater Treatment Processes for Removing Heavy Metals	6-11
6.4 Waste Disposal Assumptions - The Hypothetical Plant: Direct Discharge (1981 Dollars)	6-14

LIST OF EXHIBITS (Concluded)

<u>Exhibit</u>	<u>Page</u>
6.5 Capital Cost Per Mile Direct Discharge Option (\$1,000s of 1981)	6-18
6.6 Total Costs Per Mile (\$1,000s of 1981 Dollars)	6-19
6.7 Waste Disposal Assumptions - The Hypothetical Plant = Zero Discharge (1981 Dollars)	6-20
6.8 Capital Cost of Zero Discharge (Millions of 1981 Dollars)	6-21
6.9 Total Cost of Zero Discharge (Millions of 1981 Dollars)	6-22
6.10 The Relative Cost of Geothermal Injection Wells as a Function of Well Diameter	6-24
6.11 Cost of Drilling and Completing A Geothermal Injection Well (1981 Dollars)	6-25
6.12 Waste Disposal Assumptions - The Hypothetical Plant (1981 Dollars)	6-27
6.13 The Cost of Injection (\$1,000 of 1981 Dollars)	6-28

SUMMARY

This document reviews and evaluates the various options for the disposal of geothermal wastewater with respect to the promulgated regulations for the protection of surface and groundwaters. The Clean Water Act of 1977 and the Safe Drinking Water Act Amendments are especially important when designing disposal systems for geothermal fluids. The former promulgates regulations concerning the discharge of wastewater into surface waters, while the latter is concerned with the protection of ground water aquifers through the establishment of underground injection control (UIC) programs.

There is a specific category for geothermal fluid discharge if injection is to be used as a method of disposal. Prior to February 1982, the UIC regulations required geothermal power plant to use Class III wells and direct use plants to use Class V wells. More stringent regulatory requirements, including construction specification and monitoring, are imposed on the Class III wells. On February 3, 1982, the classification of geothermal injection wells was changed from a Class III to Class V on the basis that geothermal wells do not inject for the extraction of minerals or energy, but rather they are used to inject brines, from which heat has been extracted, into formations from which they were originally taken. This reclassification implies that a substantial cost reduction will be realized for geothermal fluid injection primarily because well monitoring is no longer mandatory.

The Clean Water Act of 1977 provides the legal basis for regulating the discharge of liquid effluent into the nation's surface waters, through a permitting system called the National Pollution Dis-

charge Elimination System (NPDES) Discharge quantities, rates, concentrations and temperatures are regulated by the NPDES permits. These permits systems are based upon effluent guidelines developed by EPA on an industry by industry basis. For geothermal energy industry, effluent guidelines have not been formulated and are not currently scheduled. There, are however, water quality standards that control the quantity and quality of wastewaters discharged into surface waters. These standards are established by the states in concert with EPA, and frequently result in NPDES conditions more restrictive than those based on effluent guidelines.

Several disposal options were evaluated in this report. For surface disposal systems, they include:

- Direct release to surface waters
- Chemical treatment and disposal
- Evaporation and ponding
- Land application
- Cascading use

For subsurface disposal systems, both injections into the producing aquifer and away from the producing aquifer were considered.

Preliminary evaluations of surface disposal systems indicated that only two systems have the potential of meeting NPDES permit requirements. These systems are:

- Chemical treatment followed by removal of precipitated solids (particularly heavy metals) through sedimentation and filtration
- Evaporation ponds (zero discharge ponds) in which all spent fluids are evaporated in large holding ponds resulting in no surface discharge.

For a typical 50 MWe binary cycle plant, the amount of spent fluids requiring disposal is in the order of 4.5 million gallons per day. On a per unit power output basis, geothermal power plants generate approximately 20 times more wastewater (including spent fluids) than fossil-fuel power plants. This makes the use of zero discharge plant prohibitively expensive for geothermal power operations.

For a geothermal power plant using fluids of medium to high salinity, injection is probably the most economic method of disposal. The fact that only a Class V instead of a Class III well is required would further reduce the cost of injection.

1.0 CONCLUSION AND RECOMMENDATIONS

Based on the results of the evaluations of surface and subsurface disposal options, as well as the regulatory implications of such options, the following conclusions can be made:

Subsurface Disposal Systems

- Injection of geothermal fluids is controlled by the underground injection control (UIC) program promulgated under the Safe Drinking Water Act. Heavy emphasis of the UIC program is placed on the design and monitoring of injection wells.
- Historically, injection of spent geothermal fluids from power plants required the use of Class III wells. Since February 3, 1982, only a Class V well is required.
- Major differences between Class III and Class V wells are design and construction criteria, and monitoring requirement. In general, the specifications for a Class III well are much more stringent than those Class V.
- Use of injection is the most common practice for the disposal of spent fluids from geothermal power plants. Typically, however, brine injection occurs at a much faster rate than that of other industrial waste injection systems.
- An added advantage of injection is that an abandoned production well can be used as an injection well.
- Injection can also be used as a means of reservoir recharge and subsidence control.
- Although the mechanism of hydrological communication between geothermal and drinking water aquifers is not well understood, injection wells can be designed to minimize such impact.

Surface Disposal Systems

- Section 304 of the Clean Water Act calls for the definition of effluent limitations through the issuance of effluent guidelines, to be issued according to industrial categories. For geothermal energy industry, effluent guidelines have not been formulated and are not currently scheduled.
- The principal basis for the control of geothermal effluent is the water quality standards promulgated under Section 303 of the Clean Water Act.

- The implementation of effluent guidelines and water quality standard is carried under the authority of section 402 of the Clean Water Act through the National Pollutant Discharge Elimination System (NPDES). Priority pollutants, that require monitoring and/or control, are defined by EPA to protect surface water quality.
- Chemical characteristics of spent geothermal fluids are complex and their occurrence and concentration levels are rather site specific. Priority pollutants most likely to be present in geothermal fluids are heavy metals. Thus treatment systems must be designed to remove or reduce these heavy metal concentrations to acceptable levels.
- Other than direct discharge to the ocean, there is no operating experience of geothermal power plant system using surface treatment and discharge as a waste disposal option. Other industries, however, such as the metal finishing and electroplating industries, have successfully designed and implemented heavy metal removal systems in their process waste stream.
- Surface treatment and disposal systems for geothermal operations can be designed to meet water quality standards promulgated under the Clean Water Act.
- The use of evaporation ponds, in which spent fluids are disposed of through evaporation resulting in no discharges to surface waters, is another option for meeting NPDES requirements. These types of systems, although relatively costly, have been successfully implemented by fossil fuel power plants. However, because of the large amount of wastewater to be disposal of, this option would not be cost-effective for geothermal power plant operations.

A comparison between surface and subsurface disposal options reveals the following findings:

- For a typical 50 MWe power plant using fluids of moderate to high salinity, injection is most likely a less expensive option compared to surface treatment and disposal.
- Direct discharge with minimal or no treatment may be feasible for direct use plants, which typically have lower fluid flow rates and the chemical characteristics are less complex.

Site specific information will be required to adequately address the problem of spent geothermal fluid disposal and to select the most appropriate option(s) for disposal, meeting NPDES and UIC requirements. However, the geothermal industry will benefit if more base-

line information concerning cost of disposal and potential environmental impacts is more readily available. On this basis, the following activities appear to be appropriate for DOE/GHTD.

- Provide more detailed cost analysis for surface treatment and disposal systems, drawing upon information from other industries that contain heavy metals in their waste stream.
- Keep abreast of development concerning changes in environmental regulations, particularly the UIC program and the NPDES system.

2.0 INTRODUCTION

2.1 Background

The disposal of geothermal fluid after it has passed through the energy conversion process is a crucial environmental issue. The major disposal options are surface discharges (into rivers/lakes or onto land) and underground injection. A range of technical, economic, and regulatory factors will influence the selection of a disposal technique at any particular site. The current preference at electricity-generating plants and large-scale direct-heat facilities tends to be for injection. This preference results from a number of technical considerations, such as:

- The large volumes of brine requiring disposal (on the order of 1 to 2 billion gallons per year for a 50 MWe binary plant).
- The chemical quality of the brine, which may contain certain types and amounts of natural constituents and added chemicals that could be unacceptable in surface waters.
- The possibility of preventing or mitigating subsidence resulting from geothermal fluid withdrawal; as a subsidence-prevention measure, injection may be a regulatory requirement.
- The potential for geothermal reservoir recharge and increased heat recovery from the formation by injected brine.

There are, however, several disadvantages associated with injection disposal, including:

- High capital and operating costs for well drilling, construction, maintenance, and replacement, and for injection pumping (where required).
- Stringent environmental monitoring currently required at geothermal power plants by the Underground Injection Control (UIC) Regulations of the Safe Drinking Water Act (SDWA).

Alternative brine disposal into surface waters or directly onto the land poses advantages and disadvantages vis-a-vis injection. Not only does surface disposal avoid the major disadvantages of injection

mentioned above, but it also presents the possibility for secondary uses of the brine as a water source, such as for wetlands/marsh enhancement, irrigation, or livestock needs. In some cases, however, treatment to remove environmentally-undesirable constituents may be needed prior to disposal. In any event, surface discharges will be subject to the National Pollutant Discharge Elimination System (NPDES) of the Federal Water Pollution Control Act (FWPCA).¹ A space-heating project in Texas recently became the first geothermal energy application to receive an NPDES permit,² setting a precedent for approved surface brine disposal.

The technical and regulatory feasibility and/or attractiveness of surface discharge may, therefore, be improved by identifying cost-effective effluent brine processing to meet NPDES disposal standards. This may include identifying secondary, non-energy brine uses.

2.2 Purpose

The purpose of this document is to systematically evaluate disposal options for spent geothermal fluids and wastewater generated from geothermal power plant operations. Because the technical and economic characteristics of injection and surface disposal systems are closely related to regulatory development, regulatory implications, especially the UIC programs and NPDES permitting systems are important considerations in this study. The relative technical and economic benefits associated with injection and surface disposal will be evaluated to determine under what circumstances one option becomes more favorable than another and how each option can best be implemented to meet the changing regulatory requirements.

2.3 Scope

This study will investigate the federal regulatory frameworks, the technical and economic issues involved in decisions regarding waste brine disposal from geothermal energy utilization systems.

Specific activities include:

- Identification and description of environmental regulations germane to the disposal of spent geothermal fluids, focussing on the changing legislative interpretation of UIC and NPDES.
- Identification and description of potential surface and subsurface disposal options based upon the quantity and quality of wastewater to be disposed of.
- Description of existing brine disposal practices associated with geothermal energy development in the U.S.
- Discussion of the implications of the SDWA and CWA for spent brine disposal, taking into consideration likely modifications of promulgated and proposed regulations.
- Evaluation of the various surface and subsurface disposal techniques based on technical, economical, legal, environmental and safety considerations.

3.0 REGULATORY REQUIREMENT

3.1 Legislative History of the Regulations

The foundation of water pollution control was laid in 1948 with the enactment of the Water Pollution Control Act.³ The act established the primary rights and responsibilities of the states with respect to water pollution control. It envisioned comprehensive water pollution control programs and designated financial assistance to states and municipalities for water treatment facilities.

In 1965, the Water Quality Act was enacted to establish and enforce water quality standards for the nation's interstate waters. The Secretary of Health, Education and Welfare (HEW--reorganized into the Department of Education and the Department of Health and Human Services in May 1980) was assigned the responsibility of establishing appropriate water quality standards and ensuring that these standards were observed throughout the nation. Each water quality standard was to provide criteria defining:

- The acceptable pollutant limits for receiving waters sufficient to protect the designated uses of the waters; and
- A plan of implementation for the standard, subject to final Federal approval.

