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The Class V Underground Injection Control Study

Volume 17

Electric Power Geothermal Injection Wells

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ELECTRIC POWER GEOTHERMAL INJECTION WELLS

The U.S. Environmental Protection Agency (USEPA) conducted a study of Class V underground injection wells to develop background information the Agency can use to evaluate the risk that these wells pose to underground sources of drinking water (USDWs) and to determine whether additional federal regulation is warranted. The final report for this study, which is called the Class V Underground Injection Control (UIC) Study, consists of 23 volumes and five supporting appendices. Volume 1 provides an overview of the study methods, the USEPA UIC Program, and general findings. Volumes 2 through 23 present information summaries for each of the 23 categories of wells that were studied (Volume 21 covers 2 well categories). This volume, which is Volume 17, covers Class V electric power geothermal injection wells.

1. SUMMARY

Several dozen power plants located in four western states use geothermal energy to produce electricity. At these power plants, hot (>100ºC (212ºF)) geothermal fluids that are produced from subsurface hydrothermal systems serve as the energy source. Following the recovery of heat energy from the produced fluids, the liquid fraction (if any) is reinjected into the same hydrothermal system through one or more electric power geothermal injection wells.

The temperature and chemical characteristics of geothermal fluids vary substantially. For example, total dissolved solids (TDS) concentrations are about 1,000 mg/l at The Geysers (in northern California) but about 250,000 mg/l at the Salton Sea geothermal field (in southern California). Despite these variations, however, concentrations of some metals (e.g., antimony, arsenic, cadmium, lead, mercury, strontium, zinc) and other constituents in the produced and injected geothermal fluids routinely exceed primary maximum contaminant levels (MCLs) or health advisory levels (HALs) at one or more geothermal fields. The specific constituents that exceed the standards and the magnitude of the exceedences varies from site to site, with substantial variations observed within some fields. Sulfate, chloride, manganese, iron, pH, and TDS also frequently exceed secondary MCLs.

At some geothermal power plants, other fluids associated with power plant operation, such as condensate and cooling tower blowdown, are injected along with the geothermal fluids. In a few situations, supplemental water from additional sources, such as surface waters, storm waters, ground water, and wastewater treatment effluent, is also injected. Concentrations of metals and other constituents in these supplemental water sources are typically lower than in the geothermal fluids. An exception is biological constituents (e.g., coliforms) that are sometimes present in injected surface water and treated wastewater at concentrations above drinking water standards. The Geysers geothermal field in California is the principle example of injection of surface waters and treatment plant effluent along with geothermal fluids. Ground water is injected (in addition to geothermal fluids) to replace mass lost through condensate evaporation at the Dixie Valley geothermal field in Nevada.

Geothermal fluids used for electric power generation are normally injected into the same subsurface hydrothermal system from which they were produced. In fact, a majority of geothermal injection wells were drilled as production wells and subsequently converted to injection wells. Both production and injection wells are carefully engineered because power production depends on the wells and drilling costs are substantial, frequently exceeding $1 million per well.

Despite this care, well failures have occurred during both drilling and operation, due to the high pressures and temperatures encountered, exposure of well equipment to the corrosive geothermal fluids, and seismic activity that sometimes bends or breaks well casings. In some cases, well failures have occurred at sites where no USDW is present. At a geothermal power plant site in Hawaii, however, ground water monitoring data indicate that temperature, chloride concentrations, and chloride/magnesium ratios increased following a blowout[1] during drilling of an injection well.

In general, electric power geothermal injection wells are not vulnerable to receiving spills or illicit discharges because geothermal fluids are handled in closed piping systems that are managed as an integral part of the power plant system. At some facilities, contaminants could be added to the injectate as a result of leaks or spills of lubricants, fuels, or chemicals at the power plant site. For example, at sites that collect and inject storm water, such as the power plants at The Geysers, injectate could include fuel, transformer oil, lubricants, or chemicals that leak or spill on the site. To help prevent injectate contamination from such sources, potential sources of leaks and spills are covered and/or are bermed separately from other parts of the facility. In addition, oil/water separators are provided for some plant areas (e.g., the electric switch yard) to provide further assurance that leaked or spilled oil is not injected.

According to the state and USEPA Regional survey conducted for this study, four states -- California, Utah, Hawaii, and Nevada -- have a total of 234 electric power geothermal injection wells, with most of the wells reported in California (174, or 74 percent) and Nevada (53, or 23 percent). The number of geothermal power injection wells is not expected to increase substantially in the foreseeable future because gas-fired power plants can generally produce power at a lower cost than geothermal plants. However, if marketing of geothermal power as a "green" energy source is successful as the utility industry is deregulated, a modest increase in the number of geothermal power plants and associated injection wells may occur. Additional geothermal power plants are currently being considered in California and have been proposed previously in Oregon. Seven additional injection wells have recently been permitted in Hawaii.

Individual permits are required for electric power geothermal injection wells in all four states that have this type of Class V injection well. The permits are issued by state agencies, US Bureau of Land Management (BLM), and/or the USEPA Regional Office, depending on the state and whether the well is located on state, federal, or private land. In general, the permits are similar to those issued for Class II injection wells. They establish requirements and oversight for design and construction, operating conditions, monitoring and mechanical integrity testing (MIT), financial responsibility, and plugging and abandonment.

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[1] Uncontrolled release of gas and/or fluids from a well.

2. INTRODUCTION

The existing UIC regulations in 40 CFR 146.5(e) define Class V wells to include "injection wells associated with the recovery of geothermal energy for heating, aquaculture and production of electric power." Class V injection wells used in association with the generation of electric power using geothermal energy sources are the subject of this information summary. These wells may inject three types of fluid: 1) spent geothermal fluids; 2) condensate and other fluids from power plant operations; or 3) supplemental water.[2]

Injection of all three types of fluids into geothermal reservoirs is an integral part of geothermal reservoir management and power production, because it serves to recharge the reservoir fluids, conserve reservoir pressure to facilitate continued heat extraction, and/or prevent degradation of surrounding water resources. An example of the features of a geothermal system is provided in Figure 1, which shows a schematic cross section for the Steamboat Springs, Nevada, power plant of Caithness Power Incorporated. As shown, production and injection wells tap the same geothermal zone but are separated laterally to allow injected fluids to be re-heated by the geothermal source before they reach the production wells. Figure 1 also shows the interconnection of ground water features and a wide range of both high and low temperature geothermal features that are present from depth to the surface.

Figure 2 provides a second example of a cross sectional view of a geothermal system at the East Mesa field in Imperial County, California. In this case, the geothermal fluids are extracted from a sandy (rather than fractured rock) formation and separated from shallow ground water by a low permeability confining clay layer. Due to the presence of ground water above the geothermal formation, injection (and production) wells are cased from the surface to the injection zone, in contrast to Figure 1 where only the injection well is continuously cased from the surface to the geothermal formation.

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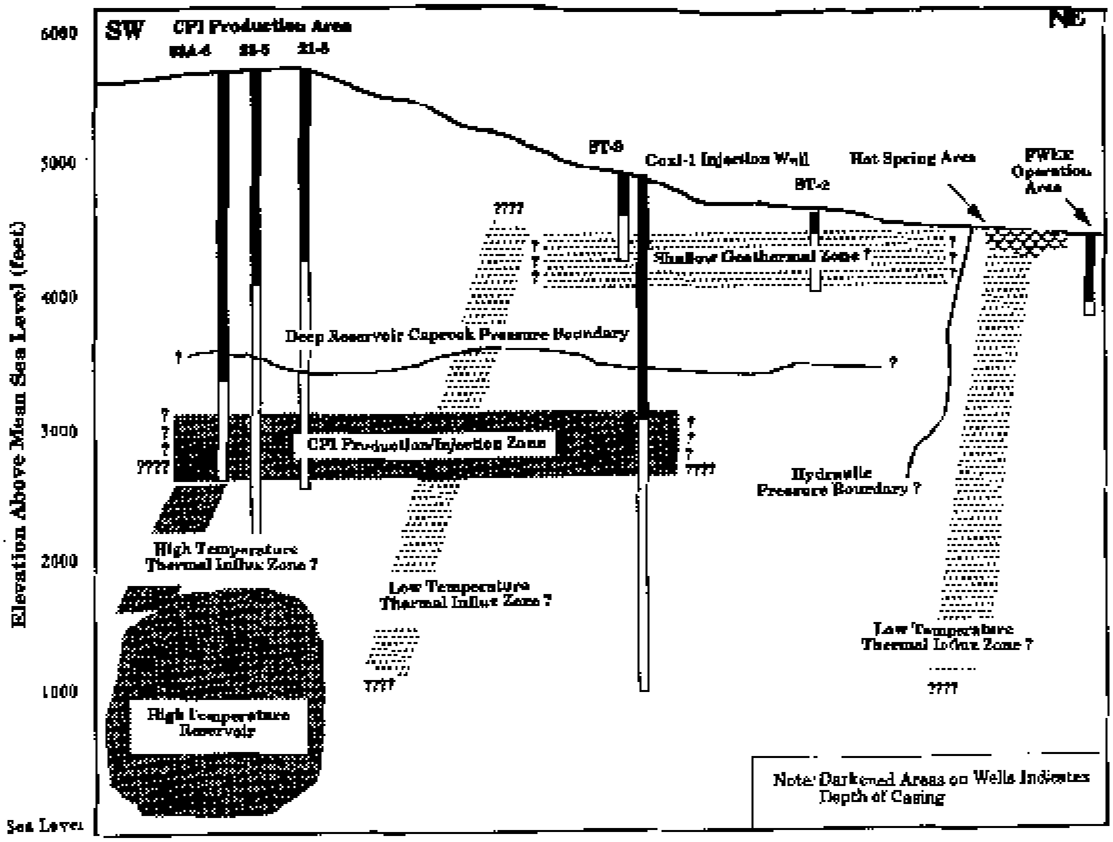
[2] Geothermal injection wells used in association with recovery of geothermal energy for purposes other than electric power generation are covered separately in Volume 18 of this document.