Grants were authorized through the Act for waste water treatment plant construction and Federal research and demonstration projects.

Amendments to modify the 1965 Act were adopted in 1966, entitled the Clean Water Restoration Act. These amendments mandated that water quality standards were to be established by the fifty states for all interstate waterways. These standards were to be subject to the approval of the Secretary of Interior and to continuing examination and upgrading as technical advances improved treatment methods and facili-

ties. In 1970, responsibility for HEW's responsibilities under the act were transferred to the U.S. Environmental Protection Agency (EPA).

Other amendments to the Federal water pollution control program were adopted in the 1970's. Two of these acts formed the basis of Federal surface and sub-surface liquid discharge control: The Clean Water Act and the Safe Drinking Water Act. These acts and the ensuing regulations mandated by them will be discussed in greater detail below.

3.1.1 The Consolidated Permitting Process

As mandated by the Water Pollution Control Act, EPA has established permitting requirements for industries discharging pollutants to the environment. EPA required operators to obtain permits through several different channels, according to the nature of the permits required. In 1980, EPA initiated a process to consolidate the permitting procedures to eliminate gaps and overlaps among programs promulgated under several different statutes to control air emissions, surface and subsurface discharge of liquid effluents, and disposal of dredged and fill material.⁴ Specifically, the following five programs were consolidated:

- The Hazardous Waste Management Program under the Resource Conservation and Recovery Act (RCRA).
- The Underground Injection Control (UIC) Program under the Safe Drinking Water Act.
- The National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act.
- The Dredge or Fill Program under the Clean Water Act.
- The Prevention of Significant Deterioration (PSD) Program under the Clean Air Act.

With respect to the disposal of geothermal wastewaters, the second and third program are the most relevant to geothermal developers, as they concern surface and subsurface liquid disposal. Potential benefits under the consolidated program include:

- Operators need to learn only one permit system; and
- Applicants who file for more than one permit on an application may receive a quicker response.

The consolidated approach applies only to permits issued by the EPA Regional Offices in states that elect not to operate their own permit programs as specified in the above statutes. The states are only encouraged to adopt a similar consolidated approach. The permit application form used is consolidated only in the sense that general information is required only once, while more detailed, program-specific, information is still required for each permit requested.

3.1.2 The States' Role in Drinking Water Regulation Enforcement

Under Federal drinking water regulations, states that submit acceptable programs to EPA assume "primacy," which entitles them to Federal grant money and shifts the mantle of responsibility for governing drinking water programs to the state level.⁵ In order to qualify for primacy, a state must:

- Adopt drinking water regulations as stringent as the national regulations;
- Have adequate procedures for enforcing the state regulations;
- Meet EPA record keeping and reporting requirements;
- Issue variances and exemptions (if the state elects to do so) under conditions equally stringent to those in the act; and
- Have a plan for providing emergency waters supplies.

A great majority of the states in the nation have adopted EPA-approved programs. Exhibit 3.1 presents the eleven states with the greatest potential for moderate- to high-temperature geothermal resources.⁶ Of these states, only Oregon does not have a drinking water program sanctioned by EPA. The remaining ten states have assumed primacy.

3.2 The Safe Drinking Water Act

3.2.1 Legislative Background

Promulgated in December of 1974, the Safe Drinking Water Act (SDWA) was enacted to safeguard the nation's primary and secondary drinking water supply.⁷ Although the Act directs the EPA to establish national standards, Congress clearly intended that the states lead in implementing the drinking water program. The Act stipulates that state governments are encouraged to assume the responsibility for administering compliance programs, drawing on EPA's technical support when necessary.

3.2.2 Underground Injection Control

One of the regulations which EPA drafted in response to the Act governed underground injection of fluids.⁸ UIC regulations are presented in 40 CFR, Part 122. Specific references appear in Subparts A and C, Parts 123, 124, 125. The technical discharge criteria appear in 40 CFR 146. In accordance with the SDWA, Underground Injection Control (UIC) regulations encourage state governments to develop UIC programs for the protection of groundwater aquifer. EPA may approve a state's program in whole or in part, but if a state fails to develop

Exhibit 3.1

STATE WITH THE GREATEST POTENTIAL FOR
MODERATE- TO HIGH-TEMPERATURE GEOTHERMAL RESOURCES

- Alaska
- Arizona
- California
- Colorado
- Hawaii
- Idaho
- Nevada
- New Mexico
- Oregon
- Utah
- Washington

an approvable program, EPA will implement a program for it. While state governments have the key role in administering their programs, EPA still maintains a role in setting broad regulatory guidelines.

The UIC regulation contains five distinct categories for injection wells. These categories group wells of a similar nature so that appropriate performance criteria can be applied for each category. In formulating the categories, several factors were considered, including information on existing and abandoned injection wells, well construction technology and practices, and the types of fluids injected into the wells.⁹ In 1980, EPA promulgated the following comprehensive well classification scheme:

- Class I: industrial and municipal disposal wells and nuclear storage and disposal wells that inject below all underground sources of drinking water.
- Class II: all injection wells associated with oil and gas storage and production.
- Class III: all special process injection wells, for example those involved in the solution mining of minerals, in situ gasification of oil shale, coal, etc., and recovery of geothermal energy for electric power generation.
- Class IV: wells used by generators of hazardous wastes or hazardous waste management facilities to inject into or above underground sources of drinking water.
- Class V: all other injection wells, including geothermal direct application wells.

In October 1981, EPA proposed to change the classification of electric power geothermal injection wells from Class III to Class V.¹⁰ The rationale behind the change was that geothermal wells really do not "inject for extraction of minerals or energy" as stipulated under Class III; rather they are used to inject brine from which heat has been extracted into the formations from which they were originally taken. In this sense, the injection process was

viewed as a means of recharging geothermal reservoirs. For this reason, according to EPA, Class V was a more appropriate classification. On February 3, 1982, the change was formally adopted.¹¹

Exhibit 3.2 summarizes the major differences between classification under Class III and Class V. In general, changing well categories will make injection less costly to resource developers than before.

Regulations under Class V of the UIC are rather general. The code requires the following:

- Owners/operators must notify appropriate authorities of the existence of wells under this category and must furnish background information on the company and injection wells; and
- State program directors must submit to EPA: (1) information on the construction features of Class V wells and the nature and volume of the injected fluids, (2) an assessment of contamination potential of the wells using available hydrogeologic data, (3) an assessment of corrective alternatives where appropriate and their environmental and economic consequences, and (4) recommendations both for the most appropriate regulatory approaches and for remedial actions.

Unlike most other classifications, wells categorized under Class V do not require specific well construction criteria or maintenance and testing programs. The presumption is that wells in Class V are not as likely to endanger drinking water resources. However, Class V wells will be the subject of EPA attention in the future. On a sub-category basis, if EPA determines that fluid injected into a well contaminates drinking water resources, the UIC regulation stipulates that EPA will adopt more stringent requirements on that sub-category under Class V.

Exhibit 3.2

OVERVIEW OF CLASS III vs. CLASS V INJECTION WELLS

<u>Requirement</u>	<u>Class III</u>	<u>Class V</u>
Injection Well Construction Criteria	Required	Not Required
Mandatory Monitor - Wells	Required	Not Required
Periodic Operating Reports	Required	Not Required
Mandatory Report if Water Contamination Occurs or Suspected	Required	Required
Maximum Term of Permit	Indefinite	10 Years
Maximum Period Between Reviews of Permit	5 Years	N.A.

3.3 The Clean Water Act

3.3.1 Legislative Background

The Clean Water Act was enacted into law in 1977. While to a large extent the Act was written to amend the Federal Water Pollution Control Act (discussed above), the Act contains independent provisions, as well. With regard to the scope of this report, the Clean Water Act provides the legal basis for regulating the discharge of liquid effluent into the nation's surface waters. Regulation is achieved through a permit system. This legislation was enacted by Congress to safeguard water supplies by establishing minimum national standards which would be enforced by EPA and state agencies.

3.3.2 National Pollutant Discharge Elimination System Regulations

Drafted in compliance with Section 402 of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) regulates the discharge of liquid effluents into the nation's surface waters.² Discharge quantities, rates, concentrations, and temperatures are regulated by the NPDES permit. NPDES regulations are detailed in 40 CFR Part 122 with regulations on UIC and Hazardous Waste Permitting. Specific references to NPDES appear in Subparts A and D, Parts 123, 124, 125, 129, 133 and 136, and Subchapter N (Parts 400-460).

NPDES permits are issued either by EPA or by states with EPA-approved programs for administering the system. Permits issued to new discharging facilities specify discharge limitations, while permits issued to operations that predate the regulations establish a schedule for upgrading controls to meet specified discharge limitations. If EPA determines that a firm is in violation of permit conditions,

it can issue a Notice of Violation or an Administrative Order directing the offending party to resolve the problem. If the problem is not resolved, serious offenders may be fined up to \$100,000 per day.

Unlike the UIC regulations, no specific geothermal category is designated in the NPDES regulations. Under NPDES, classifications are structured more by the end product produced than by the energy source utilized in the production process. Consequently, geothermal effluent is not treated in a consistent manner. Resource development firms must be familiar with the standards developed for the industry in which the resource will be utilized, because different disposal criteria may be applied to a developer supplying different industries using the same geothermal reservoir.

This presents a problem not only for the developer but for EPA officials or state administrators who must review the NPDES permit applications. Because no discrete categories are established, it may be difficult to force geothermal applications into the NPDES framework. This may cause arbitrary judgements to be rendered, working either against or in favor of the applicant. Barring any adaptation in the NPDES regulations to accomodate geothermal resoures, precedent may be used in the reveiwing process. One factor that will facilitate the NPDES review process is a variance procedure contained in 40 CFR, Subchapter D, 125.30 which can be called into play when a discharge facilities, equipment, processes, and other factors are "fundamentally different" from the factors used in establishing the guidelines.

The adverse impact of these different criteria is compounded by the fact that water quality standards vary not only from state to

state, but within many states, according to the designated uses of the various water resources. Indeed, the classification governing one stretch of a water source is frequently different from the classification governing a contiguous stretch. This situation presents particularly acute problems for resource developers who discharge near a classification boundary or whose discharges straddle that boundary.

Because EPA-approved state programs may be stricter than requirements specified in the NPDES regulations, developers engaged in interstate business must carefully determine the applicable guidelines in each area. With regard to NPDES, it is important to reiterate that, while the regulations establish minimum national standards, several jurisdictions have adopted more stringent requirements.

3.3.2.1 Definitions. As indicated above, NPDES regulations were promulgated to control discharge quantities, rates, concentrations, and temperatures. In addition, EPA determined that certain industries are more apt to discharge undesirable effluents than others. The regulation, therefore, distinguishes between "primary" industries and the remaining industries. Monitoring and reporting requirements are generally more stringent for primary industries than for the other industries.

NPDES regulations also distinguish between liquid outfall and process wastewater. While the latter is a subset of the former, process wastewater is defined as "... any water which, during manufacturing or processing, comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product." This definition is important

when considered in the context of geothermal direct applications because, generally speaking, geothermal resources do not come into direct contact with the product being manufactured. Most likely geothermal heat is transferred in a closed loop through a heat exchanger to provide industrial process heat. It would appear, therefore, that geothermal outfall should not be considered process wastewater, exempting it from the more rigid criteria.