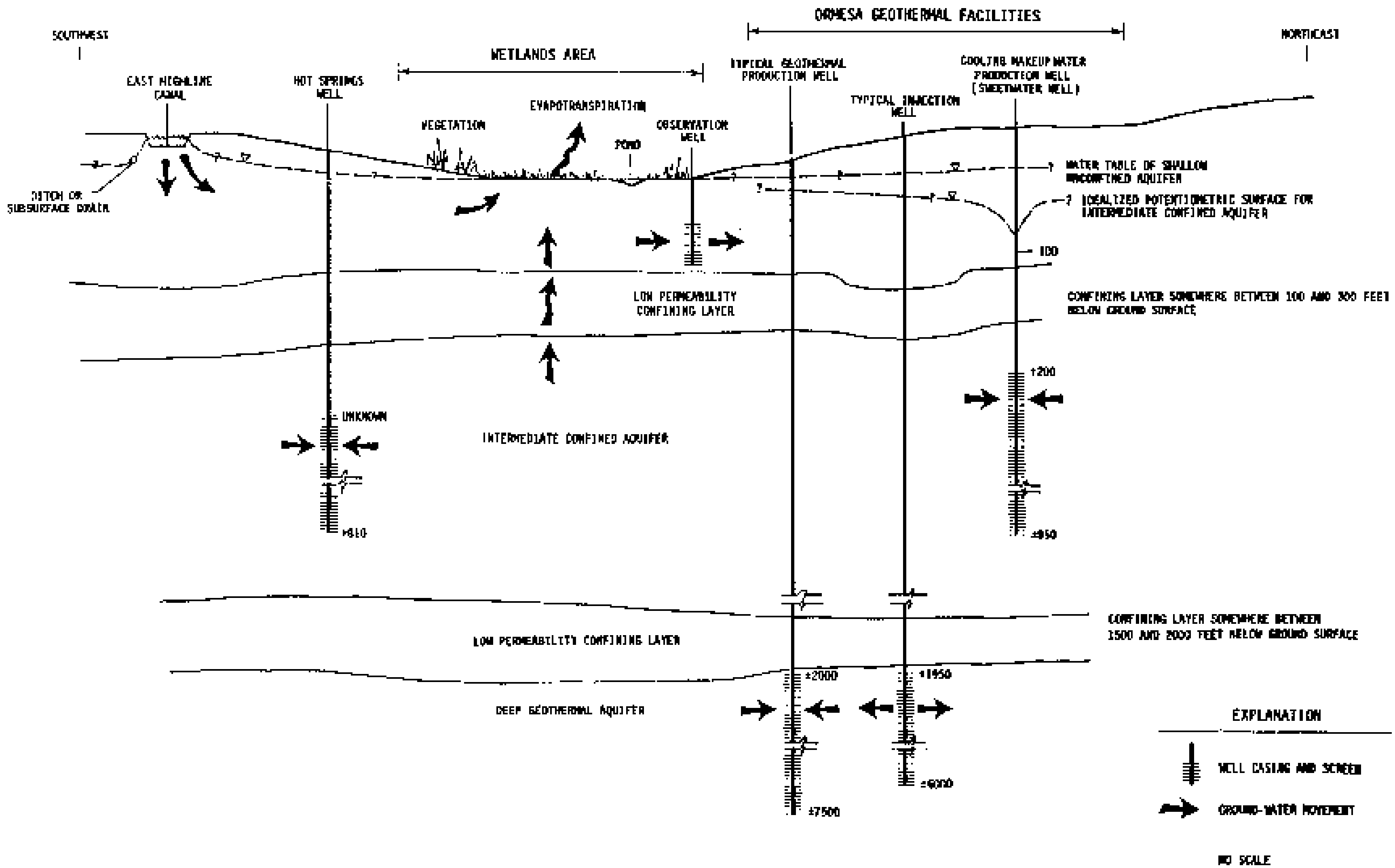
Figure 1. Geothermal Well System at Caithness Power Inc.'s Steamboat Springs, Nevada, power plant



A Southwest-Northeast Schematic Cross Section of the Steamboat Springs Geothermal System

Source: Goranson, 1990

Figure 2. Geothermal System at East Mesa Field, Imperial County, California



Source: Stollar, 1989

3. PREVALENCE OF WELLS

For this study, data on the number of Class V electric power geothermal injection wells were collected through a survey of state and USEPA Regional UIC Programs. The survey methods are summarized in Section 4 of Volume 1 of the Class V Study. Table 1 lists the numbers of Class V electric power geothermal injection wells in each state, as determined from this survey. The table includes the documented number and estimated number of wells in each state, along with the source and basis for any estimate, when noted by the survey respondents. If a state is not listed in Table 1, it means that the UIC Program responsible for that state indicated in its survey response that it did not have any Class V electric power geothermal injection wells.

Table 1. Inventory of Electric Power Geothermal Injection Wells

State	Documented Number of Wells	Estimated Number of Wells[1]	
		Number	Source of Estimate and Methodology
USEPA Region 1 -- None			
USEPA Region 2 -- None			
USEPA Region 3 -- None			
USEPA Region 4 -- None			
USEPA Region 5 -- None			
USEPA Region 6 -- None			
USEPA Region 7 -- None			
USEPA Region 8			
UT	4	4	Best professional judgment.
USEPA Region 9			
CA	174	174	N/A
HI	3	3	N/A
NV	53	53	N/A
USEPA Region 10 -- None			
All USEPA Regions			
All States	234	234	

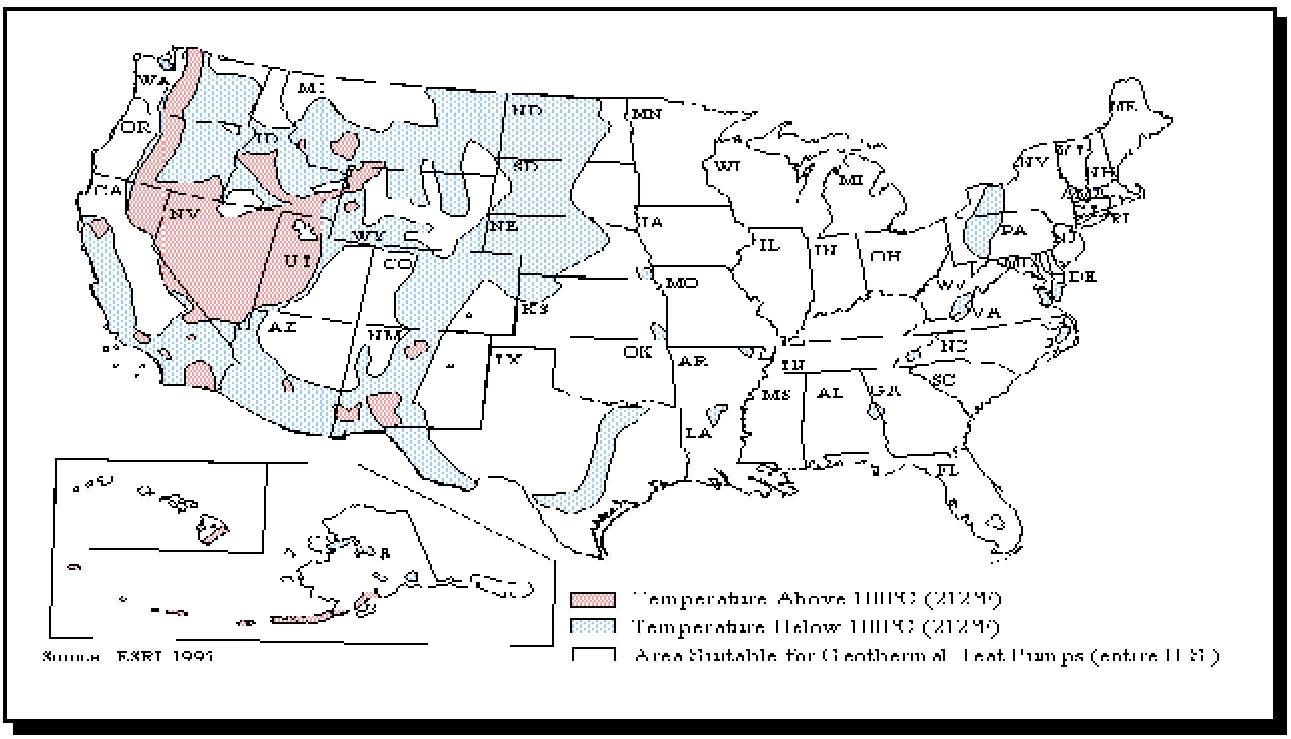
[1] Unless otherwise noted, the best professional judgement is that of the state or USEPA Regional staff completing the survey questionnaire.

N/A Not available.

A total of 234 documented electric power geothermal injection wells exist in the United States. Information provided by state and USEPA Regional UIC programs indicates that such wells are currently in use in California (174),[3] Hawaii (3), Nevada (54), and Utah (4). Idaho also has geothermal wells, but they are not active at this time.

The on-going deregulation of electric power generation and the associated effects on energy prices and consumer choice of energy suppliers may cause either an increase or decrease the number of operating facilities and injection wells. If demand for geothermal power declines, then existing facilities (and wells) could close. If market prices and demand warrant the development of additional electricity production from geothermal sources, existing geothermal fields could be developed further or additional fields could be developed as well. Increases are anticipated for at least one current facility in Hawaii where USEPA issued a permit (on June 16, 1999) that authorizes drilling of seven new geothermal injection wells in addition to the three existing (permitted) wells at the facility. New fields are currently proposed for development in northern California and additional geothermal resources potentially appropriate for power production (with temperatures >100°C (212°F)) also exist in New Mexico, Wyoming, Montana, Oregon, Washington, and Alaska (see Figure 3) (Geo-Heat Center, 1998).

Figure 3. Geothermal Resources in the U.S.



Source: Geo-Heat Center, 1998

[3] Documented well information based on the California Department of Conservation, Division of Oil, Gas and Geothermal Resources (CDOG). USEPA Region 9 inventory indicates 96 wells. Source of the difference is not known, but the CDOG inventory is well documented.

4. INJECTATE CHARACTERISTICS AND INJECTION PRACTICES

4.1 Injectate Characteristics

This section summarizes data on the chemical characteristics of injectate. As noted in Section 1, these wells routinely inject into the same formation from which the geothermal fluids were extracted. Because the characteristics of the producing geothermal resource play a dominant (although not exclusive) role in determining the injectate characteristics, data on the characteristics of geothermal fluids are presented for individual geothermal fields. The fields are grouped by state for consistency with other sections of the document and not as a result of similar characteristics. In spite of the substantial variations among fields, there are some similarities. In particular, geothermal fluids used in electric power generation commonly exceed primary and secondary drinking water standards for TDS, fluoride, chloride, and sulfate (USEPA, 1987).

- **Hawaii**. As shown in Table 2, data for the Puna geothermal project indicate that mean concentrations of TDS, arsenic, barium, boron, cadmium, chloride, and iron exceed drinking water standards and HALs (Puna Geothermal Venture, 1996).

- **Nevada**. As shown in Table 3, data from three geothermal fields in Nevada indicate that TDS, arsenic, chloride, fluoride, and manganese concentrations and pH routinely exceed drinking water standards. Exceedences of the primary or secondary standards have also been noted on occasion for aluminum, lead, mercury, selenium, iron, and cadmium (Nevada Bureau of Water Pollution Control, 1999).