3.3.2.2 Emissions Criteria. While monitoring and reporting requirements vary according to industry classification, all industries are required to report quantitative data on certain characteristics of their outfall. Specifically, all industries must monitor and prepare reports on the following effluent parameters:

- Biochemical Oxygen Demand
- Chemical Oxygen Demand
- Total Organic Carbon
- Total Suspended Solids
- Ammonia (as N)
- Temperature (both winter and summer)
- pH

The applicant may ask EPA to wave any or all of these reporting requirements. No guidance, however, is provided regarding the criteria used by EPA to decide upon such a request. Because a small business exemption is cited in other subsections regarding effluent characteristics but not in the instant subsection, one may presume that a small business rationale would not be the most compelling reason on which to base the request.

The NPDES regulation specifically details several other pollutants that must be monitored as well. The extent to which monitoring and reporting is required is determined in some part by the classification of the industry applying for a permit. Analysis of process wastewater from primary industries must assess a larger variety of pollutants than need be assessed for other industries. Exhibit 3.3 lists the primary industries considered most likely to utilize geothermal resources as an energy source. Exhibit 3.4 depicts the geothermal temperature requirements for each of these industries.

The list of priority pollutants that EPA has developed includes 31 volatiles, 11 acid compounds, 46 base/neutral substances and 25 pesticides.¹² In addition, several other pollutants must be monitored if an operator has reason to suspect their presence in the effluent stream. Data from the analysis must be submitted to EPA on a regular basis. Exhibit 3.5, Category A, lists the most likely pollutants to be present in geothermal effluents from primary industries.

While monitoring and reporting requirements are mandatory for primary industries for these (and other) pollutants, non-primary industries need only report test results to EPA if the resource developer knows or has reason to believe that the pollutant will be discharged from the outfall. Any test revealing that threshold quantities of a pollutant exist within the outfall must be submitted to EPA for examination.

Exhibit 3.5, Category B, presents pollutants which, if identified or suspected in the waste stream, must be reported to EPA. While Category B does not include all pollutants that EPA has cited in its broader reporting category, it does detail those most commonly associated with geothermal brines.

Exhibit 3.3

EPA-DESIGNATED PRIMARY INDUSTRIES
WHICH ARE MOST LIKELY TO UTILIZE GEOTHERMAL ENERGY

- Leather Tanning and Finishing
- Pulp and Paper Mills
- Rubber Processing
- Steam Electric Power Plants
- Textile Mills

EXHIBIT 3.4

TEMPERATURE REQUIREMENTS OF GEOTHERMAL
APPLICATIONS ON THE EPA NPDES INDUSTRIAL LIST

Exhibit 3.5

POLLUTANTS CITED BY NPDES REGULATIONS
MOST LIKELY TO BE PRESENT IN GEOTHERMAL WASTE STREAM

<u>Category A*</u>	<u>Category B**</u>
<ul style="list-style-type: none"> • Antimony • Arsenic • Beryllium • Cadmium • Chromium • Copper • Lead • Mercury • Nickel • Selenium • Silver • Thallium • Zinc 	<ul style="list-style-type: none"> • Aluminum • Barium • Boron • Cobalt • Iron • Magnesium • Molybdenum • Manganese • Tin • Titanium

* Quantitative testing data is required for these pollutant from all primary industries; testing data is required from any non-primary industry if a developer knows or expects to pollutants to be present.

** Quantitative testing data is required only if developer knows or expects the pollutant to be present. This requirement applies to all industries, regardless of whether the industry is in the primary classification or non-primary classification.

4.0 WASTE CHARACTERIZATION

Exhibit 4.1 presents the general features of a geothermal power plant using a binary cycle, emphasizing features that affect liquid disposal. The schematic presented in the exhibit can be arbitrarily divided into four major components:

- The geothermal fluid and the heat exchange unit
- The turbine and the power generation system
- The condenser and the hot well water reservoir
- The cooling tower and the cold well reservoir.

In a binary cycle system, geothermal fluid arrives at the power plant at near well-head temperature. The fluid is used to heat a working fluid, which is generally a low boiling point fluid (such as Freon). At this stage, it becomes necessary to dispose of the liquid portion of the spent geothermal fluid, usually by injection. The vapor of the working fluid drives a turbine to produce electric power. The exhaust from the turbine flows to a condenser where it is cooled below the vapor point and then condenses. The cold water used to cool the working fluid is obtained from a cold well at the bottom of the cooling tower. The hot water from the condenser is then collected in the hot well reservoir and pumped to the cooling tower as shown in the exhibit. Part of the water is lost through the cooling tower as water vapor, and thus make-up water is required to replenish the water loss. The water in the cold well, hot well and cooling tower system can be recycled. However, as the water is lost from the tower system through evaporation, the dissolved solids in the cooling water will accumulate, to the point that it may create operational problems. The cooling tower water will have to be discharged to control the

EXHIBIT 4.1

SIMPLIFIED FLOW DIAGRAM OF A BINARY CYCLE
GEOTHERMAL POWER PLANT

concentration of salts and other impurities. The blowdown water is generally combined with the spent geothermal fluids for treatment and disposal.

Many interrelated factors affect the quantity and quality of wastewater discharged from a geothermal power plant. Some of the more important areas are described below:

- Resource characteristics. High salinity fluids contain more dissolved solids and consequently produce poor quality effluent. A high-temperature resource generally results in a more efficient thermal/electrical energy conversion process, thereby requiring less fluid per unit power output and subsequently less fluid to be disposed of.
- Thermal efficiency. Typically, a geothermal power plant has a thermal efficiency of about 10%. An increase in the thermal efficiency of the power plant will affect the quantity of fluids to be disposed of in two ways. First, less geothermal fluid is required to achieve the same amount of power output. Second, an increase in thermal efficiency reduces the amount of waste heat thereby reducing the amount of cooling water required
- Concentration Factor. The concentration factor, or cycles of concentration, is defined as the ratio of total dissolved solids (TDS) in the circulating water to the TDS in the make-up water of a cooling tower. Increasing the concentration factor decreases the quantity of wastewater to be discharged but also increases the dissolved solids content of the blowdown water.

Because of these and many other variables affecting the quality and quantity of fluids requiring treatment and disposal, it is helpful to establish a baseline so that disposal options for geothermal fluids can be systematically evaluated. A "typical" 50 MWe power plant*, using a binary cycle will be used as a basis for the comparison of treatment and disposal options. The assumptions used for this illustrative 50 MWe power plant are:

* It should be noted that not all proposed power plants in the U.S. are of binary design and that proposed geothermal power plants range from 5 to 110 MWe.

- Brine flow rate of 100,000 lbs per hour per well
- 14 production wells,
- plant operating 7,000 hours per year (0.8 capacity factor), and
- Conventional evaporative (wet) cooling tower for waste heat dissipation.

The following discussion on the quantity and quality of wastewater is based on these assumptions.

4.1 Quantity of Wastewater

The largest source of wastewater from a geothermal power plant is the geothermal fluid itself. Fourteen (14) production wells pumping fluids at a rate of 100,000 lbs per hour would yield about 4.05 million gallons per day (MGD) of fluids. The second largest source of wastewater is the cooling tower blowdown, which is estimated at about 0.16 MGD. With the inclusion of an H₂S abatement system, the total amount of wastewater generated from a 50 MWe binary plant is about 4.5 MGD.

On a per unit power output basis, the amount of wastewater to be treated and discharged from a geothermal power plant is approximately 20 times higher than that of a fossil fuel plant using conventional combustion processes. Exhibit 4.2 compares the quantity of wastewater generated by these power plants.¹³ Since a typical fossil fuel plant has an installed capacity of 500-1,000 MWe, a hypothetical plant of 50 MWe has been created to facilitate comparison with a 50 MWe geothermal power plant.

Another method to put the quantity of geothermal wastewater into perspective is to compare the amount of liquid waste generated from geothermal power plants to that of the domestic wastewater treatment

Wastewater Discharges	Fossil Fuel Plant (Conventional Combustion)		Geothermal Plant
	500 MWe Typical	50 MWe Hypothetical	50 MWe Typical
Power Conversion			
• Spent Geothermal Fluid	-	-	4.05
• Plant Drain	0.48	0.048	-
• Ash Handling	0.01	0.001	-
Subtotal	0.49	0.049	4.05
Emission Control			
• Fly Ash Transportation	0.07	0.007	-
• FGD or H ₂ S Abatement	0.82	0.082	0.16
Subtotal	0.89	0.089	0.16
Cooling Tower			
• Blowdown	0.55	0.055	0.27
Total Wastewater	1.93	0.193	4.48

EXHIBIT 4.2

COMPARISON OF THE WASTEWATER DISCHARGE OF FOSSIL-FUEL
POWER PLANT AND GEOTHERMAL POWER PLANT
(MILLIONS OF GALLONS/DAY)

processes. Per capita water consumption in the U.S. is about 150 gallons per day. Because of infiltration and peak load considerations, however, most domestic treatment plants are designed assuming 200 gallons per day per capita of sewage flow. Thus, the wastewater produced by a 50 MWe geothermal power plant is approximately equivalent to the required wastewater treatment facility of a small city of about 22,000 persons. The design capacity of the Blue Plain wastewater treatment plant in Washington, D.C. is about 230 MGD which is about 50 times the hydraulic capacity of the wastewater from a 50 MWe geothermal power plant. The Blue Plain treatment plant handles wastewater from Washington, D.C. as well as Montgomery and Prince Georges counties in Maryland.

4.2 Quality of Wastewater

As discussed in the previous section, the major sources of wastewater in a geothermal power plant are spent geothermal fluids and cooling tower blowdown. Chemical constituents present in spent geothermal fluids may even be more complex than the ones present in the raw fluids. This is in part due to the following phenomena:

- Changes in temperature and pressure may cause some materials, particularly carbonates and silicates, to precipitate out.
- Additional changes may occur when geothermal fluids are partially exposed to air, resulting in oxidation of some chemical species.
- Chemical additives, such as acids, bases, or organic polymers added to the geothermal fluid for scale control, will reappear in the spent fluid.

Exhibit 4.3 is a list of common chemical constituents found in geothermal fluids.¹⁴ This exhibit is prepared to show the wide concentration range of chemical species. Priority pollutants, under

EXHIBIT 4.3
COMMON CHEMICAL SPECIES FOUND IN GEOTHERMAL
FLUIDS AND THEIR CONCENTRATION (ppm)

NPDES, are highlighted in the exhibit. Although there are presently no published data on the chemical characteristics of spent geothermal fluid, Exhibit 4.3 provides some insight into the quality of spent geothermal fluids.

Exhibit 4.4 is a list of chemicals that can be used as scale inhibitors in geothermal fluids.¹⁵ In order for these inhibitors to be effective, a concentration range of 10 ppm to 100 ppm is generally required. The amount of inhibitors required is dependent upon the type of inhibitor itself, as well as the concentration of the scale producing compounds (mainly silicates and carbonates) and the salinity of the fluid.

The major types of contaminants present in cooling tower blowdown are residual chlorine and corrosion products. Chlorine is the most common chemical used to inhibit the growth of slime-forming organisms (e.g., fungi, bacteria, iron bacteria, sulfur bacteria) on the water side of the condenser tube thereby inhibiting the heat exchange process. The addition of chlorine to water may cause the formation of toxic compounds and chlorinated organics which may be priority pollutants.