- **California**. As shown in Table 4, data for the East Mesa field indicate that TDS and chloride concentrations routinely exceed drinking water standards and that sulfate, iron, boron, and arsenic concentrations and pH occasionally exceed drinking water standards or HALs (Stollar, 1989; EMA, 1995). Data for the Salton Sea geothermal field shown in Table 5 indicate that TDS, ammonium, barium, boron, cadmium, chloride, copper, iron, lead, manganese, strontium, and zinc concentrations routinely exceed drinking water standards or HALs (Williams, 1989; Elders, 1992). For the Heber geothermal field, data presented in Tables 6a, 6b, and 6c indicate that antimony, arsenic, barium, boron, chloride, lead, manganese, mercury, and strontium concentrations and pH routinely exceed drinking water standards or HALs (SIGC, 1993; CDOG, 1998e). Data for The Geysers geothermal field (see Tables 7a-f) indicate that arsenic, boron, sulfate, and mercury routinely exceed drinking water standards or HALs (Unocal, 1998; CALPINE, 1994 and 1998; NCPA, 1988, 1995 and 1998; Crockett, 1990; Freeport-McMoRan, 1989; GEO Operator Corp., 1987 and 1989;

Table 2. Injectate Characteristics at the Puna Geothermal Field

Constituents	Drinking Water Standards mg/l	Drinking Water Standards P/S*	Health Advisory Levels mg/l	Health Advisory Levels N/C**	Concentration (mg/l unless otherwise noted) Mean	95 % Confidence limits Lower	95 % Confidence limits Upper
TDS	500	S	--		5680	4521	6839
pH (Std. units)	6.5-8.5	S	--		4.85	4.67	5.02
Arsenic	0.05	P	0.002	C	0.08	0.06	0.1
Barium	2	P	2	N	2.45	1.77	3.13
Boron	--		0.6	N	2.59	2.3	2.87
Cadmium	0.005	P	0.005	N	0.03	0	0.09
Calcium	--		--		49.65	38.27	61.03
Chloride	250	S	--		3099	2469	3731
Chromium	0.1		0.1	N	0.01	0.005	0.02
Copper	1.3		--		0.005	0	0.13
Fluoride	4.0		--		0.02	0	0.03
Hydrogen Sulfide (H_2S)	--		--		538	465	611
Iron	0.3	S			0.64	0.49	0.79
Lead	0.015	P			0.001	0	0.001
Lithium	--		--		0.82	0.64	1
Magnesium	--		--		0.25	0.16	0.33
Manganese	0.05	S	--		0.2	0.16	0.24
Mercury	0.002	P	0.002	N	0.001	0	0.002
Nickel	--		--		0.003	0	0.008
Potassium	--		--		397	316	479
Silica ($_{Si02}$)	--		--		286	234	336
Silver	0.1	S	0.1	N	0.001	0	0.002
Sodium	--		--		1740	1383	2099
Sulfate (SO_4^{-2})	500	P	--		10.5	7.49	13.51
Vanadium	--		--		0.001	0	0.001
Zinc	5	S	2	N	0.01	0	0.21

Source: Puna Geothermal Venture, 1996

* Drinking Water Standards: P= Primary; S= Secondary
** Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

Table 3. Constituent Data for Selected Geothermal Wells in Nevada
(concentrations in mg/l except as noted)

	Drinking Water Standards *		Health Advisory Levels **		Desert Peak					Beowawe		Yankee/ Caithness		Stillwater/Amor IV					
					Injectate				*Formation*	Injectate	*Formation*	Injectate	*Formation*	Injectate				*Formation*	
Constituent	mg/l	P/S	mg/l	N/C	6/16/94	3/14/95	12/31/96	10/21/97	*12/18/76*	12/31/96	*6/20/86*	5/28/93	*5/1/81*	6/30/95	7/12/96	2/13/97	10/31/97	*8/22/88*	*10/30/89*
TDS	500	S	--		9,840	9,296	10,541	9,728	*7,500*	930	*1,946*	2,607	*2,090*	4,493	4,460	4,390	4,490	*5,000*	*7,440*
pH (std units)	6.5 - 8.5	S	--		8.03	8.18	8.50	8.49	*7.90*	9.38	*7.29*	8.85	*NR*	7.91	7.53	7.44	7.45	*8.76*	*8.3*
Antimony	0.006	P	0.003	N	NR	NR	NR	NR	*NR*	NR	*0.73*	NR	*NR*	NR	NR	NR	NR	*NR*	*NR*
Arsenic	0.05	P	0.002	C	0.167	0.1	0.2	0.21	*0.08*	NR	*<0.61*	2.96	*NR*	0.075	0.021	0.032	0.05	*<0.49*	*<0.49*
Barium	2	P	2	N	0.27	0.49	0.72	0.67	*NR*	NR	*<0.61*	0.08	*NR*	NR	NR	NR	0.094	*0.35*	*0.36*
Beryllium	0.004	P	0.0008	C	NR	NR	NR	NR	*NR*	NR	*NR*	NR	*NR*	NR	NR	NR	NR	*NR*	*NR*
Boron	--		0.6	N	22.4	20	NR	20	*18*	NR	*1.29*	48.3	*39*	14.34	20.24	19.69	15.61	*NR*	*38.34*
Cadmium	0.005	P	0.005	N	<0.05	<0.002	<0.02	0.02	*NR*	NR	*<0.06*	<0.001	*NR*	NR	NR	NR	NR	*<0.05*	*<0.05*
Calcium	--		--		154	160	160	190	*101*	NR	*10.49*	9	*7.2*	67.68	81.65	75.06	73.32	*67.31*	*101.27*
Chloride	250	S	--		5,170	5,300	5,600	5,000	*4,000*	62	*808*	938	*655*	2,385	2,302	2,368	2,325	*2,520*	*4,270*
Chromium	0.1	P	0.1	N	<0.01	<0.05	<0.02	0.08	*NR*	NR	*<0.05*	<0.005	*NR*	NR	NR	NR	NR	*<0.12*	*<0.12*
Cyanide	0.2	P	0.2	N	NR	NR	NR	NR	*NR*	NR	*NR*	NR	*NR*	NR	NR	NR	NR	*NR*	*NR*
Copper	1.3	P	--		<0.01	<0.02	<0.02	<0.02	*NR*	NR	*<0.06*	NR	*NR*	NR	NR	NR	NR	*<0.06*	*<0.06*
Fluoride	4.0	P	--		6.14	6	6.8	6.2	*3.8*	15.14	*7.4*	2.9	*2.3*	4.16	3.92	4.12	4.07	*6.2*	*2.72*
Iron	0.3	S	--		1.91	1.3	0.65	<1.0	*NR*	NR	*<0.02*	0.02	*NR*	NR	NR	NR	0.159	*<0.02*	*<0.02*
Lead	0.015	P	--		<0.02	<0.01	<0.02	0.02	*NR*	NR	*<0.24*	<0.005	*NR*	NR	NR	NR	NR	*<0.24*	*<0.24*
Lithium	--		--		NR	NR	NR	4.2	*NR*	NR	*1.32*	NR	*6.8*	NR	NR	NR	2.084	*2.01*	*6.71*
Magnesium	--		--		<0.01	0.7	<1.00	<2.00	*0.35*	NR	*0.6*	NR	*0.29*	0.82	NR	0.78	0.31	*0.33*	*0.42*
Manganese	0.05	S	--		<0.01	0.85	0.09	0.08	*NR*	NR	*0.32*	NR	*NR*	NR	NR	NR	4	*<0.24*	*<0.24*
Mercury	0.002	P	0.002	N	<0.0003	<0.01	0.0016	<0.0005	*NR*	NR	*NR*	0.0005	*NR*	NR	<0.0005	<0.0005	<0.0005	*NR*	*NR*
Nickel	0.1	P	0.1	N	NR	NR	NR	NR	*NR*	NR	*NR*	<99.999	*NR*	NR	NR	NR	NR	*NR*	*NR*
Nitrate	10	P	--		<24	<0.45	<1.0	<2.25	*0.12*	NR	*NR*	0.8	*NR*	NR	NR	NR	NR	*NR*	*NR*
Potassium	--		--		331	360	370	320	*227*	NR	*15.84*	78	*50*	121.41	107.04	104.27	99.15	*149.94*	*76.88*
Selenium	0.05	P	--		NR	<0.001	<0.02	<0.02	*NR*	NR	*NR*	<0.01	*NR*	NR	<0.0006	<0.0005	<0.0005	*NR*	*NR*
Silica	--		--		NR	110	NR	95	*198*	371.34	*86.18*	402	*301*	193.87	173.91	193.75	143.678	*NR*	*160.36*
Silver	0.10	S	0.1	N	<0.05	<0.005	<0.02	<0.02	*NR*	NR	*<0.05*	<0.005	*NR*	NR	NR	NR	NR	*<0.05*	*<0.05*
Sodium	--		--		3,550	3,100	3,000	3,000	*2,400*	233.67	*718.6*	716	*566*	1,476	1,475	1,552	1,422	*1,669*	*2,900*
Strontium	--		17	N	NR	NR	NR	NR	*NR*	NR	*0.26*	NR	*NR*	NR	NR	NR	NR	*NR*	*NR*
Sulfate	500	P	--		102	100	110	99	*122*	NR	*102*	143	*123*	183	177	194	201	*214*	*294*
Thallium	0.002	P	0.0005	N	NR	NR	NR	NR	*NR*	NR	*NR*	NR	*NR*	NR	NR	NR	NR	*NR*	*NR*
Zinc	5	S	2	N	<0.01	<0.02	<0.2	<0.2	*NR*	NR	*<0.12*	NR	*NR*	NR	NR	NR	NR	*NR*	*0.2*

Source: Nevada Bureau of Water Pollution Control, 1999

Table 3. Constituent Data for Selected Geothermal Wells in Nevada -- Con't
(concentrations in mg/l except as noted)

	Drinking Water Standards *		Health Advisory Levels **		Empire/Amor II Injectate		Brady Injectate		Brady Formation	Dixie Valley Injectate	Soda Lake II/Amor IX Injectate				
Constituent	mg/l	P/S	mg/l	N/C	12/18/96	12/18/97	11/20/96	10/23/97	*11/25/98*	10/16/97	7/18/95	10/25/95	7/15/96	12/9/96	10/29/97
TDS	500	S	--		4,180	3,974	2,802	2,792	*1,847*	2,000	5,480	5,425	5,390	5,930	5,430
pH (std units)	6.5 - 8.5	S	--		7.38	6.79	8.84	8.8	*8.69*	9.11	6.29	5.81	6.38	5.69	6.1
Antimony	0.006	P	0.003	N	NR	NR	NR	NR	*0.026*	NR	NR	NR	NR	NR	NR
Arsenic	0.05	P	0.002	C	<0.003	<0.01	NR	0.216	*0.084*	0.98	NR	0.09	0.22	<0.054	<0.007
Barium	2	P	2	N	0.18	0.23	0.062	0.063	*0.38*	0.06	NR	0.244	NR	0.128	0.31
Beryllium	0.004	P	0.0008	C	NR	NR	NR	NR	*<0.005*	NR	NR	NR	NR	NR	NR
Boron	--		0.6	N	6.1	5.6	5.1	5.065	*13*	13.85	12.52	12	11.1	10.1	11.6
Cadmium	0.005	P	0.005	N	<0.001	<0.01	NR	NR	*<0.005*	<0.005	NR	<0.005	NR	<0.005	<0.004
Calcium	--		--		150	180	50	48.153	*110*	10.09	111.52	121	NR	120	104
Chloride	250	S	--		2,131	2,200	1,117	1,148	*3,800*	580	2,974	2,910	NR	2,830	2,940
Chromium	0.1	P	0.1	N	<0.005	<0.01	NR	NR	*<0.005*	<0.05	NR	<0.005	NR	NR	<0.005
Cyanide	0.2	P	0.2	N	NR	NR	NR	NR	*NR*	NR	NR	NR	NR	NR	NR
Copper	1.3	P	--		NR	<0.01	NR	NR	*<0.005*	<0.05	NR	0.037	NR	<0.011	<0.009
Fluoride	4.0	P	--		4.08	3.3	6.96	6.82	*2.5*	16.29	0.91	1.21	1.14	1.05	0.94
Iron	0.3	S	--		0.87	3.1	0.122	0.006	*0.06*	0.03	3.8	1.73	NR	0.283	0.267
Lead	0.015	P	--		<0.005	<0.01	NR	NR	*<0.005*	<0.05	NR	<0.04	NR	<0.077	0.01
Lithium	--		--		NR	NR	NR	NR	*2.9*	2.61	NR	2.92	NR	3.16	2.76
Magnesium	--		--		1	0.73	0.08	0.05	*4.5*	<0.01	0.57	0.75	NR	0.71	0.62
Manganese	0.05	S	--		0.12	0.16	NR	0.007	*0.029*	<0.05	NR	0.4	NR	0.13	0.096
Mercury	0.002	P	0.002	N	<0.0005	<0.0005	NR	NR	*<0.0005*	<0.0005	NR	<0.007	NR	<0.0007	0.003
Nickel	0.1	P	0.1	N	NR	NR	NR	NR	*0.017*	NR	NR	NR	NR	NR	NR
Nitrate	10	P	--		NR	<2.5	NR	NR	*<4.5*	<1.0	NR	NR	NR	<0.13	<2.4
Potassium	--		--		110	110	69.47	64.8	*170*	80.56	180.66	178	NR	183	165
Selenium	0.05	P	--		<0.001	<0.01	NR	NR	*<0.005*	<0.1	NR	NR	NR	NR	<0.011
Silica	--		--		118	177	227.6	227.822	*131*	672.46	214	171	NR	NR	253
Silver	0.10	S	0.1	N	<0.005	0.01	NR	NR	*<0.005*	<0.01	NR	0.077	NR	<0.003	<0.008
Sodium	--		--		1,280	1,300	841.4	895.469	*2,300*	520.87	NR	NR	NR	NR	1,680
Strontium	--		17	N	NR	NR	NR	NR	*NR*	NR	NR	5.00	NR	5.1	NR
Sulfate	500	P	--		180	200	448	470	*100*	239	70	73	NR	77	67.7
Thallium	0.002	P	0.0005	N	NR	NR	NR	NR	*<0.005*	NR	NR	NR	NR	NR	NR
Zinc	5	S	2	N	NR	0.29	NR	0.02	*<0.05*	<0.05	NR	<0.005	NR	<0.025	<0.01

Source: Nevada Bureau of Water Pollution Control, 1999

Table 4. Constituent Data for the East Mesa Geothermal Field, California

Constituents	Drinking Water Standards * mg/l	Drinking Water Standards * P/S	Health Advisory Levels** mg/l	Health Advisory Levels** N/C	1995 Data (1) Concentrations in mg/l except where noted: Ormesa I	Ormesa IE	Ormesa IH	Ormesa II	1988 Data (2) Concentrations in mg/l except where noted: OG-I Plant 88-31	OG-I Plant 72-31	OG-I Plant 38-30	OG-I Plant 14-5	OG-II Plant 84-1	OG-II Plant 18-5	OG-II Plant 45-6	OG-II Plant 21-6	OG-IE Plant 14-32
					Average values for production wells												
TDS	500	S	--			7,680.00	6,468.08	5,997.57	7480	5064	1978	758	6812	6722	7794	7018	6632
EC (µmhos/cm)	--		--		7270	12100	10716.67	9930									
pH (Std. Units)	6.5-8.5	S	--		6.47	7.12	6.09	8.02	8.4	8.3	9	8.6	8.2	8.7	8.4	8.3	8.6
Arsenic	0.05	P	0	C	<0.60	0.00	ND	0.39									
Barium	2	P	2	N	<0.61	0.21	0.75	0.69									
Boron	--		0.6	N	7.34	ND	8.25	ND									
Calcium	--		--		37.69	389.00	51.35	32.51	29.92	20.256	0.5934	1.52	13.62	20.17	15.59	21.05	
Chloride	250	S	--		2037.9	4,090.00	3,398.00	3087.14	4099	2638	538	411	3699	3623	4248	3818	3648
Fluoride	4	P	--		2.03	1.14	1.69	2.4									
Iron	0.3	S	--		<0.22	15.20	0.12	0.29									
Lithium	--		--		3.76		6.72										
Magnesium	--		--		2.53	209.00	2.70	1.64	3.74	5.064	0.3956	0.23	2.725	0.672	2.338	2.807	
Potassium	--		--		78.89	24.70	136.21	144	119.7	96.2	27.7	30.3	156.7	201.7	233.8	161.4	
Silica (SIO_2)	--		--		158.57		165.44										
Sodium	--		--		1566.32	2080	2357.72	1853.67	2790	1914.2	714.1	277	2616	2433	2923	2632	
Strontium			--		3.63		5.80										
Sulfate (SO_4^{-2})	500	P	--		123.6	700	95.33	63.57	97.2	111.4	191.9	11.4	95.4	127.7	109.1	98.3	66.3
Zinc	5	S	–		<0.07	0.85	ND	ND									

Sources:
(1) R.L. Stollar & Associates, Inc, 1989.
(2) Environmental Management Associates, 1995.

* Drinking Water Standards: P= Primary; S= Secondary
** Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

Table 5. Constituent Data for the Salton Sea Geothermal Field, California

	Drinking Water Standards		Health Advisory Levels		Representative Flash-corrected Brine Analysis Concentrations in ppm unless otherwise noted: Hypersaline Brines (1-4)				Low TDS Brines (5-8)			
Constituents	mg/l	P/S	mg/l	N/C	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature(°C)	--		--		305	330	300	295	240	230	190	200
Well Depth (meters)	–		--		1,850-1,890	2,500-3,220	660-1,070	700-1,070	570-720	710-940	?-520	410-990
TDS (wt %)	500	S	--		~25.6	~26.5	~21.4	~20.0	~12.7	~6.2	~3.5	~1.3
pH (Std. units)	6.5-8.5	S	--		5.4	5.1	5.2	5.3		6.9		7.6
Ammonium (NH_4^+)	--		30	N	333	330	339	341		103	321	
Barium	2	P	2	N	203	353 **	183	156		45	3	0.7
Boron	--		0.6	N	257	271	204	197		92	100	32
Bromide	--		--		99	111	95	78		24	15	10
Cadmium	0.005	P	0.005	N	2.2	2.3	1.0	1.4		ND		ND
Calcium	--		--		27,400	28,500	22,800	20,900	11,000	2,520	1,130	117
Chloride	250	S	--		151,000	157,500	128,000	116,000	85,000	31,000	19,700	6,900
Copper	1.3		--		5.9	6.8		2		ND		ND
Hydrogen Sulfide (H_2S)	--		--		15	10	15	20				
Iron	0.3	S	--		1560	1,710	582	969	65	86	0.7	25
Lead	0.015	P	--		100	102	69	67		2.6		ND
Lithium	--		--		194	209	157	152	93	55	40	9
Magnesium	--		--		33	49	19	33		54	74	24
Manganese	0.05	S	--		1450	1,500	801	855		>255	>120	102
Potassium	--		--		16700	17,700	12,500	11,800	5,000	2,480	1,250	297
Silica ($SI0_2$) ***	--		--		>461	>588	>336	>404		>255	>120	102
Sodium (wt ppm)	--		--		53000	54,800	46,200	41,400	25,000	15,000	10,600	4,800
Strontium	–		17	N	411	421	376	345	513	112	85	10
Sulfate (SO_4^{-2})	500	P	--		65	53	~100	53		53	621	440
Zinc	5	S	2	N	518	507	321	323		11		ND

Sources: Elders, et. al. 1992; Williams & McKibben, 1989

- For Drinking Water Standards: P = Primary, S = Secondary
- For Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

* Concentrations corrected for ~5% dilution by drilling fluid
** Probable contamination from drilling fluid
*** Silica values low due to precipitation prior to sampling

Samples
(1) Salton Sea Scientific Drilling Project State 2-14 (12) -1985
(2) Salton Sea Scientific Drilling Project State 2-14 (3) - 1986 *
(3) Commercial Well #11b
(4) Commercial Well #10
(5) Woolsey Well # 1
(6) Commercial Well #B1
(7) I.I..D. Well #3
(8) Commercial Well # 113

Table 6a. Constituent Data for the SIGC Plant, Heber Geothermal Field, California

Constituents	Drinking Water Standards *		Health Advisory Levels **		SIGC (Second Imperial Geothermal Company) Binary Plant (Concentrations in ppm except as noted)					
					Production Wells			Injection Wells		
					HGU 210	HGU 201	HGU 204	HGU 253	HGU 155	HGU 170 (Holtz 2)
TDS	500	S	--		13,270	13,140	12,660	13,592	11,300	16,330
EC (µmhos/cm)			--					21,000		
pH (units)	6.5-8.5	S	--					6.2		
Antimony	0.006	P	0.003	N				ND	1.91	
Arsenic	0.05	P	0.002	C	0.12	0.11	0.08	0.1	<.05	
Barium	2	P	2	N	2.83	2.85	2.38	2.99	0.23	3
Bicarbonate	--		--		54	38	37	35	52.98	
Boron	--		0.6	N	5.51	5.42	4.82	243.8	4.3	12
Calcium	–		--		977.92	990.91	964.82	995.29	1078	1062
Cesium	--		--						12.18	NA
Chloride	250	S	--		7,662	7,520	7,343	7,893	7,900	8,242
Iron	0.3	S	--		0.22	0.17	0.25	0.35	6.88	0.4
Lithium	--		--		5.75	5.74	4.82	5.55	3.45	4.1
Magnesium	--		--		2.1	2.25	1.89	1.55	7.13	23
Manganese	0.05	S	--		0.13	0.13	0.12	0.13	0.52	0.9
Potassium	--		--		340.09	347.23	287.96	329.59	419	231
Silica ($SI0_2$)	--		--		217.29	232.11	128.88	243.8		187
Sodium	--		--		3,957.92	4,109.15	3,745.84	3,889.33	3,378	4,720
Strontium	--		17	N	38.03	39.07	34.5	36.98	40.31	42
Sulfate	500	P	--		105	117	142	98	64	148
Zinc	5	S	2	N	0.08	ND	ND	0.01	0.17	0.1

Source: CDOG, 1998e.

* Drinking Water Standards: P= Primary; S= Secondary
** Health Advisory Levels: N= Noncancer

Table 6b. Constituent Data for the SDG&E Plant, Heber Geothermal Field, California

	Drinking Water Standards *		Health Advisory Levels **		SDG&E POWER, Binary Plant, HEBER GEOTHERMAL FLUID TYPICAL BRINE ANALYSIS									
					Production Wells (wt ppm)									
Constituents	mg/l	P/S	mg/l	N/C	Well not specified				HGU 101	HGU 102	HGU 103	HGU 104	HGU 105	HGU 106
Sampling Date	--		--		8/23/74	11/18/74	10/17/74	12/4/74						
pH (Std. units)	6.5-8.5	S	--		6.60	6.30	5.80	6.45						
TDS	500	S	--		14,110	14,470	14,310	14,195						
Aluminum	0.05 - 0.2	S	--		31	15	28	1.0						
Antimony	0.006	P	0.003	N					0.05	0.05	0.05	0.05	0.051	0.05
Arsenic	0.05	P	0.002	C					0.167	0.207	0.146	0.106	0.119	0.151
Barium	2	P	2	N	3	5	5	5	0.155	6.536	0.050	0.216	3.734	0.140
Bicarbonate (HCO_3^{-1})			--					64						
Boron	--		0.6	N	7.2	5.2	5.7	4.0	6.048	9.723	5.592	2.605	6.531	6.592
Bromide	--		--						11.7	10.9	8.4	1.9	11.1	11.9
Calcium	--		--		656	859	2,063	844	810	1,004	1,006	885	915	864
Carbonate (CO_3^{-2})	--		--					0						
Cesium	--		--						0.600	0.881	0.624	0.583	0.654	0.672
Chloride	250	S	--		7,246	7,600	7,764	7,363	9,133	18,472	9,111	9,143	10,808	13,926
Copper	1.3	P	--		0.5	0.6	1.1	0.8						
Fluoride	4.0	P	--		1.5	1.6	2.2	3.0						
Iodide	--		--						0.625	0.620	0.522	0.464	0.403	0.762
Iron	0.3	S	--		6	14	34	68	0.100	0.161	0.352	0.100	0.276	0.301
Lead	0.015	P	--		0.3	1.3	1.3	0.6	0.005	0.095	0.004	0.010	0.050	0.089
Lithium	--				5	3.8	5	4	8.504	12.982	7.846	10.147	7.664	7.021
Magnesium	--				3.4	5.9	3.8	5.9	1.101	1.421	1.609	1.507	1.328	1.304
Manganese	0.05	S	--		0.6	0.9	3.1	3.1	0.130	0.123	0.151	0.121	0.102	0.050
Mercury	0.002	P	0.002	N					2.790	0.002	3.417	2.704	0.002	2.799
Potassium	--		--		250	238	250	228	415	398	402	372	393	385

	Drinking Water Standards *		Health Advisory Levels **		SDG&E POWER, Binary Plant, HEBER GEOTHERMAL FLUID TYPICAL BRINE ANALYSIS									
					Production Wells (wt ppm)									
Constituents	**mg/l**	**P/S**	**mg/l**	**N/C**	**Well not specified**				**HGU 101**	**HGU 102**	**HGU 103**	**HGU 104**	**HGU 105**	**HGU 106**
Rubidium	--		--						3.101	1.800	1.911	1.608	1.839	2.106
Silica ($SI0_2$)	--		--		214	281	281	294	223	240	205	81	247	227
Silver	0.1	S	0.1	N	ND	ND	ND	ND						
Sodium	--		--		3,750	4,313	4,219	4,312	5,052	4,397	4,002	3,557	4,333	3,952
Strontium	--		17	N	39	37	36	38	28.9	42.2	34.7	27.0	34.1	34.8
Sulfate (SO_4^{-2})	500	P	--		74	88	81	80	115.2	40.5	54.2	67.2	69.6	76.9
Zinc	5	S	2	N	0.3	0.7	0.6	0.3						

Source: Second Imperial Geothermal Company, 1993.