Heavy metals, and corrosion products, are also present in spent geothermal fluids and cooling tower blowdown. Corrosion is an electrochemical process that occurs when a metal is immersed in water. A difference in electrical potential between different parts of the metal cause a migration of electrons resulting in the oxidation of the metal and dissolution of metal ions into water. Copper alloys, because of their high conductivity, are used in power plant condensers.

A-1100	Darex 41s	Lipal 200C	Schercoquat DAB-90
A-1160	Dearborn 8010	Marasperse N-3	Starpol 100
AlCl ₃	Dequest 2060	Mirapol A-15	Surfactant AR-150
Alkaphos Q.S.	Drewplex 502	Mirapol A-15 + Cycloryl NA	Surfynol 465
Alkateric 2CIB	Drewsperser 747	Natrosol 180LR	Surfynol 485
Arquad 18/50	Duomac T	Natrosol 250HR	Tetronic 1504
B-2014-25	Duoquad T-50	Natrosol 250LR	Thermosol APS
B-2080-182	E-400	Natrosol 420H	Triton X-100
Belclene 200	Emcol CC-36	P-100, Chloracetic Derivative	Tween-20
Betz 419	Ethomeen 18/60	P-100, Glycidol Derivative	Tylose MHB
Calgon CL-77W	Ethomeen C/25	P-100, Quaternized	Variquat K-1215
Calgon SL-500	Ethoquad 18/25	P-400	Varstat 66
Carbowax 350	Ethoquad HT-60MS	PAE·HCl	Vinsol AR-150
Carbowax 1,000	Ethoquad 18/25	Pluronic F38	Visco 3744
Carbowax 6,000	Ethoquad 18/25	Polymer JR-125	XD-8779.00
Carbowax 14,000	Ethoquad 18/25	Polyox WSRN-10	XD-8918.00
Cellosize QP-09-L	Fluorad FC430	Polyox WSRN-80	XD-30469.00
CL-165	Geomate 256	Polysperse Plus	XFS-43075
CMHEC-420H	Geomate 259	Pyronate 40	XZ-8-5061
Conco NI-125	Goodrite K732	Q-C-50	Z-6020
Corcat P-18	Glyoxal	Quat 188	Z-6070
Corcat P-100	Hipochem ADN	RC-412	Z-6071
Corcat P-145	Hyamine 1622	RC-413	Zonyl FSB
Corcat P-200	Jeffox FF-200	Resorcinol	Zonyl FSN
Cortron R-16	KH ₂ PO ₄	S-404	Zonyl's (series)
Crotein BTA		SC-210	
CYAF-5103			

EXHIBIT 4.4

LIST OF CHEMICAL ADDITIVES USED FOR SCALE
CONTROL IN GEOTHERMAL POWER PLANTS

Consequently, copper ions are a likely corrosion product. Exhibit 4.5 shows common pollutants found in cooling tower blowdown of steam electric power plants.¹⁶ The concentration factor is defined as the ratio of the intake metal ion concentration to that of the discharge.

CHEMICAL SPECIES	PLANT #1			PLANT #2			PLANT #3			PLANT #4		
	INTAKE	DISCHARGE	CONCENTRATION FACTOR	INTAKE	DISCHARGE	CONCENTRATION FACTOR	INTAKE	DISCHARGE	CONCENTRATION FACTOR	INTAKE	DISCHARGE	CONCENTRATION FACTOR
ANTIMONY	11	14	1.27	5	6	1.20	5	7	1.40	5	10	2.00
ARSENIC	5	8	1.60	5	13	2.60	5	9	1.80	-	-	-
CADMIUM	15	40	2.67	10	25	2.50	-	-	-	-	-	-
CHROMIUM	16	23	1.44	37	75	2.03	5	11	2.20	6	11	1.83
COPPER	25	13	0.52	25	150	6.00	21	70	3.34	8	95	11.88
LEAD	5	5	1.00	5	17	3.40	7	8	1.14	-	-	-
MERCURY	0.34	0.58	1.71	0.41	0.91	2.22	0.88	1.02	1.16	0.15	0.29	1.93
NICKEL	21	29	1.38	8	100	12.50	8	58	7.25	6	10	1.67
SELENIUM	55	87	1.58	5	23	4.60	15	22	1.47	5	8	1.60
SILVER	40	64	1.60	9	32	3.56	45	65	1.44	-	-	-
ZINC	5	9	1.80	41	67	1.63	-	-	-	23	19	0.83

EXHIBIT 4.5
 CHEMICAL SPECIES AND THEIR CONCENTRATIONS (ppm)
 PRESENT IN COOLING TOWER BLOWDOWN

5.0 TREATMENT AND DISPOSAL OPTIONS

Two basic methods of liquid waste disposal are applicable to geothermal systems: surface and subsurface disposal. The selection of one of these disposal options depends on many parameters. From the engineering design point of view, the quality and quantity of effluents to be treated and disposed of are the most important considerations. Legal constraints and institutional factors may also influence the selection and design of disposal systems. The following subsections present the state-of-the-art technologies for treatment and disposal systems applicable to geothermal energy systems.

5.1 Surface Disposal Systems

5.1.1 Direct Release to Surface Waters

The most economic waste disposal method is the direct discharge of spent geothermal fluids to the local surface drainage system. This was done at The Geysers for many years until the level of brine and other constraints in the fluid caused regulators to require alternate methods of disposal. At the present time direct discharge is not being used in the U.S., but it is still being used extensively in many other nations.¹⁷

Most surface discharge systems involve discharging wastewater into a river or a lake. Because the chemical composition of spent geothermal fluids is more compatible with seawater than inland waters, ocean disposal is becoming a viable option. The obvious limitation would be the distance between geothermal resources and coastal waters.

5.1.2 Chemical Treatment and Disposal

Wastewater treatment processes may be classified as physical, chemical, and biological. Descriptions of common unit processes used to purify wastewater are presented in Appendix A. Biological treatment processes, effective in removing organic and biodegradable substances, cannot be used for the removal of undesirable inorganic chemicals present in geothermal fluids. For this reason, these processes are not suitable to geothermal applications and will not be considered further in this paper.

Conventional wastewater treatment systems use a combination of physical and chemical treatment processes, to remove suspended solids through processes of rapid mixing, flocculation, and sedimentation. Chemicals are usually added to promote flocculation and settling. Sometimes chemicals (e.g., lime, alum, iron chloride) are used to promote the precipitation of heavy metal ions. The final step in the conventional process is the filtration of liquid effluent to remove turbidity and fine particulates.¹⁸ A typical process flow diagram is shown in Exhibit 5.1.

The flow rate of fluids is one of the most important parameters in the design of wastewater systems. This is because an adequate detention time is required for the chemicals within the mixing tank to remain in contact with one another. Sufficient detention is also necessary to allow suspended substances to settle. Greater rates require larger sedimentation tanks if a constant detention time (e.g., 4 to 6 hours) is to be maintained.

EXHIBIT 5.1
SIMPLIFIED PROCESS FLOW DIAGRAM FOR THE REMOVAL OF SOLIDS

Advanced wastewater treatment processes may be applicable to certain types of spent geothermal fluids if conventional treatment systems cannot achieve a desired water quality. The most common types of advanced treatment processes include ion exchange, reverse osmosis, and electrodialysis. Unfortunately, most of these processes operate most effectively for the treatment of brackish waters (i.e., water with salinity of about 10,000 mg/l). For this reason, their application to the highly saline fluids commonly encountered in geothermal systems may be somewhat limited.

The precipitated solids (i.e., sludges) collected from the above treatment systems create additional surface waste disposal needs. Typically, sludges from these treatment processes have a water content of about 95% to 98%. In general, sludges must be further processed (mainly dewatered) before they can be incinerated or deposited in landfills. Although advanced wastewater treatment systems will produce high quality effluents, they would also produce larger quantities of sludges requiring disposal.

5.1.3 Evaporation and Ponding

One method of disposing wastewater is to let it evaporate in a holding pond. The amount of water loss through evaporation is very much dependent upon local climatic conditions, such as precipitation, humidity, and solar radiation. Evaporation ponds can be designed so that there is no liquid discharge to the environment, but in geothermal electric systems the volume of wastewater to be handled will necessitate evaporation ponds covering extremely large tracts of land.

Ponding can become expensive if impermeable liners are required. Modifications to the basic pond design can be made so as to facilitate salt concentration. Exhibit 5.2 illustrates a multi-pond surface evaporation that uses the evaporative heat loss mechanisms to concentrate the salt solution. Specifically, as a consequence of the temperature drop in each successive pond, the salt concentration will reach its saturation point and precipitate out in the last pond.

5.1.4 Land Application

Several systems of land application of wastewater have been developed for industrial and domestic wastewater. These systems include spray irrigation, overland flow, and infiltration/percolation. All of these systems rely on the biodegradation of the waste constituents through microbial actions in the soil. Spent geothermal fluids, however, potentially contain high levels of inorganic contaminants and may accumulate rather than biodegrade in the soil. Accumulation of heavy metals in the soil may pose a threat to plant and animal life and may interfere with ground and surface water uses. Consequently, land application does not appear to be a viable option for fluid disposal.

5.1.5 Cascading Use

Consumptive use of spent geothermal fluids will eliminate the need for disposal. The key to consumptive use is to find systems that are compatible with the quality and quantity of spent fluid; for example fluids with low dissolved solid contents can be used as irrigation or in aquaculture, (e.g., hatcheries, fish farms, algae ponds).

EXHIBIT 5.2

MULTIPOND SURFACE EVAPORATION SYSTEM

Secondary uses of spent fluids will therefore eliminate the need for disposal.

5.2 Subsurface Disposal

Subsurface disposal of spent geothermal fluids through the use of injection wells is a viable alternative for geothermal operations. In addition to providing a means of waste disposal, spent fluid injection offers a number of other advantages. If injected at the production horizon, injection may serve as a means of reservoir recharge. It may also control or prevent land subsidence.

Problems such as scaling and corrosion can make injection procedures difficult, however. Scaling resulting from the deposition of substances such as carbonates, silica, and metal sulfides, may lead to reduced injectivity due to plugging of injection wells and/or rock formation. Scaling and plugging will probably remain a greater problem in geothermal power plants than in oil producing plants using injection to dispose of brines, because geothermal liquid wastes typically contain substantially more dissolved solids than oil field liquid wastes. In addition, the greater volumes of brine produced at geothermal plants will escalate the incidence and severity of scaling, plugging and corrosion.

For comparison, the injection rates of operating geothermal power plants and other industrial wastes¹⁹ are shown in Exhibit 5.3. Because of the large amount of waste to be disposed of, injection rates for geothermal fluids are higher than other fluid injection

EXHIBIT 5.3

COMMON INJECTION RATE OF GEOTHERMAL POWER
PLANTS AND OTHER INDUSTRIAL WASTE DISPOSAL SYSTEMS

systems. A high injection rate would lead to a higher tendency of operational failure. On the other hand, the use of higher injection rates will require less injection wells, which are high capital cost items.

6.0 EVALUATION OF TREATMENT/DISPOSAL OPTIONS

Despite the typically high temperature and high solids content of spent geothermal fluids, treatment and disposal facilities can be designed to handle these types of fluids. Technological and economic factors are important in the selection of a treatment and disposal option. In addition, meeting the regulatory requirements and protecting the environment are major considerations. This section compares and evaluates the different disposal options based on four groups of evaluation criteria: regulatory requirements technological readiness, economics, and environmental considerations. Regulatory requirements are the first consideration in selecting a disposal option; only those systems that have the potential of meeting the various regulatory requirements can be considered as viable options. Technological readiness limits the selection of disposal systems to the types of technology that have been used by geothermal industries or other related industries. Based on these two criteria, several disposal options can be developed. Cost comparison of these different disposal options can then identify the most cost/effective system. Finally, the potential environmental impact on the surface or subsurface level must be considered for disposal systems discussed.

6.1 Regulatory Implications

Four acts constitute the primary environmental legislation affecting the disposal of spent geothermal fluids:

- The Clean Water Act
- The Safe Drinking Water Act
- The Resource Conservation and Recovery Act
- The Toxic Substances Control Act

The Clean Water Act and the Safe Drinking Water Act have direct implications for spent fluid disposal, and the Resource Conservation and Recovery Act and the Toxic Substances Act are applicable to sludge disposal and the marketing of by-products from geothermal fluids.

Several sections of the Clean Water Act apply to geothermal development. The most significant uses are in Title III - Standards and Enforcement. Section 304 calls for the definition of effluent limitations defined through the issuance of effluent guidelines. These guidelines are "technology based," in that EPA identifies, for each industry, the treatment and control processes suitable for controlling the toxic pollutants in that industry. In addition, EPA assesses the long-term performance, operational limitations and reliability of each treatment and control technology. Effluent guidelines are issued according to industrial categories. For geothermal energy industry, effluent guidelines have not been formulated and are not currently scheduled.

In the absence of effluent guidelines, the principal base for control of geothermal effluent is the receiving water quality standards promulgated under Section 303 of the Clean Water Act. Water quality criteria are qualitative or quantitative estimates of the concentration of a constituent in ambient waters that, if not exceeded, will assure a water quality sufficient for a specified water use. Exhibit 6.1 shows the water quality criteria established by EPA under the various use categories. Water quality criteria are not standards and in themselves have no regulatory power. Water quality standards are established by the states in concert with EPA, and frequently result in NPDES conditions more restrictive than those based upon

EXHIBIT 6.1

EPA QUALITY CRITERIA FOR WATER

Water Quality Characteristic or Pollutant	Criteria												
Aesthetic Qualities	<p>All waters free from substances attributable to waste-water or other discharges that:</p> <ol style="list-style-type: none"> (1) settle to form objectionable deposits; (2) float as debris, scum, oil, or other matter to form nuisances; (3) produce objectionable color, odor, taste, or turbidity; (4) injure or are toxic or produce adverse physiological responses in humans, animals, or plants; and, (5) produce undesirable or nuisance aquatic life. 												
Alkalinity	20 mg/l or more as CaCO_3 for freshwater aquatic life except where natural concentrations are less.												
Ammonia	0.02 mg/l (as un-ionized ammonia) for freshwater aquatic life.												
Arsenic	50 $\mu\text{g/l}$ for domestic water supplies (health); 100 $\mu\text{g/l}$ for irrigation of crops.												
Barium	1 mg/l for domestic water supply (health).												
Beryllium	<p>11 $\mu\text{g/l}$ for the protection of aquatic life in soft fresh water; 1,100 $\mu\text{g/l}$ for the protection of aquatic life in hard fresh water; 100 $\mu\text{g/l}$ for continuous irrigation on all soils; except 500 $\mu\text{g/l}$ for irrigation on neutral to alkaline fine-textured soils.</p>												
Boron	750 $\mu\text{g/l}$ for long-term irrigation on sensitive crops.												
Cadmium	<p>10 $\mu\text{g/l}$ for domestic water supply (health). Aquatic Life:</p> <table> <tr> <th colspan="2"><u>Fresh Water</u></th></tr> <tr> <th><u>Soft Water</u></th><th><u>Hard Water</u></th></tr> <tr> <td>0.4 $\mu\text{g/l}$</td><td>1.2 $\mu\text{g/l}$ for cladocerans and salmonid fishes;</td></tr> <tr> <td>4.0 $\mu\text{g/l}$</td><td>12.0 $\mu\text{g/l}$ for other, less sensitive, aquatic life.</td></tr> <tr> <th colspan="2"><u>Marine</u></th></tr> <tr> <td colspan="2">5.0 $\mu\text{g/l}$</td></tr> </table>	<u>Fresh Water</u>		<u>Soft Water</u>	<u>Hard Water</u>	0.4 $\mu\text{g/l}$	1.2 $\mu\text{g/l}$ for cladocerans and salmonid fishes;	4.0 $\mu\text{g/l}$	12.0 $\mu\text{g/l}$ for other, less sensitive, aquatic life.	<u>Marine</u>		5.0 $\mu\text{g/l}$	
<u>Fresh Water</u>													
<u>Soft Water</u>	<u>Hard Water</u>												
0.4 $\mu\text{g/l}$	1.2 $\mu\text{g/l}$ for cladocerans and salmonid fishes;												
4.0 $\mu\text{g/l}$	12.0 $\mu\text{g/l}$ for other, less sensitive, aquatic life.												
<u>Marine</u>													
5.0 $\mu\text{g/l}$													
Chlorine	<p>Total residual chlorine: 2.0 $\mu\text{g/l}$ for salmonid fish; 10.0 $\mu\text{g/l}$ for other freshwater and marine organisms.</p>												
Chromium	<p>50 $\mu\text{g/l}$ for domestic water supply (health); 100 $\mu\text{g/l}$ for freshwater aquatic life.</p>												
Fecal Coliform Bacteria	<p><u>Bathing Waters:</u> Based on a minimum of not less than five samples taken over a 30-day period, the fecal coliform bacterial level should not exceed a log mean of 200 per 100 ml nor should more than 10 percent of the total samples taken during any 30-day period exceed 400 per 100 ml.</p> <p><u>Shellfish Harvesting Waters:</u> Not to exceed a median fecal coliform bacterial concentration of 14 per 100 ml with not more than 10 percent of samples exceeding 43 per 100 ml for the taking of shellfish.</p>												
Color	<p>Waters shall be virtually free from substances producing objectionable color for aesthetic purposes;</p> <p>The source of supply should not exceed 75 color units on the platinum-cobalt scale for domestic water supplies; and</p> <p>Increased color (in combination with turbidity) should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.</p>												
Copper	<p>1.0 mg/l for domestic water supplies (welfare).</p> <p>For freshwater and marine aquatic life, 0.1 times a 96-hour LC50 as determined through non-aerated bioassay using a sensitive aquatic resident species.</p>												
Cyanide	5.0 $\mu\text{g/l}$ for freshwater and marine aquatic life and wildlife.												

EPA QUALITY CRITERIA FOR WATER

(Continued)

Gases. Total Dissolved	To protect freshwater and marine aquatic life, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures.
Iron	0.3 mg/l for domestic water supplies (welfare). 1.0 mg/l for freshwater aquatic life.
Lead	50 ug/l for domestic water supply (health). 0.01 times the 96-hour LC ₅₀ value, using the receiving or comparable water as the diluent and soluble lead measurements (nonfilterable lead using an 0.45 micron filter), for sensitive freshwater resident species.
Manganese	50 ug/l for domestic water supplies (welfare); 100 ug/l for protection of consumers of marine mollusks.
Mercury	2.0 ug/l for domestic water supply (health); 0.05 ug/l for freshwater aquatic life and wildlife; 0.10 ug/l for marine aquatic life.
Nickel	0.01 of the 96-hour LC ₅₀ for freshwater and marine aquatic life.
Nitrates, Nitrites	10 mg/l nitrate nitrogen (N) for domestic water supply (health).
Oil and Grease	For domestic water supply: Virtually free from oil and grease, particularly from the tastes and odors that emanate from petroleum products. For aquatic life: 0.01 of the lowest continuous flow 96-hour LC ₅₀ to several important freshwater and marine species, each having a demonstrated high susceptibility to oils and petrochemicals. Levels of oils or petrochemicals in the sediment which cause deleterious effects to the biota should not be allowed. Surface waters shall be virtually free from floating nonpetroleum oils of vegetable or animal origin, as well as petroleum derived oils.
Dissolved Oxygen	Aesthetics: Water should contain sufficient dissolved oxygen to maintain aerobic conditions in the water column and, except as affected by natural phenomena, at the sediment-water interface. Freshwater aquatic life: A minimum concentration of dissolved oxygen to maintain good fish populations is 5.0 mg/l. The criterion for salmonid spawning beds is a minimum of 5.0 mg/l in the interstitial water of the gravel.
Aldrin-Dieldrin	0.003 ug/l for freshwater and marine aquatic life. The persistence, bioaccumulation potential and carcinogenicity of aldrin-dieldrin cautions human exposure to a minimum.
Chlordane	0.01 ug/l for freshwater aquatic life. 0.004 ug/l for marine aquatic life. The persistence, bioaccumulation potential and carcinogenicity of chlordane cautions human exposure to a minimum.
Chlorophenoxy Herbicides	2, 4-D; 100 ug/l for domestic water supply (health) 2, 4, 5-TP: 10 ug/l for domestic water supply (health)
DDT	0.001 ug/l for freshwater and marine aquatic life. The persistence, bioaccumulation potential, and carcinogenicity of DDT cautions human exposure to a minimum.
Dementon	0.1 ug/l for freshwater and marine aquatic life.
Endosulfan	0.003 ug/l for freshwater aquatic life; 0.001 ug/l for marine aquatic life.
Endrin	0.2 ug/l for domestic water supply (health); 0.004 ug/l for freshwater and marine aquatic life.
Guthion	0.01 ug/l for freshwater and marine aquatic life.
Heptachlor	0.001 ug/l for freshwater and marine aquatic life. The persistence, bioaccumulation potential and carcinogenicity of heptachlor cautions human exposure to a minimum.

EPA QUALITY CRITERIA FOR WATER

(Continued)

Lindane	4.0 µg/l for domestic water supply (health); 0.01 µg/l for freshwater aquatic life; 0.004 µg/l for marine aquatic life.
Malathion	0.1 µg/l for freshwater and marine aquatic life.
Methoxychlor	100 µg/l for domestic water supply (health); 0.03 µg/l for freshwater and marine aquatic life.
Mirex	0.001 µg/l for freshwater and marine aquatic life.
Parathion	0.04 µg/l for freshwater and marine aquatic life.
Toxaphene	5 µg/l for domestic water supply (health); 0.005 µg/l for freshwater and marine aquatic life.
pH	Range: 5-9 Domestic water supplies (welfare); 6.5-9.0 Freshwater aquatic life; 6.5-8.5 Marine aquatic life. (... but not more than 0.2 units outside of normally occurring range)
Phenol	1 µg/l for domestic water supply (welfare), and to protect against fish flesh tainting.
Phosphorus	0.10 µg/l yellow (elemental) phosphorus for marine or estuarine waters.
Phthalate Esters	3 µg/l for freshwater aquatic life.
Polychlorinated Biphenyls	0.001 µg/l for freshwater and marine aquatic life and for consumers thereof. Every reasonable effort should be made to minimize human exposure.
Selenium	10 µg/l for domestic water supply (health); For marine and freshwater aquatic life; 0.01 of the 96-hour LC_{50} as determined through bioassay using a sensitive resident species
Silver	50 µg/l for domestic water supply (health). For marine and freshwater aquatic life; 0.01 of the 96-hour LC_{50} as determined through bioassay using a sensitive resident species
Solids (Dissolved) and Salinity	250 mg/l for chlorides and sulfates in domestic water supplies (welfare).
Solids (Suspended, Settleable) and Turbidity	Freshwater fish and other aquatic life: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonably established norm for aquatic life.
Sulfide - Hydrogen Sulfide	2 µg/l undissociated H_2S for fish and other aquatic life, fresh and marine water.
Tainting Substances	Materials should not be present in concentrations that individually or in combination produce undesirable flavors which are detectable by organoleptic tests performed on the edible portions of aquatic organisms.
Temperature	Freshwater Aquatic Life: For any time of year, there are two upper limiting temperatures for a location (based on the important sensitive species found there at that time): (1) One limit consists of a maximum temperature for short exposures that is time dependent and is given by the species-specific equation: $\text{Temperature } (C^{\circ}) = 1/b (\log_{10} \text{ time}_{(min)} - a) - 2^{\circ}C$ where: $\log_{10}$ = logarithm to base 10 (common logarithm) a = intercept on the "y" or logarithmic axis of the line fitted to experimental data and which is available from Appendix II-C, NAS, 1974 for some species. b = slope of the line fitted to experimental data and available from Appendix II-C, NAS, 1974 for some species. and (2) The second value is a limit on the weekly average temperature that:

EPA QUALITY CRITERIA FOR WATER

(Concluded)

Temperature (continued)

- a. In the cooler months (mid-October to mid-April in the north and December to February in the south) will protect against mortality of important species if the elevated plume temperature is suddenly dropped to the ambient temperature, with the limit the acclimation temperature -2°C when the lower lethal threshold temperature equals the ambient water temperature (in some regions this limitation may also be applicable in summer); or
 - b. In the warmer months (April through October in the north and March through November in the south) is determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most sensitive important species (and appropriate life state) that normally is found at that location and time.
 - c. During reproductive seasons (generally April through June and September through October in the north and March through May and October through November in the south) the limit is that temperature that meets site-specific requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species. These local requirements should supersede all other requirements when they are applicable.
 - d. There is a site-specific limit that is found necessary to preserve normal species diversity or prevent appearance of nuisance organisms.
-

effluent guidelines. Exhibit 6.2 lists in a matrix format pollutants limited by water quality standards in states with geothermal energy potentials.²⁰

The implementation of effluent guidelines and water quality standards is carried out under the authority of Section 402 of the Clean Water Act through the NPDES program. For any point source discharge to surface waters, a permit based upon effluent guidelines and/or water quality standards is required. While effluent guidelines for geothermal development have not been established, it is anticipated that direct discharge without treatment is not adequate to meet water quality standards. For most spent geothermal fluids, the presence of heavy metal ions will be a major concern. Thus, it becomes apparent that only two systems of surface discharge have the potential of meeting the NPDES permit requirements:

- Evaporation ponds, in which all spent fluids are being evaporated by the use of large holding ponds with no surface discharge, and
- Chemical treatment followed by removal of precipitated solids through sedimentation and filtration.

Part C of the Safe Drinking Water Act directed EPA to develop minimum requirements for state programs to protect underground drinking water sources from contamination by underground injection. EPA has issued regulations for this purpose and has defined five classes of injection wells. Since February 1982, the classification of geothermal injection wells has been changed from Class III to Class V. Class V regulations are the least stringent of the classifications, and no specific well construction criteria or maintenance and testing programs are required.

EXHIBIT 6.2

POLLUTANTS LIMITED BY WATER QUALITY STANDARDS
IN STATES WITH GEOTHERMAL POTENTIAL

	Alaska	Arizona	California	Colorado	Hawaii	Idaho	Louisiana	Montana	Nevada	New Mexico	Oregon	Texas	Utah	Washington	Wyoming
Total dissolved solids....	d				d		d		d	d	d	d	p		
Chloride.....							d		s	d	d	d	p		
Sodium.....															
Calcium.....															
Magnesium.....															
Potassium.....															
Aluminum.....															
Iron.....							d				d		p		
Bromide.....															
Manganese.....											d		p		
Strontium.....															
Boron.....		d							d		d				
Zinc.....		d					d				d	s	p		
Barium.....		d	s								d	s	p		
Lithium.....															
Cesium.....															
Fluoride.....											d		p		
Lead.....		d	s				d				d	s	p		
Rubidium.....															
Iodine.....															
Copper.....		d					d				d	s	p		
Sulfur.....															
Arsenic.....		d	s				d				d	s	p		
Mercury.....		d	s				d					s			
Chromium.....		d	s								d	s	p		
Antimony.....												s			
Nickel.....												s			
Bismuth.....															
Tin.....															
Silver.....		d										s	p		
Cadmium.....		d	s					d			d	s	p		
Beryllium.....															
Selenium.....		d	s									s	p		
Sulfate.....							d			d		d	p		
Silica.....															
Ammonium.....															
Nitrate (+ nitrate).....			s							s			p		
Ph (range).....	s	d	d	s	s	s	s	s	s	s	s	s	s	s	s
Radioactivity.....	d	s	d	s	s	s		d	s	s	s	s	s	s	s
Total dissolved gas.....								s		s	s			s	d
Toxic materials.....	d	f		f	f	s	s	s	f	s		s		s	f
Temperature.....	d	d	d	d	d	d		d	d	d	d	d	d	d	d
Dissolved oxygen (min.)..	s	d	d	a	s	s	s	d	s	s	s	s	s	s	s
Phosphorus.....									d	d					
Conductivity.....										d	d				

d=criteria for designated waters; s=criteria applied statewide; p=criteria conform with USPHS Drinking Water Standards, 1976; f=free from toxic materials.

Two types of injection wells can be designed to meet the regulatory requirements. They are:

- o Injection into the producing aquifer--this system may also have the advantage of using an old production well as an injection well, and
- o Injection away from the producing aquifer--in this system, injection occurs at a place where there is a physical barrier between the injecting zone and the production zone.

6.2 Technological Readiness

6.2.1 Surface Disposal

Of the different surface disposal systems described in Section 5.0, only chemical treatment and evaporation ponds have the potential of meeting the NPDES. Direct discharge of spent geothermal fluids was used at The Geysers until the level of boron and other contaminants in the fluids caused the regulators to require injection. At present, only one direct use plant, the Torbett-Hutchings-Smith Memorial Hospital, in Marlin, Texas, discharges untreated spent geothermal fluid into the city storm sewer.²¹ The fluid characteristics of this plant, however, are significantly different from the typical 50 MWe plant in the following manner:

- The quantity of wastewater is substantially less than that of a 50 MWe plant, where its peak flow rate of 160 gpm (about 0.25 mgd) is rated to have insignificant impact on the river which has a 150,000 to 24,000,000 gpm annual flow,
- The temperature of the spent fluid at the discharge point is about 100°F, which is lower than most typical geothermal power plant operations, and
- The TDS content of 4,000 ppm is lower than the typical salinity of geothermal fluids used for power generation.

Physical and chemical waste treatment processes have been used for years by other industries for the treatment of industrial wastes. Conventional waste treatment processes may be effective on many of

the geothermal liquid wastes. These treatment systems remove suspended solids from wastewater in a four-step process. The first three unit operations, namely rapid mixing, flocculation and sedimentation, can be performed in a single vessel. Quite frequently, chemicals such as alum (Al_2O_3), iron compounds (FeCl_3), and lime (CaO) are added to promote flocculation and settling. These compounds are also very effective in removing heavy metal ions in the fluids. The last step in the conventional treatment process is the filtration of the liquid effluent to remove turbidity and suspended particles.

Although at this time, none of the geothermal power plants in the U.S. are using chemical treatment and direct discharge, treatment systems and processes developed by other industries are applicable for the treatment of spent geothermal fluid. Exhibit 6.3 is a process flow diagram for the removal of heavy metals commonly found in metal and finishing industries.²² Detailed descriptions of applicable treatment processes are provided in Appendix A.

Instead of building their own treatment facilities, some industries discharge their wastewater to publicly-owned wastewater treatment plants. This approach is not likely to be a viable option for geothermal electric power producers, because of the high volume of fluid discharges, and because most geothermal power plants are not expected to be located in heavily populated areas with publicly-owned treatment plants large enough to handle the high volume waste flow of a geothermal power plant.

Several advanced wastewater treatment processes may also be applicable for geothermal effluents. These advanced treatments can be used when conventional systems cannot achieve a desired water

EXHIBIT 6.3
WASTEWATER TREATMENT PROCESSES FOR REMOVING HEAVY METALS

quality levels. These treatments include ion exchange, reverse osmosis, electrodialysis, and evaporation/distillation (see Appendix A for more detailed description). However, the high temperature of geothermal fluid may pose operational problems in some of these treatment processes. Both reverse osmosis and electrodialysis use membranes to selectively allow the passage of ions. Membranes for these two processes are presently limited to about 30°C for reverse osmosis and 60°C for electrodialysis.

Another disposal option for meeting the NPDES requirements is the use of closed cycle evaporation ponds. In this system, all spent fluids are disposed of through evaporation, and no discharges are made to surface waters. There are several advantages with the evaporative cooling process, including:

- Very little interaction with the utilization process,
- Absence of moving parts outside of the pumps to propel fluids from the energy conversion unit to the ponds,
- Possible salt residues as useful by-products,

On the other hand, disadvantages of ponding include:

- Adverse weather conditions which may cause the evaporative rate to be below normal, and
- The need for costly pond linings to prevent contamination of groundwater.

In general, the successful usage of evaporative cooling is very site specific and is very much dependent upon climatic conditions, particularly ambient temperature and humidity. Closed-cycle ponding is being used as the disposal technique at Cerro Prieto's first 75-MWe facility.²³ However, this technique has not been used in the U.S. for geothermal power plants. On the other hand, there are more than 30 zero discharge (i.e. closed-cycle ponding) plant in operation in

the U.S.. Most of these are used in coal-fired power plants but some are in use in nuclear, oil, and natural gas power plants.²⁴ Cost is a major deterrent in the construction and use of zero discharge plants (see Section 6.3).

6.2.2 Subsurface Disposal

Subsurface disposal, through the use of injection wells, is being used at some of the major power producing facilities throughout the world, including The Geysers. This method has also been used by the oil industry, primarily for the disposal of oil brine wastes, for over 50 years. Brine injection wells are deep to avoid contamination of fresh water aquifers and to increase the gravity head, thereby reducing cost. Other industrial wastes, including chemical and nuclear wastes, have been disposed of by deep well injection. The petroleum and industrial waste disposal industries have provided some of the most significant transferable technologies to the geothermal industry. The most significant difference between spent geothermal fluid injection and other types of industrial waste injection is the volume of waste to be disposed of. This high volume of waste (4.5 mgd for a typical 50 MWe plant) implies the need for high injection rates to reduce the requirement of constructing additional injection wells.

There are problems, however, associated with injection. The most significant ones are corrosion and scaling (see Section 5). Injectivity can be severely decreased by scale and the precipitates that may accumulate in the well bore, in and around the slotted liner

and in the injection formation. Scaling is believed to be caused by the following mechanisms:

- Polymerization and precipitation of silica and silicates
- Precipitation of carbonate, sulfates, and hydroxide of the alkaline earth metals
- Precipitation of heavy metal sulfides
- Precipitation caused by the oxidation of certain chemical species within the fluid.

Scale formation can be controlled or inhibited through the addition of chemicals to cause precipitation prior to injection. The solids produced will have to be removed either through filtration or sedimentation prior to injection. Chemical inhibitors can also be used to keep the chemicals in solution during the injection process.

Dispite various operational difficulties, injection is a viable option from the technology readiness point of view. In addition, injection offers flexibility to the power plant operation system. Frequently an abandoned production well can be used as an injection well, thereby eliminating the need of drilling a new injection well.