* Drinking Water Standards: P= Primary; S= Secondary

** Health Advisory Levels: N= Noncancer

Table 6c. Constituent Data for the HGC Plant, Heber Geothermal Field, California

Constituents	Drinking Water Standards *		Health Advisory Levels **		Heber Geothermal Company, Flash Plant Concentrations in mg/l unless otherwise noted			
	mg/l	P/S	mg/l	N/C	Injection Wells			
					HGU 53	HGU 55	HGU 57	HGU 5
Sampling Date	--		--		3/29/85	3/29/85	3/29/85	
TDS	500	S	--					17,000
pH (Std. Units)	6.5-8.5	S	--					8
Antimony	0.006	P	0.003	N	2.03	1.98	1.75	
Arsenic	0.05	P	0.002	C	<0.05	<0.05	<0.05	
Barium	2	P	2	N	0.56	1.12	0.74	4.5
Bicarbonate	--		--					32.0
Boron	--		0.6	N	7.8	8.1	6.3	5.6
Calcium	--		--		1022	756	575	940
Cesium	--		--		13.28	13.3	12.32	
Chloride	--		--		8,650	8,756	7,185	8,200
Chromium	0.1	P	0.1	N	0.66	0.58	0.46	
Copper	1.3	P	--		0.42	0.17	0.71	0.02
Fluoride	4	P	--		0.65	0.55	0.55	2.0
Iron	0.3	S	--		20.25	19.50	6.88	0.12
Lead	0.015	P	--		1.43	0.35	1.59	ND
Lithium	--		--		8.65	8.13	8.79	7.7
Magnesium	--		--		5.38	8.50	1.75	1.6
Manganese	0.05	S	--		1.07	1.46	0.46	0.12
Mercury	0.002	P	0.002	N	0.002	0.011	0.005	
Potassium	--		--		428	441	313	310
Sodium	--		--		4,072	4,150	3,494	4,300
Strontium	--		17	N	50.45	58.39	44.47	35
Sulfate	500	P	--		25	26	59	68.0
Zinc	5	S	2	N	0.21	0.15	1.38	

Source: CDOG, 1998e.

* Drinking Water Standards: P= Primary; S= Secondary
** Health Advisory Levels: N= Noncancer

Table 7a. Constituent Data for The Geysers Geothermal Field, California

Constituents	Drinking Water Standards * mg/l	Drinking Water Standards * P/S	Health Advisory Levels ** mg/l	Health Advisory Levels ** N/C	SOUTHEAST GEYSERS: UNOCAL CORPORATION Concentrations in mg/l unless otherwise noted — 1997 Grab Sample Analyses: Units 5&6	Units 7 & 8		Units 9&10	Units 11	Unit 12	Unit 14	Unit 17	Unit 18	Unit 20	Average Condensate Analyses 1991-1996: Unit 5&6	Unit 7&8	Unit 9&10	Unit 11	Unit 12	Unit 14	Unit 17	Unit 18	Unit 20
EC (usiemens)	–		--		8,380	6900	6930	2940	11800	4280	260	6500	1810	600	6,808	6,220	2,756	9,246	3,189	329	7,049	693	800
Ammonia (dissolved)	–		30	N	1,200	800	790	12	1400	560	51	100	180	8.6	757	705	11	1,046	263	39	692	59	34
Arsenic (ppm/w)	0.05	P	0.002	C	0.28	0.28	0.29	0.62	0.029	0.19	0.015	0.13	0.5	0.38	0.30	0.25	0.44	0.13	0.64	0.30	0.71	1.19	0.36
Boron (ppm/w)	–		0.6	N	200	230	230	150	140	150	17	96	200	99	202	173	128	124	146	59	279	201	101
Nitrate	10	P	--		0.05	<0.03	<0.03	<0.03	0.08	0.13	<0.03	0.05	0.14	1.1	4	3	7	6	0.92	0.73	2	1	0.15
Nitrite	1	P	--		0.12	0.13	0.11	1.2	<0.03	0.34	<0.03	0.13	0.03	0.04	0.31	1.23	3	0.66	0.35	0.15	0.80	0.26	0.04
Sulfate	500	P	--		1,900	1,100	1,300	550	2,000	1,300	38	280	660	170	852	1,387	389	2,156	1,131	48	2,326	218	128

Source: UNOCAL Corporation, 1998.

* Drinking Water Standards: P = Primary, S = Secondary
** For Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

Table 7b. Constituent Data for The Geysers Geothermal Field, California -- Con't

	Drinking Water Standards *		Health Advisory Levels **		CALPINE Geysers Company Concentrations in mg/l, unless otherwise noted					
					(1)		SMUDGEO 1 Power Plant Annual Injectate Analysis (2)	Pacific Gas and Electric Unit 13 (2)	SMUDGEO 1 Power Plant Annual Injectate Analysis (3)	Aidlin Power Plant Reinjectate (4)
Constituents	mg/l	P/S	mg/l	N/C	Unit 13 Injection	Unit 16 Injection				
Sampling Date	--		--		12/22/92	12/22/92	12/29/93	12/29/93	12/30/97	11/23/98
EC (µmhos/cm)	–		--		450	620	560	614		8,860
Ammonia	--		30	N			45		1.0***	1,280
Arsenic	0.05	P	0.002	C	0.42	0.085	0.32	0.50	ND	0.053
Boron	--		0.6	N	77	32	110	94	190	95
Calcium	--		--					ND		
Calcium Carbonate	--		--		ND	ND		ND		
Chloride	250	S	--		ND	ND		1.5		
Magnesium	--		--		ND	ND		ND		
Nitrate	10	P	--		0.76	0.37	0.13	ND	0.12	2.3
Nitrite	1	P	--				0.03			8.5
Sulfate	500	P	--		88	120	97	150	260	1,900

Sources:
(1) CALPINE Geysers Company, 1993.
(2) CALPINE, 1994.
(3) CALPINE, 1998.
(4) CALPINE, 1999.

* Drinking Water Standards: P = Primary, S = Secondary
** For Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk
*** Non-distilled sample

Table 7c. Constituent Data for The Geysers Geothermal Field, California -- Con't

Constituents	Drinking Water Standards * mg/l	P/S	Health Advisory Levels ** mg/l	N/C	Northern California Power Agency, Concentrations in mg/l unless otherwise noted: Effluent Monitoring Data (1), 1994, Unit 1	Unit 2	Unit 3	Unit 4	1997, Unit 1	Unit 2	Unit 3	Unit 4	Condensate Analysis (2), 1988, Plant 1	Plant 2
EC (µmhos/cm)	–		--		439	456	539	687	333	264	666	736	108	384
Ammonia	–		30	N	56.00	52.92	62.31	81.77	41.3	37.4	82.7	92.9	17.17	41.95
Arsenic	0.05	P	0.002		0.06	0.06	0.01	0.09	0.17	0.10	0.02	0.04	0.128	0.033
Boron	--		0.6	N	64.01	87.59	31.46	57.93	81.4	132.6	43.8	53.1	59.5	21.9
Nitrate	10	P	--		3.76	3.39	3.44	1.92	1.7	0.9	1.2	1.8	0.071	1.54
Nitrite	1	P	--		0.242	0.198	0.288	0.19	0.07	0.05	0.28	0.28	0.027	0.08
Sulfate	500	P	--		124	113	160	209	87.7	64.6	265.9	290	5.61	88.5

Sources:
(1) Northern California Power Agency, 1995 & 1998.
(2) Northern California Power Agency, 1988.

* Drinking Water Standards: P = Primary, S = Secondary
** For Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

Table 7d. Constituent Data for The Geysers Geothermal Field, California -- Con't

Constituents	Drinking Water Standards * mg/l	P/S	Health Advisory Levels ** mg/l	N/C	GEO Operator Corporation (a.k.a. GRI Operator, a.k.a. Thermogenics) Unit 15, Chemical Analysis of Condensate Concentrations in mg/l, unless otherwise noted											
Sampling Date	--		--		10/15/79	11/24/80	10/13/81	10/15/81	5/19/82	10/21/82	11/1/82	10/18/83	8/17/84	2/25/85	10/7/86	11/14/88
TDS	500	P	--						1,200	160		1,500	3,200	1,900	1,138	2,660
EC (µmhos/cm)	--		--		850	1,300	1,100	1,200	1,700	1,950	1,680	2,300		2,800		
pH (Std. Units)	6.5-8.5	P	--				7.3	7.3	6.5	6.5	7.3	5.8	6.9	7.0	4.20	
Aluminum	0.05 - 0.2	S	--							0.06	0.28	0.22	0.6	<0.5	ND	
Ammonia	--		30	N	96.0	115.0	130	140	150	230	201	280	430	280	240	265
Arsenic	0.05	P	0.002	C					0.44	0.62		0.41	0.36	0.19	ND	0.04
Barium	2	P	2	N									<0.2	<0.3	ND	
Bicarbonate (HCO_3^{-1})	--		--										12	57		
Boron	--		0.6	N	160	200	160	180	140	280	133	180	270	130	114.77	115.77
Calcium	--		--				<1.0	<1.0	3.8	<1.0		2.7	1.2	#0.1	1.42	
Calcium Carbonate (Total hardness)	--		--						12	<1		6.8	10	47		
Chloride	250	S	--				1.1	1.8	< 2.0	4.9		<0.5	5	#1	16.00	
Chromium	0.1	P	0.1	N					<0.005	<0.005		0.012			ND	
Fluoride	4	P	--										0.1	0.1		
Iron	0.3	S	--						0.21	0.35		3.1	3.5	0.29	3.98	
Lead	0.015	P	--						<0.05	<0.05		<0.05	<0.01	<0.005	ND	
Lithium	–		--										<0.01	<0.01	ND	
Magnesium	--		--				<0.5	<0.5	0.6			<1.0	0.5	0.07	1.04	
Manganese	0.05	S	--										0.10	0.025	ND	
Mercury	0.002	P	0.002	N					0.008	0.006		0.43	0.0016	0.017		
Nitrate	10	P	--		<0.10	0.25	1.6	1.9	<0.10	3.9		1.6	<0.1			<0.10
Nitrite	1	P	--		0.05	0.93	6.4	1.5	0.33	2.3		.99				
Potassium	--		--				0.34	0.48					0.2	#0.05	ND	
Silica (SIO_2)	--		--				2.3	2.1	2.5	2.5	0.22	<0.1	4.0	<0.2	1.85	
Silver	--		0.1	N											ND	
Sodium	--		--				13.0	22.0	47	3.0		<1.4	2.3	1.8	26.99	
Strontium	–		17	N											0.01	
Sulfate	500	P	--		210	390	450	470	660	840	696	1,100	1,300	790	732	1,085
Sulfide	–		--				0.01	0.01					<0.05	< 5		
Zinc	5	S	2	N					0.06	<0.050		0.23			0.16	

Source: CDOG, 1998d; GEO Operator Corporation, 1987 & 1989; California Regional Water Quality Control Board, 1999.