6.3 Economics

6.3.1 Surface Disposal

As with the injection disposal option, discharging geothermal brine through the NPDES option involves both the capital cost of constructing holding ponds and attendant pump and piping systems, and O&M costs which are incurred each operating year. Estimating capital and O&M costs for surface disposal is more complicated than subsurface (injection) disposal, because a wide variety of options exist with regard to the method and requirements of surface disposal.

Disposal options range from no treatment, direct discharge, to zero discharge, where no effluent is discharged at all. Since only one facility using geothermal energy currently disposes of its spent brine under NPDES permit--Torbett-Hutchings-Smith Memorial Hospital in Marlin, Texas--there is no clear precedent on which to base a hypothetical surface disposal case, making the task of generating reasonable cost estimates extremely speculative. To facilitate a cost comparison between surface and subsurface disposal options, it is necessary to generate two surface disposal scenarios. The reader should select the most appropriate scenario for analyzing costs in a given location. The two scenarios include the aforementioned extremes, direct discharge and zero discharge. A compromise option, partial effluent conditioning before discharge, may be constructed from these extremes.

6.3.1.1 Direct Discharge. The direct discharge option is relatively inexpensive when compared to the other two alternatives, assuming the distance to the final discharge point is equivalent. Direct discharge is most feasible when:

- The effluent temperature is low enough so as not to adversely impact the receiving environment,
- Pollutants within the wastestream are at minimal concentrations, and
- The quantity of wastewater is minimal.

As indicated elsewhere in this report, an NPDES permit must be granted stipulating specific water conditioning and reporting requirements.

Assumptions used in generating the costs of direct discharge are detailed in Exhibit 6.4. These assumptions are consistent with earlier assumptions. Exhibit 6.5 displays the capital cost per mile

EXHIBIT 6.4
Waste Disposal Assumptions
The Hypothetical Plant: Direct Discharge
(1981 Dollars)

- Plant Size: 50 MWe
- Waste Water Disposal Requirements: 4.5 Mgd
- Land Cost: \$3,900/Acre
- Land Required: 12.25 Acres
- O&M Cost: 1.5% of capital cost/year*

*Does not include energy costs for pumps.

of the direct discharge option. Because cost is directly related to the distance between the energy use facility and the pipeline outlet, presenting costs on a per mile basis is preferable. Exhibit 6.6 incorporates O&M costs with annualized capital costs to illustrate the total estimated cost of the direct discharge option on a per mile basis. The cost per mile is 0.038¢ per kilowatt hour.

6.3.1.2 Zero Discharge. The cost of zero discharge is much higher than other surface and subsurface discharge options. The most significant cost associated with zero discharge is the capital cost of constructing a lined pond. For the purpose of building the hypothetical case, assumptions detailed in Exhibit 6.7 are employed. Using these assumptions, the capital cost of zero discharge is presented in Exhibit 6.8. Finally, the total estimated 30 year cost of the zero discharge option is presented in Exhibit 6.9. The capital cost of a zero discharge plant is about \$37 million, which is very high. If this cost is annualized, the total cost of a zero discharge plant would be about 2¢ per kilowatt-hour. A major determining factor for a zero discharge plant is the rate of evaporation. The assumed rate of 60 inches per year is considered to be very optimistic. If the evaporation rate is only 30 inches per year, the cost of the pond would approach 4¢ per kilowatt-hour.

EXHIBIT 6.5

CAPITAL COST PER MILE
DIRECT DISCHARGE OPTION
(\$1,000s of 1981)

<u>Cost Category</u>	<u>Cost/Mile</u>
Land Aquisition	\$ 47.8
Pipeline	\$475.3
Pumping System*	\$ 47.5
TOTAL	\$570.6

*Pumping costs are assumed to be 10% of pipeline costs. Pumping systems are not always required.

SOURCE: Reference 25

EXHIBIT 6.6

TOTAL COSTS PER MILE (1981 Dollars)

<u>Cost Categories</u>	<u>Annualized Cost</u>	<u>Cost per Kilowatt-hour</u>
Capital Cost	\$ 94,100*	0.027¢
Energy Cost	\$ 31,800	0.009¢
Other O&M Costs	\$ 8,600	0.002¢
Total Cost	\$134,500	0.038¢

*Based on a 12 year amortization at an interest rate of 13%.

EXHIBIT 6.7

WASTE DISPOSAL ASSUMPTIONS THE HYPOTHETICAL PLANT = ZERO DISCHARGE (1981 Dollars)

- Plant Size: 50 MWe
- Waste Water Disposal Requirements: 4.5 MgD
- Land Cost: \$3,900/Acre
- Land Required: 1,000 Acres
- Evaporation Rate: 15 Million Gallons/Year/Acre
(60 inches net per year)
- Cost of Construction and Lining Pond: \$20,000/Acre
- O&M: 1.5% of Capital Cost/Year

EXHIBIT 6.8

CAPITAL COST OF ZERO DISCHARGE
(1981 Dollars)

<u>Cost Category</u>	<u>Cost</u>
Land Acquisition	\$ 3,900,000
Pond Construction and Lining	\$35,000,000
TOTAL	\$36,900,000

EXHIBIT 6.9

TOTAL COST OF ZERO DISCHARGE
(1981 Dollars)

<u>Cost Category</u>	<u>Annualized Cost</u>	<u>Cost per Kilowatt-hour</u>
Capital Cost	\$6,090,000	1.740¢
O&M Costs	\$ 550,000	0.157¢
TOTAL COST	\$6,640,000	1.897¢

*Based on a 12 year amortization at an interest rate of 13%.

6.3.2 Subsurface Disposal

The cost of injecting spent geothermal brine underground may be divided into two discreet categories:

- the capital cost of drilling and completing an injection well (including the cost of installing pipe and equipment associated with the well),
- operating and maintenance costs.

While the latter costs are incurred over the life of the plant, the former are fixed at the time the well is brought into service.

6.3.2.1 Capital Costs of Injecting. The following well parameters are used in calculating the capital cost of an injection well:

- Well and Pipe Diameters. As shown in Exhibit 6.10, cost is proportional to the size of the well. The optimal diameter is a function of both capital costs and O&M costs.
- Pumping System Requirements. The capital cost of pumping equipment is highly dependent upon hydrostatic characteristics of the well environment and the desired disposal rate. In designing the pumping system, engineers must take into account the probability of deteriorating well conditions.
- Well Depth. Cost is proportional to the depth of the well.
- Geology of the Site. Drilling costs vary appreciably according to the nature of the rock formations through which the well is drilled.

Exhibit 6.11 illustrates an estimated cost range for drilling and completing an injection well. This information was based on 1977 cost figures provided by Geonomics, Inc. An update of these cost figures based on the GNP deflator shows that the general cost of an injection well is between \$73 and \$148 per foot.

EXHIBIT 6.10

THE RELATIVE COST OF GEOTHERMAL INJECTION WELLS
AS A FUNCTION OF WELL DIAMETER

EXHIBIT 6-11

Cost of Drilling and Completing
A Geothermal Injection Well*
(1981 Dollars)

<u>DEPTH</u> <u>(feet)</u>	<u>LOW ESTIMATE</u> <u>(\$1,000)</u>	<u>HIGH ESTIMATE</u> <u>(\$1,000)</u>
5,000	\$366	\$ 739
10,000	\$732	\$1,478

*Source: EER, Inc. based on a study by Geonomics, Inc.,
1977.

6.3.2.2 Operations and Maintenance Costs of Injecting. The gen-

eral components of operation and maintenance costs are detailed below:

- Energy Cost. This cost is associated with the pumps (if any) that are used to pump spent brine down-hole. Potentially representing the greatest portion of O&M costs, energy costs are related primarily to the pressure required to dispose of spent brine. A reasonable estimate of the cost to dispose of 1,000 gallons of fluid at one pound per square inch (psi) is .07 cents. Because the energy cost/pressure function is linear, one can easily calculate energy costs.
- Other O&M Costs. These costs may vary considerably from location-to-location. In certain instances the costs may be marginal. In others, the costs may be considerable due to pump failure and pump/well plugging, materials corrosion and system wear. Maintenance costs tend to be about 4% of capital costs.

In order to compare the cost of each disposal option, it is helpful to use a hypothetical plant for each disposal scenario. Exhibit 6.12 incorporates the basic assumptions presented in Section 4.0. Additional assumptions are needed to facilitate the calculation of injection costs.

- Well Depth--The assumption is based on an average between the two benchmarks, 5,000 and 10,000 feet.
- Well Capital Costs--The assumption represents an average of the cost per foot detailed above.
- Injection Pressure--The assumption is based on the injection pressure at Raft River, Idaho.
- Number of Wells--Calculations for this assumption are based on 3 wells disposing of 62,500 gallons of brine per hour.
- Replacement of Failing Injection Wells--It is generally assumed that abandoned production wells will replace injection wells which have failed.

Exhibit 6.13 utilizes the assumptions detailed in Exhibit 6.12 to generate the total annualized cost of the injection scenario. The total cost of injecting spent brine is approximately 0.316¢ per kilowatt-hour.

EXHIBIT 6-12

Waste Disposal Assumptions
The Hypothetical Plant
(1981 Dollars)

- Plant Size: 50 MWe
- Waste Water Disposal Requirements: 4.5 MgD
- Injection Well Depth: 7,500 feet
- Well Capital Cost Per Foot: \$110.50
- Injection Pressure: 500 psi
- Number of Wells Required: 3
- O&M Cost: 4% of capital cost/year*
- Abandoned Production Wells Replace Failing Injection Wells

*Does not include energy costs for injection pumps

Source: EER, Inc.

EXHIBIT 6-13

TOTAL ANNUALIZED COST OF INJECTION (1981 Dollars)

<u>Cost Category</u>	<u>Annualized Cost</u>	<u>Cost per Kilowatt-hour</u>
Capital Cost	\$ 410,000*	0.117 ¢
Energy Cost	\$ 600,000	0.171 ¢
Other O&M Cost	\$ 99,500	0.028 ¢
Total Cost	\$1,109,000	0.316 ¢

*Based on a 12 year amortization at an interest rate of 13%.

6.4 Environmental Considerations

6.4.1 Surface Disposal

In general, surface treatment and discharge systems can be designed to meet water quality criteria and standards. As long as these standards are met, the chance for water pollution is low. Sampling of receiving water should be performed to assure that water quality does not deteriorate with time. Except for unexpected and undetected changes in fluid chemical characteristics, release of toxic substances will not be a problem because the wastewater to be discharged has to meet legal criteria before it can be released to surface water. Thermal pollution may be a problem because most states only allow a 2° - 5°C change in ambient temperature.

In the case of zero discharge, i.e., close cycle ponding, water pollution potential still exists because liner materials may fail after several years of service. Unfortunately, early detection of liner failure is difficult due to the large size of evaporation ponds. In addition, bank erosion from heavy precipitations and flash floods are important factors to be considered in pond design.

Sludges generated from treatment plants and evaporation ponds will have to be disposed of in a manner acceptable to local regulations and conforming to the regulations promulgated under the Resource Conservation and Recovery Act (RCRA).

6.4.2 Subsurface Disposal

Injection of geothermal fluids, particularly at the production horizon, is not likely to create any adverse environmental impact. Toxic contaminants, if present in the spent fluid, are returned to

geothermal reservoir. However, the system is subject to failure due to accident, such as pipe rupture. It is therefore important to design back-up systems, such as alternative injection wells, holding ponds, and/or means to collect and direct accidental spills.

Seismicity and land subsidence are major environmental concerns associated with injection. Although the probability of inducing significant seismic events is very low seismic monitoring should be performed at operating geothermal power plants.