* Drinking Water Standards: P = Primary, S = Secondary

** For Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

Table 7e. Constituent Data for The Geysers Geothermal Field, California -- Con't

	Drinking Water Standards *		Health Advisory Levels **		Concentration in mg/l unless otherwise noted		
					The Geysers (1)	West Ford Flat (2)	Bear Canyon (3)
Constituents	mg/l	P/S	mg/l	N/C		Injectate	Steam Condensate
Sampling Date	--		--			3/27/89 - 3/30/89	1/12/89
TDS	500	S	--			640	192
EC (µmhos/cm)	–		–		280		200
pH (Std. units)	6.5-8.5	S	--			7.2	8.4
Aluminum	0.05 - 0.2	S	--			0.1	
Ammonia	--		30	N		14	
Arsenic	0.05	P	0.002	C	0.95	1.4	
Boron	--		0.6	N	160	105	22
Calcium	--		--			0.5	
Calcium Carbonate	--		--			79	54
Chloride	250	S	--			1.3	0.1
Fluoride	4.0	P	--				<0.1
Iron	0.3	S	--			0.9	
Magnesium	--		--			1.6	
Mercury	0.002	P	0.002	N		<0.001	
Nitrate	10	P	--		1.2		
Nitrite	1	P	--		0.07		
Potassium	--		--			<0.5	
Silica ($SI0_2$)	--		--			0.8	0.1
Sodium	--		--			1.4	
Sulfate	500	P	--		52	38	50
Sulfide	--		--			0.2	

Sources:
(1) Crockett & Enedy, 1990.
(2) Freeport-McMoRan Resource Partners / Geysers Geothermal Company. 1989.
(3) Freeport-McMoRan Geothermal Resources Company, Geysers Geothermal Company, 1989.

* Drinking Water Standards: P = Primary, S = Secondary
** For Health Advisory Levels: N= Noncancer Lifetime; C= Cancer Risk

Table 7f. Constituent Data for The Geysers Geothermal Field, California -- Con't

	Drinking Water Standards *		Health Advisory Levels **		Southeast Geysers Effluent Pipeline Project						
					Estimates of Injection Water 1995 (1)			Southeast Treatment Plant (SETP) Reservoir (2,3)		Lake Intake Pump System (LIPS) (3)	
Constituents	mg/l	P/S	mg/l	N/C	Lake	WWTP Effluent	Blended Lake / Effluent				
Sampling Date	--		--					1995	2/11/98	8/28/98	9/7/98
Flow, MGD	--		--		3.38	1.84					
Temperature (^oC)	–		–		6-28	6-26	6.26				
TDS	500	S	--		134-390	348-390	228	346	232		
Suspended Solids	--		--		5-50	10-30	20				
EC (µmhos/cm)	–		–		69-364			541	362		
pH (Std. Units)	6.5-8.5	S	--		7-9.3	6.5-8.5	7.9	7.9	7.1		
Turbidity (NTU)	0.5-1.0	P	--					32	20		
BOD					3-9	10-30	11				
Total Coliforms per 100									100	3000	700
Fecal Coliforms per 100									100	3000	60
Alkalinity ($CaCO_3$)	--		--		67-170	170-240	143	171	125		
Hardness ($CaCO_3$)	--		--		94-170	150-190	137		61		
Total Salts	--		--		140-260	500-600	325				
Aluminum	0.05 -	S	--					1			
Bicarbonate (HCO_3^{-1})	--		--		80-210	210-290	173	209			
Boron	--		0.6	N					153		
Calcium	--		--		16-33	30-40	26	33	25		
Chloride	250	S	--					54	20		
Fluoride	4	P	--					ND	ND		
Iron	0.3	S	--					1.44	0.96		
Magnesium	--		--		12-21	20-25	18	19	14		
Manganese	0.05	S	--					0.069	0.12		
Nitrate	10	P	--					14	1.1		
Oxygen (dissolved)	--		--		0.1-17	1-10	7.2				
Potassium	--		--					10	3.6		
Silver	--		0.1	N	14		14				
Sodium	--		--					56	21		
Sulfate	500	P	--					68	14		
Zinc	5	S	2	N					0.038		

Source:
(1) ESA. 1994.
(2) Alpha Analytical Laboratories, 1995 & 1998.
(3) Lake Labs, 1998

CRWQCB, 1999). Data on the quality of the treatment plant effluent injected at The Geysers shows no exceedences of primary drinking water standards for inorganic constituents (Alpha Analytical Laboratories, 1995). Data for both the treated wastewater and water from Clear Lake that is injected at The Geysers show exceedences of the primary drinking water standard for fecal coliform (Lake Labs, 1998).

When interpreting any of these data, it is important to note that the data do not include measurements for all constituents of potential interest at all sites. Further, the available data are based on samples of geothermal power plant fluids collected at various (often not well defined) points between the production well(s) and the injection well(s). As a result, there is some uncertainty with respect to the exact concentrations of constituents in injected fluids.

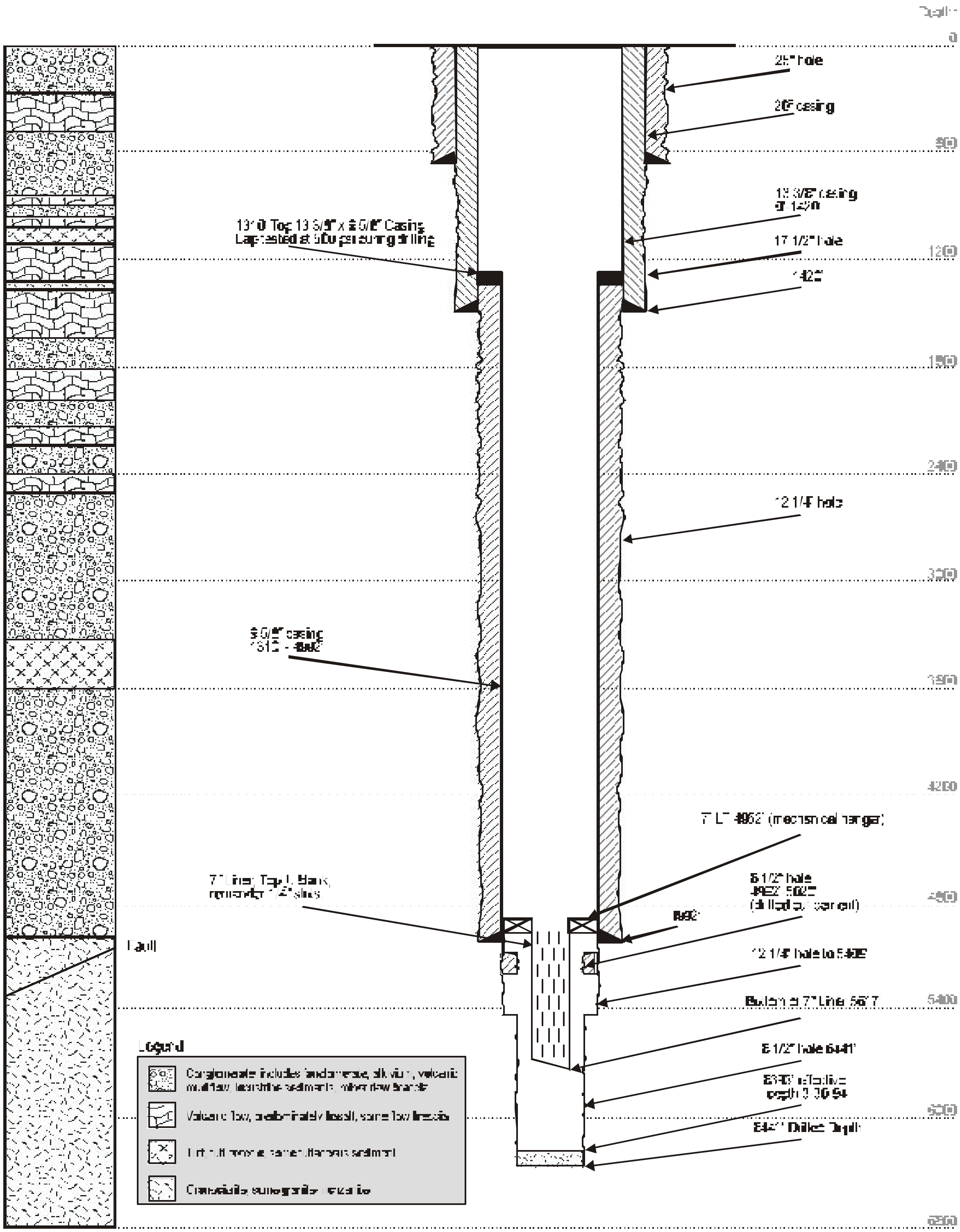
The chemical characteristics exhibited by the injected fluids are primarily (although not exclusively) determined by the characteristics of the geothermal resource, the technologies used to produce the power, the chemicals used in conjunction with power plant operations (e.g., for treatment of steam or geothermal fluid), and the characteristics of supplemental water sources (in any). Each of these four factors is discussed in Attachment A of this volume.

4.2 Well Characteristics

Design, construction, operation, and maintenance of electric power geothermal injection wells is highly dependent on site-specific conditions, such as site geology, formation pressure, and geothermal fluid characteristics. Injection wells range from about 500 to 12,000 feet (Land, 1997). Bottom hole completions, either open hole or with slotted or perforated casing, generally range in size from 6 to 12.25 inches in diameter and generally are located below the lowermost USDW (unless the geothermal resource itself meets the definition of a USDW). The use and type of casings or liners often depend upon the characteristics of the subsurface formation. If the subsurface formation may collapse when wet, a slotted liner or perforated casing may need to be installed in the well. If the geothermal fluids are highly corrosive, casing materials need to be corrosion resistant. In situations where it is important to prevent leakage into unintended zones (e.g., USDWs), the well casing needs to be encased with specialized cements able to withstand the pressure and temperature conditions found in the well (Land, 1997). Wellhead assemblies also vary depending on local geologic conditions, including the formation pressure that must be overcome to inject fluids (USEPA, 1987). During initial well drilling and subsequent work-overs or repairs, injection wellheads are equipped with blowout prevention equipment (BOPE) that shuts down well operations during abnormal flow conditions caused by malfunctions and/or unstable down-hole well conditions. The specific BOPE employed depends on site-specific factors such as the maximum anticipated pressure, temperature, and corrosiveness of the geothermal fluids at the wellhead.