Land subsidence may be caused by withdrawal of geothermal fluids in large quantities. Injection of spent fluid to the producing horizon is believed to be effective in preventing land subsidence.

REFERENCES

1. Clear Water Act of 1977, 33 U.S.C., Sections 300f to 300 j-9.
2. 33 U.S.C. Section 1342 (1977).
3. Federal Water Pollution Act Amendments of 1972, 33 U.S.C. Section 1311(b)(1).
4. Water Programs; Consolidated Permit Regulations and Technical Criteria and Standards; State Underground Injection Control Programs, Final Rule for Part 146 and Amendments to Part 122. FR Vol. 45, No. 123; June 24, 1980, pp 42472-42512.
5. 40 C.F.R. Subpart D Additional Requirements for State NPDES Programs.
6. Engineering and Economics Research, Inc., Hydrothermal Industrialization Electric Power System Development, (DOE/ID/12186) Washington, D.C., 1982.
7. Safe Drinking Water Act, 42 U.S.C., Section 300 f to 300 j-10.
8. Underground Injection Control Program Criteria and Standards, Technical Amendments to Final Amendments, FR Vol. 46, No. 166, August 27, 1981, pp 43156-43163.
9. 45 Federal Register 42472 (1980).
10. Underground Injection Control Program Criteria and Standards, Proposed Rule, FR Vol 46, No. 190, October 1, 1981; pp 48243-48255.
11. Underground Injection Control Program Criteria and Standards, Final Rule, FR Vol. 47, No. 23; February 3, 1982; pp 4992-5001.
12. 33 U.S.C., 1317(a), 1982.
13. U.S. Department of Energy, Technology Characterizations Environmental Information Handbook, DOE/EV-0072, Washington, D.C., 1980.
14. Reeber, R.R., "Coatings in Geothermal Energy Production", Thin Solid Films, Vol. 72, 1980.
15. Crane, C.H. and D.C. Kenkeremath, Review and Evaluation of Literature on Testing of Chemical Additives for Scale Control in Geothermal Fluids, prepared for U.S. Department of Energy (DOE/ID/12183-T1), Washington, D.C., 1981.
16. U.S. Environmental Protection Agency, Development Document for Proposed Effluent Limitations Guidelines, New Source Performance Standards, and Pretreatment Standards for the Steam Electric Point

Source Category, (EPA 440/1-80/029-b), Washington, D.C., 1980.

17. Coulter, G.W., "A Preliminary Appraisal of Effects on Aquatic Environments of Geothermal Development in New Zealand", Geothermal Resource Council Transaction, Vol. 2, July 1978.

18. Metcalf and Eddy, Inc., Washington Engineering: Collection, Treatment, Disposal, McGraw-Hill xxxxx Company, New York, 1972.

19. Weiss, R.B., et. al., Geothermal Environmental Impact Assessment; Groundwater Monitoring Guidelines for Geothermal Development. Prepared for U.S. Environmental Protection Agency (EPA-600/7-79-218). Las Vegas, Nevada (1979).

20. Hartly, R.P. and R. DiPippo, "Environmental Considerations " in Kestin, J. (ed.), Sourcebook on The Production of Electricity from Geothermal Energy, (DOE/RA/4051-1), U.S. Department of Energy, Washington, D.C., 1980.

21. U.S. Environmental Protection Agency: National Pollutant Discharge Elimination System (NPDES), Permit No. TX0086321, June 14, 1981.

22. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Control Technology for the Metal Finishing Industry - Evaporators, Summary Report, EPA 62518-79-002, Cincinnati, Ohio, 1979.

23. Defferding, L.S., State of the Art of Liquid Waste Disposal for Geothermal Energy System: 1979, DOE/EV-0083, U.S. Department of Energy, Washington, D.C., 1980.

24. "Balancing The Water Budget", EPRI Journal, June 1981, pp 6-11.

25. U.S. Environmental Protection Agency, Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category, (EPA 440/1-79/014-b), Washington, D.C., 1979.

APPENDIX

DESCRIPTION OF WASTEWATER TREATMENT
UNIT PROCESSES

CHEMICAL PRECIPITATION

Process Description

Chemical precipitation in wastewater treatment involves the addition of chemicals for the purpose of removing specific components contained in the wastewater. Many different substances can be used as precipitants. The most common ones include lime ($\text{Ca}(\text{OH})_2$), alum ($\text{Al}_2(\text{SO}_4)_3$) and ferrous sulfate (FeSO_4). An advantage of chemical precipitation is that such a process is more readily incorporated into an existing treatment facility. It involves the use of a chemical feed system directly to the flocculation tank, and perhaps ancillary monitoring equipment to monitor the chemical characteristic, of influent and effluent. Further, many other types of chemicals can be used to enhance solid formation.

Because of the low solubility of sulfide salts, sodium sulfide (Na_2S) and sodium bisulfide (NaHS) has been used to remove heavy metal ions in solution. Such systems have been tested by the electroplating industry and is also being studied at a pilot plant scale for the removal of heavy metal ions in geothermal fluids.

Status

Chemical precipitation is perhaps the most versatile unit process for the removal of heavy metals in geothermal fluids. It is possible to selectively precipitate one or a few chemicals from the fluid thereby improving the overall quality of the sludge.

SEDIMENTATION

Process Description

Sedimentation is the separation of suspended particles that are more dense than water by gravitational settling. Although the concept of sedimentation is rather simple, many design options are available to increase the efficiency of the operation. Sedimentation tanks are designed on the basis of surface loading rate expressed in gallons per day per square foot of horizontal area. The selection of loading rate depends on the types of suspension to be separated. The surface loading rate together with the depth of the sedimentation tank will determine the detention time of the fluid to be treated.

Most treatment plants now use mechanically cleaned sedimentation tanks of standard circular or rectangular design. A typical tank, as shown above, has a sloped bottom at about 1 inch per foot to form an inverted cone. The sludge is scraped to a relatively small hopper near the center of the tank. Sedimentation tanks can be used by themselves or in conjunction with other treatment processes, particularly chemical precipitation and flocculation.

Status

Spent geothermal fluids typically contain higher amounts of suspended solid relative to raw geothermal fluids mainly because of the decrease in temperature after they pass through the energy conversion system. Sedimentation is probably the most simple and least expensive pre-treatment process.

FLOCCULATION

Process Description

Flocculation is an essential part of any chemical or chemically aided precipitation system. It involves stirring or agitation to increase the opportunity for particle contact after the chemicals have been added. Increased particle contact will promote floc growth. However, if the agitation is too vigorous, the shear forces that are set up will break up the floc into smaller particles. Agitation should be carefully controlled so that the floc particles will be of suitable size and settle readily.

Two types of flocculation systems are available for wastewater treatment, namely mechanical agitation and aeration. Paddles for mechanical agitator usually have a peripheral speed of about 1.5 feet per second. Sometimes stationary slats or stator blades are installed in the flocculation tanks to break up the mass rotation of fluid and promote mixing. For air agitation systems, porous tubes or diffuser nozzles are used. The amount of air required is approximately 0.10 cubic feet per gallon for a 45-minute detention period. A typical tank design, as shown above, is similar aeration tanks used in many wastewater treatment systems.

STATUS

Flocculation is used to improve the settling of suspended solids. It can be used in association with chemical precipitation.

FILTRATION

Process Description

Filtration is generally used following the coagulation-sedimentation process and is designed to further remove the solid particles from the treated water. Filter beds are generally designed with consideration given to the characteristics of the fluid to be treated. The suspended solids concentration; particle size and distribution; and particle changes often determine the types of filter medium to be used.

In recent years, increasing emphasis has been placed on the use of multi medium filter beds. Common filter media includes anthracite, sand, garnet, activated carbon, and weighted spherical resin bed. Since filter performance is related directly to the characteristics of the liquid to be filtered, it is recommended that pilot plant studies be conducted to determine the optimum combination of filter materials.

STATUS

Filtration is a necessary step following chemical precipitation and sedimentation.

FLOTATION

Process Description

Flotation is a process used to separate solid or liquid particles from a liquid phase. Separation is brought about by introducing fine gas bubbles into the liquid phase. The bubbles attach to the particulate matter and the bouyant force of the combined particle and gas bubbles causes the particle to rise to the surface. Given particles with a higher density then water can be made to rise. Once the particles have floated to the surface, they can be collected by a skimming operation. The major advantage of flotation over sedimentation is that very small or light particles that settle slowly can be removed more completely and in a short time using the flotation method.

Sometimes chemicals are used to aid the flotation process. These chemicals function to create a surface or a structure that can easily absorb or entrap air bubbles. Aluminum and iron salts, and activated silica are the most common chemicals used.

STATUS

Flotation can be most effectively applied to fluid systems that contain solids having specific gravity slightly greater than unity. It will have limited application in the geothermal fluid system if precipitation of heavy metal ions is the main concern.

REVERSE OSMOSIS

Process Description

Reverse osmosis is a process in which water is separated from dissolved salts in solution by filtering through a semipermeable membrane at a pressure greater than the osmosis pressure caused by the dissolved salts in the fluid. Operating pressure ranging from atmospheric to 1,500 psi is generally required to overcome the osmotic pressure.

Most membranes currently in use are cellulose acetate. Under existing manufacturing process, a semipermeable membrane is subject to temperature treatment that sets the rate at which water can be produced. Therefore different membranes have different permeability for various ions. A great drawback of the reserve osmosis system is that the wastewater must not contain precipitated salts or colloidal substances which may deposit on the membrane and greatly reduce its permeability.

STATUS

While reverse osmosis may be practical for the desalination of brackish waters, it has limited application for the treatment of geothermal fluids, which typically are more saline than brackish water and generally contain suspended solids.

ELECTRODIALYSIS

Process Description

Electrodialysis is a process by which ionic components of a solution are separated through the use of semipermeable ion-selective membranes. An electrodialysis cell consists of alternate cation and anion permeable membranes arranged in a stack with positively and negatively charged electrodes on each side. The application of an electrical potential between the two electrodes causes the migration of the cations to the negative electrode and anions to the positive electrodes. Because of the alternate spacing of cation and anion permeable membranes, cells of concentrated and dilute salts are formed.

While electrodialysis is found practical for the desalination of brackish waters, it is not very suitable for the treatment of high salinity fluids, primarily because of the high energy requirement. In addition, fouling of the membranes by colloidal matters is a common problem. To reduce membrane fouling, activated carbon treatment, preceded by chemical precipitation and filtration may be required.

STATUS

The major product of electrodialysis is product water with high purity. The waste product is concentrated fluids which still need to be processed before salts can be recovered.

ION EXCHANGE

Process Description

Ion exchange is a process by which ions of a given species are displaced from insoluble exchange materials by ions of a different species in solution. The exchange material is usually in a synthetic resin placed in a bed or packed in a column, and the water to be treated is passed through it. The chemistry of ion exchange process may be represented by the following equilibrium equation:

where R is the synthetic resin and M is the metallic cation to be removed from solution. As indicated in the above equation, the undesirable cation is removed from the solution and bound to the resin.

After the ability of the resin to pick up the metallic ions has been diminished, the ion exchange column have to be regenerated, usually by backwashing with an acid solution:

The metallic salt, MCl, can be recovered by evaporation or crystallization.

STATUS

Ion exchange can be designed to selectively remove cations from the solution. However, most ion exchange resins suffer rapid degeneration at elevated temperatures. The presence of Na and K ions may also interfere with the heavy metal ion exchange processes.