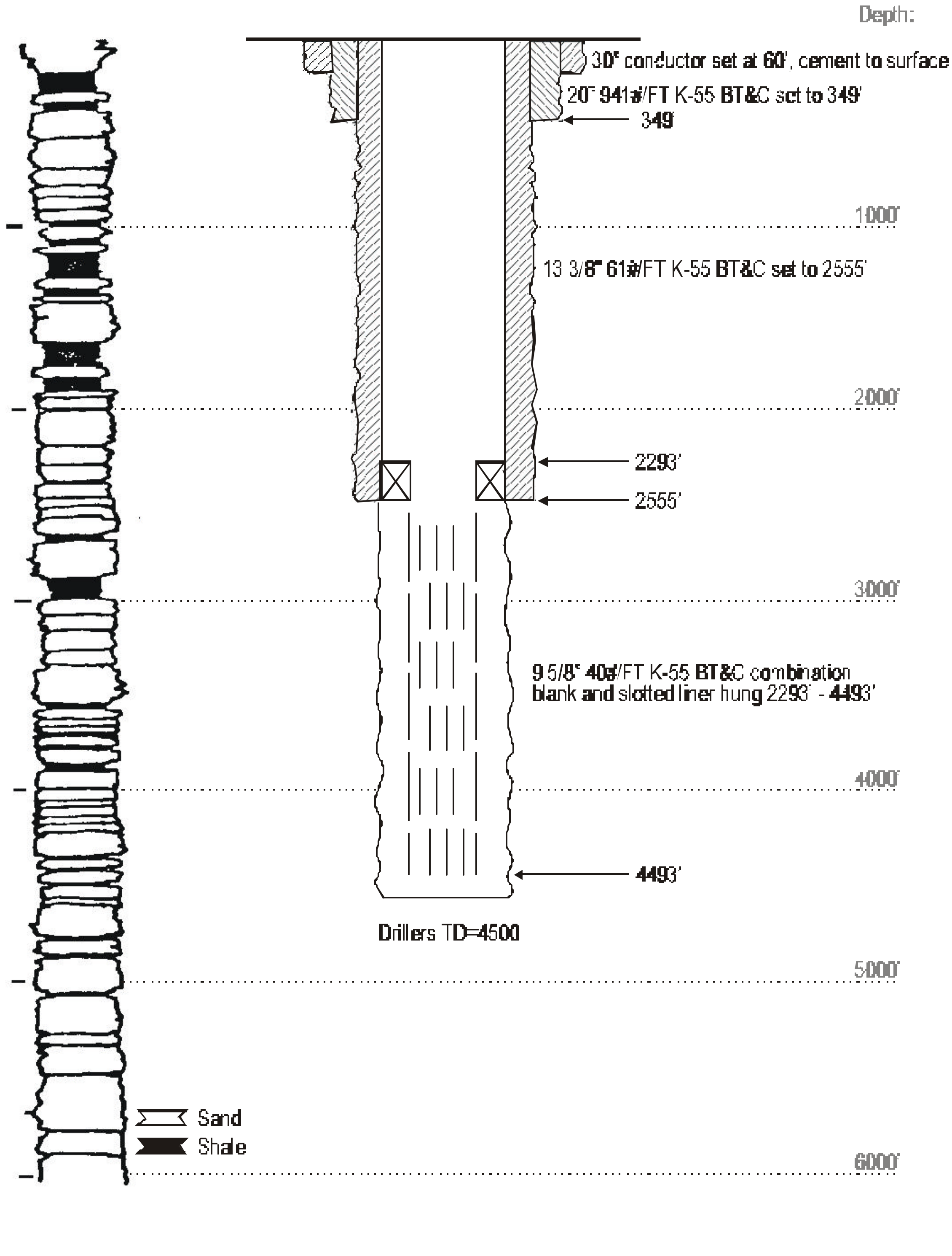
Figures 4 and 5 show examples of geothermal injection wells associated with electric power generation. Several features distinguish geothermal injection wells from other Class V well types.

Figure 4
Example Schematic of Geothermal Injection Well Associated With Electric Power Generation



Source: CDOG, 1998c

Figure 5
Example Schematic of Geothermal Injection Well Associated With Electric Power Generation



Source: Second Imperial Geothermal Company, 1993

These injection wells are typically drilled to greater depths, are cemented from the bottom of the casing shoe to the surface, and use thicker casings than most other Class V wells.

4.3 Well Siting

On the surface, injection wells may be sited individually or on well pads along with other injection and/or production wells (to minimize surface disturbance). For example, Figure 6, which shows injection well locations at the Heber geothermal field in Imperial County, California, illustrates the use of directional drilling that enables surface locations to be clustered while bottom hole locations are distributed within the reservoir. In this example, clustering of the wells at a limited number of surface locations minimizes the amount of land removed from agricultural production as a result of geothermal activities and enables more cost-effective control of access to the well location.

Underground, the well locations for injection of geothermal fluids are selected to protect the geothermal resource by recharging fluids to the formation at locations where the heat content of the fluid will be restored before the fluid is again extracted through a production well (Stock, 1990; Crockett, 1990; Defferding, 1978; and Vetter, 1979). In practice, many wells used for injection were initially drilled as production wells, and so siting consists not of locating the well but rather selecting which existing well to use for injection.

4.4 Operating Practices

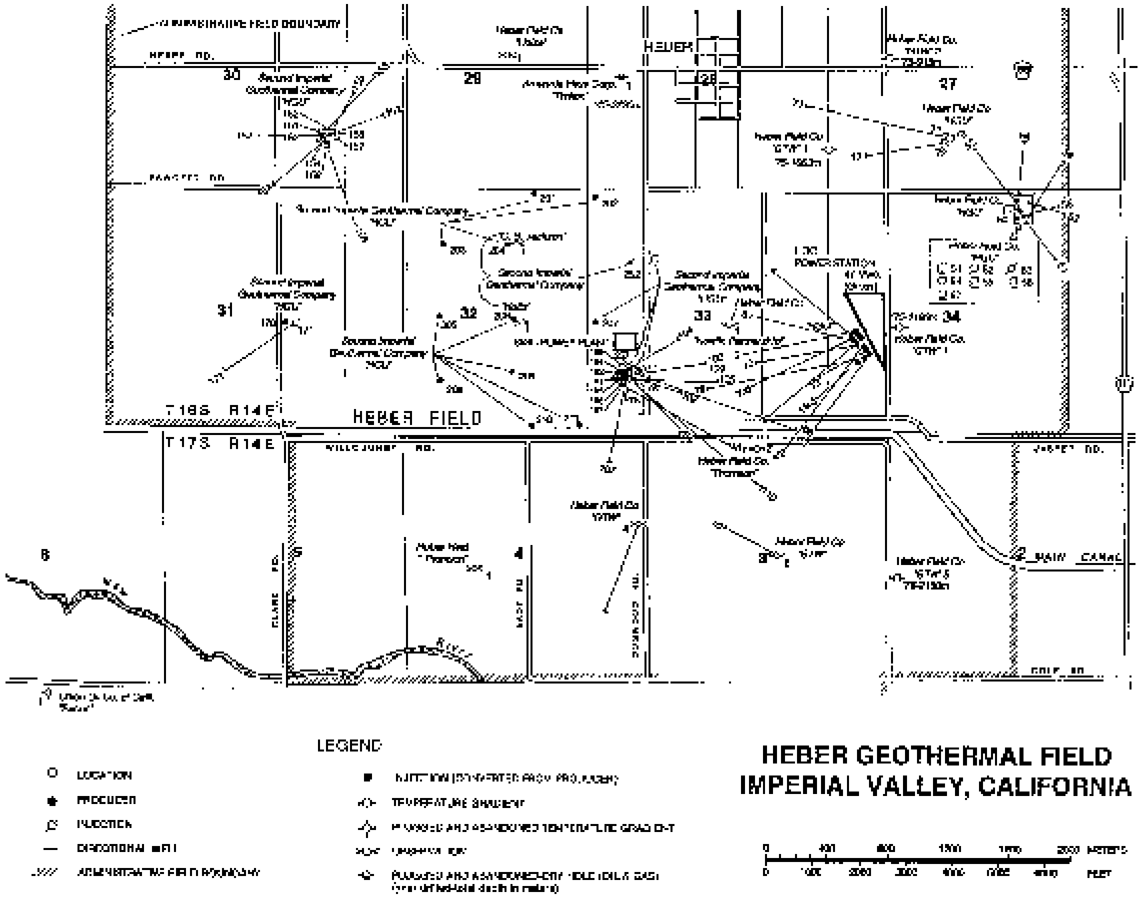
Injection of fluids into geothermal reservoirs used for electric power generation is an integral part of management of the geothermal reservoir that promotes maximum energy recovery and not simply fluid disposal. In some cases, wells are used for production during some periods and for injection during others (Meade, 1998).[4] Accordingly, injection operations receive on-going oversight to monitor what is injected and where it is injected (i.e., into the geothermal reservoir and not into a USDW). In addition, injection operations are also the subject of frequent study and analysis, as reservoir characteristics (e.g., fracture flow patterns) may change.

Well integrity is monitored on a continuous or periodic (e.g., every 1 to 5 years) basis as a routine part of injection management activities to ensure that injected fluid is reaching the intended injection zone and is not being released to shallower formations that may be USDWs. The type of monitoring performed is highly variable depending on site-specific characteristics.

Continuous monitoring often includes monitoring of injection pressure, flow rate, and volume for changes that may signal a leak in the injection tubing (if used) or well casing. In some cases, annulus pressure monitoring is also used on a continuous basis (USEPA Region 9, 1998) to detect leakage of

[4] At The Geysers, for example, some wells are routinely used for injection during the winter when rainfall is high and more supplemental water is available. The same wells are also used for production during the summer when the quantity of fluids available for injection is lower and the demand for electric power output is higher (Dickerson, 1998).

Figure 6. Site Plan for Heber Field Showing Well Clustering and Directional Drilling



Source: CDOG, 1996

either the casing or the injection tubing. Periodic MIT is performed before a well is put into service or returned to service after workover or repairs, and at established intervals during normal operations. Specific methods used and considerations for selecting among the available methods are discussed in Section 6.3.

Because injected fluids recharge the geothermal reservoir and normally will reappear at some point in the future in geothermal fluid production wells, operators have an incentive to ensure that the fluids injected will not adversely affect plant operations. At some facilities, especially those that use binary technology, the production and subsequent reinjection of geothermal fluids occurs in what is essentially a closed-loop system. While some limited amount of other fluids (e.g., cooling tower blowdown) may be injected along with the geothermal fluids, the opportunities for accidental contamination of the injection fluids is quite limited at these facilities. At other facilities, primarily those that inject storm water or other supplemental fluids, accidental contamination of injected fluids could potentially occur as a result of spills or other releases. In addition, accidental contamination or misuse for disposal could occur where the contents of surface ponds (for emergency steam release) is pumped to the injection wells. Measures taken to prevent accidental contamination are discussed in Section 6.

4.5 Well Plugging and Abandonment

Although electric power geothermal injection wells may function effectively for decades, eventually use is discontinued and the wells are plugged and abandoned. Plugging and abandonment normally includes removing injection tubing or liner (if present), plugging the well, cutting off the well casing below (normally 5 feet) the ground surface, welding a steel plate to the top of the remaining casing, and restoring the ground surface. Well plugging typically involves installation of one or more cement plugs in the well. In some cases, a continuous cement plug is installed from below the bottom of the casing in the injection zone to the surface. In other cases, multiple cement plugs are installed and the remainder of the well is filled with drilling mud. When multiple cement plugs are used, plugs are normally installed at or near the bottom of the casing and across any perforated intervals closer to the surface. In addition, a cement plug, often several hundred feet or more in length, is installed at the surface to prevent fluid migration down the well. The remaining well volume is typically filled with drilling mud that is heavy enough to prevent fluid movement into the well bore and between zones (see Figure 7)[5]. Using these approaches, plugging serves to protect both ground water and public safety.[6]

As discussed in Section 7, well operators are required to prepare plugging plans for review and approval by state or federal (e.g., BLM) agencies prior to conducting the plugging activities. In addition, agency representatives have the opportunity to observe plugging and abandonment activities, with particular emphasis on setting of the well plug(s), and operators and/or agency representatives are required to report actual plugging activities.

As a result of the characteristics of these injection wells (e.g., depth, relatively large diameter) and the closure requirements, costs for plugging and abandonment can be substantial. While generally much less than the cost of drilling a well, plugging and abandonment costs for a single geothermal injection well can easily exceed $100,000 and in some cases have been greater than $1 million.

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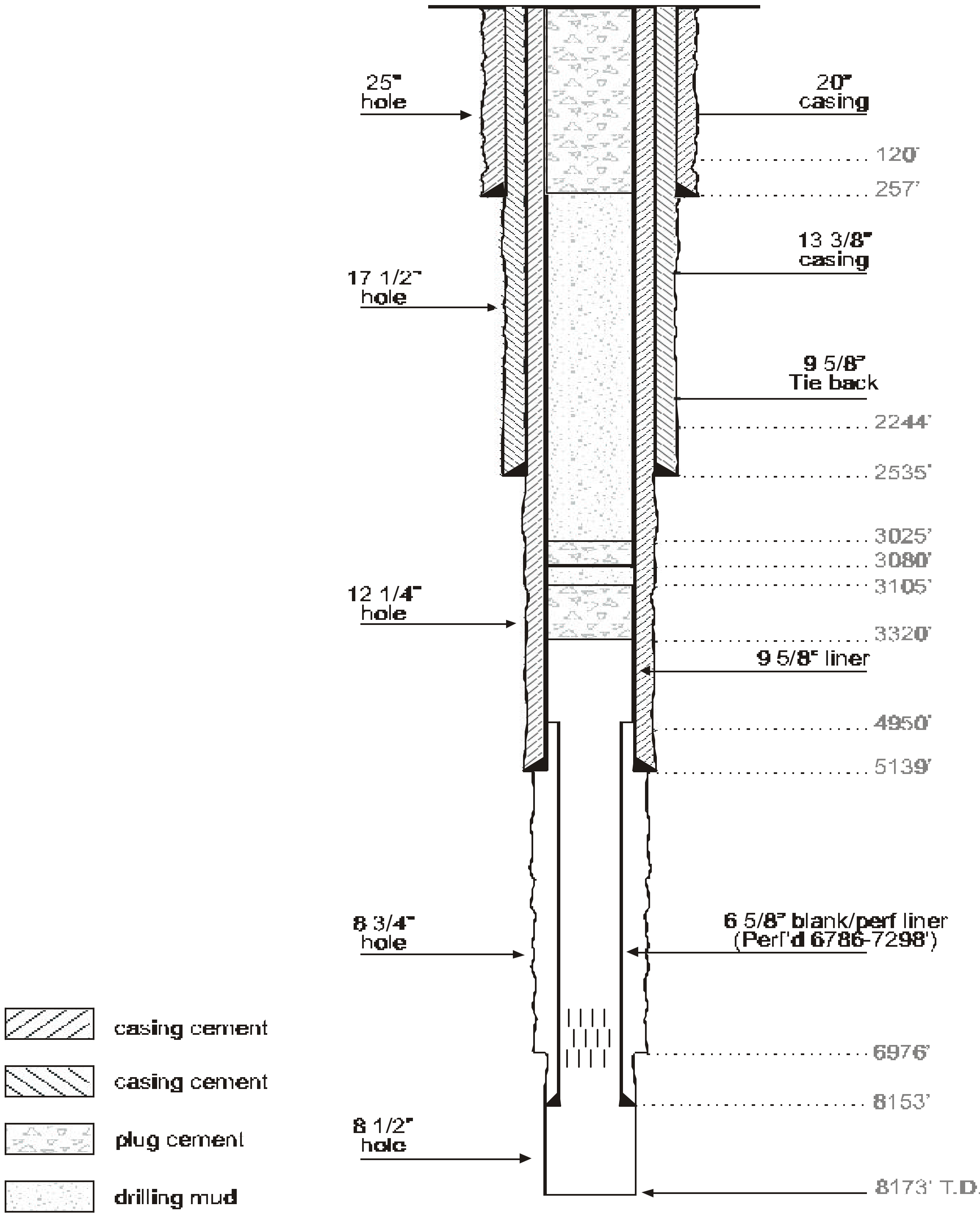
[5] Based on review of selected well abandonment plans and completion reports and permits from BLM and state agency offices in CA and NV. For additional information of the operating history of the well shown in Figure 7, see Crockett and Enedy (1990).

[6] Many geothermal reservoirs contain sufficient pressure that injection wells drilled into the reservoirs are artesian and would flow at the surface in the event of a piping, valve or casing failure. Because such a failure would create a safety hazard due to the release of hot water or steam, and in some cases toxic gas (e.g., H_2S) emissions, well plugging both improves safety and protects USDWs.

Figure 7. Example of Well Plugging with Multiple Cement Plugs



Source: CDOG, 1998b

5. POTENTIAL AND DOCUMENTED DAMAGE TO USDWs

5.1 Injectate Constituent Properties

The primary constituent properties of concern when assessing the potential for Class V electric power geothermal injection wells to adversely affect USDWs are toxicity, persistence, and mobility. The toxicity of a constituent is the potential of that contaminant to cause adverse health effects if consumed by humans. Appendix D of the Class V Study provides information on the health effects associated with contaminants found above drinking water standards or HALs in the injectate of electric power geothermal injection wells and other Class V wells.

Persistence is the ability of a chemical to remain unchanged in composition, chemical state, and physical state over time. Appendix E of the Class V Study presents published half-lives of common constituents in fluids released in electric power geothermal injection wells and other Class V wells. All of the values reported in Appendix E are for ground water. Caution is advised in interpreting these values, because ambient conditions have a significant impact on the persistence of both inorganic and organic compounds. Appendix E also provides a discussion of the mobility of certain constituents found in the injectate of electric power geothermal injection wells and other Class V wells.

Based on the information presented in Section 4.1, the following constituents were found to routinely or frequently exceed health-based standards at one or more geothermal fields: antimony, arsenic, barium, boron, cadmium, copper, fluoride, lead, mercury, strontium, sulfate, zinc, and total coliform. Aluminum, copper, iron, manganese, TDS, and pH also have been measured above secondary drinking water standards at some sites.

When injection is into the producing formation, the persistence and mobility of constituents present in spent geothermal fluids at levels above MCLs or HALs is expected to be the same following injection as in the produced fluid, with the exception of biological constituents (e.g., coliform) the are present in some injected surface water and treated effluent. Biological constituents are not thought to be either persistent or mobile in the environment of a geothermal reservoir.

5.2 Observed Impacts

Failures of injection well casings and release of geothermal fluids to the surrounding formation do sometimes occur, primarily as a result of seismic activity or corrosion of the casing. At the Salton Sea geothermal field, for example, the highly corrosive nature of the geothermal fluids readily corrodes steel well casings, with the result that the operator is increasingly using titanium casings to reduce casing failures and other operational problems resulting from corrosion. At this geothermal field, as well as some others, no USDWs are present, so geothermal fluid releases due to casing failures have not affected a USDW.

In other instances, releases have occurred that may have affected ground water quality. At the Puna geothermal field in Hawaii, for example, a blowout during drilling of a well (designated KS-8) on

June 11-13, 1991 resulted in fracturing of and release of steam to the formation at the bottom of the casing shoe (below the lowermost USDW) at a depth of 2,103 feet. Subsequent monitoring (of well designated MW2, about 1,000 feet from KS-8) of the USDW at a depth of approximately 630 feet indicated that temperature, chloride concentrations, and chloride/magnesium ratios increased from June 1991 through 1992.[7] The proximity of the wells and the timing of the changes in the monitoring well indicate a possible relationship between the observed chemical changes and the blowout (USGS, 1994).[8] TDS measurements in MW2 also show an increase beginning about July 16th. Earlier, TDS had also shown a sharp increase in MW2 from March 4 through March 10, 1991, shortly after the blowout of well KS-7 on February 21, 1991.[9] In addition, KS-7 shows an increase in temperature from June 16, 1991 through June 20, 1991, following the KS-8 blowout, with fluctuations occurring through mid-September 1991 (USEPA Region 9, 1999). For both the KS-7 and KS-8 wells, releases and possible impacts on ground water were associated with well construction rather than injection activities.

At the East Mesa geothermal field (see Figure 2), near-surface casing failures (e.g., well 84-7 in 1994) below the floor of the cellars[10] around casing wellheads have resulted in release of geothermal fluids to the ground surface and presumably to unconfined, near-surface ground water (USBLM, 1998). Data on the effects, if any, of the casing failures on the quality of the near-surface ground water are not available. In general, the quality of this near-surface ground water, which passes through a wetland between the canal (the presumed source of the water, along with irrigation drainage) and the East Mesa facility, is poor. As a result, the ground water is not used, although TDS is less than 10,000 mg/l. Similar near-surface leaks have also occurred in Nevada at some wells constructed with cellars around the casing wellhead (Land, 1999).

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[7] Chloride concentrations and Cl/Mg rations increased from about 500 mg/l to 1,100 mg/l and 30 to 100 mg/l respectively. Variations in chloride of this magnitude were observed in other wells, but no consistent trend is apparent. Downhole temperatures rose and fell by about 7°C in June 1991. Susequent measurements indicate a long-term increase of about 10°C through 1992 (USGS, 1994).

[8] Although the uncontrolled steam discharge at the KS-8 wellhead lasted for only 31 hours, temperature measurements indicate that steam continued to leak upwards past the casing shoe until the well was quenched (cooled) and plugged several months later on September 9, 1991 (USGS, 1994).

[9] KS-7 blewout for 15 minutes until the valve was shut down. Rock debris in the hole and subsequent difficulties encountered in attempting to resume drilling of the well caused the operator to cement the well back to a depth of 740 feet. KS-7, which is approximately 500 feet from KS-8, was then used as a monitoring well to measure temperature and water level until it was permanently plugged in 1993 (USGS, 1994).

[10] An excavation, usually concrete-lined and several feet deep, around the well casing.

6. BEST MANAGEMENT PRACTICES

A number of best management practices (BMPs) can be implemented to provide increased protection of USDWs and, in many cases, also provide improved safety and cost performance for electric power geothermal injection wells. The BMPs listed below are most effective when selected and implemented in combinations that are based on site-specific factors, which are highly variable. Individually, each practice addresses specific challenges and problems that may occur in operating these wells. When combined, each BMP becomes part of an integrated system that can increase the overall effectiveness of well system operations. For instance, pressure and plugging problems can be avoided with proper design and construction. Well failures due to stresses on well casings and equipment can also be reduced with proper design and construction. System monitoring and MIT, when used together, give a broad view of many operational aspects, ensuring safety and integrity across numerous variables rather than one or two at a time. The following discussion is neither exhaustive nor represents an USEPA preference for the stated BMPs. Each state, USEPA Region, and federal agency may require certain BMPs to be installed and maintained based on that organization's priorities and site-specific considerations.

6.1 Design and Construction

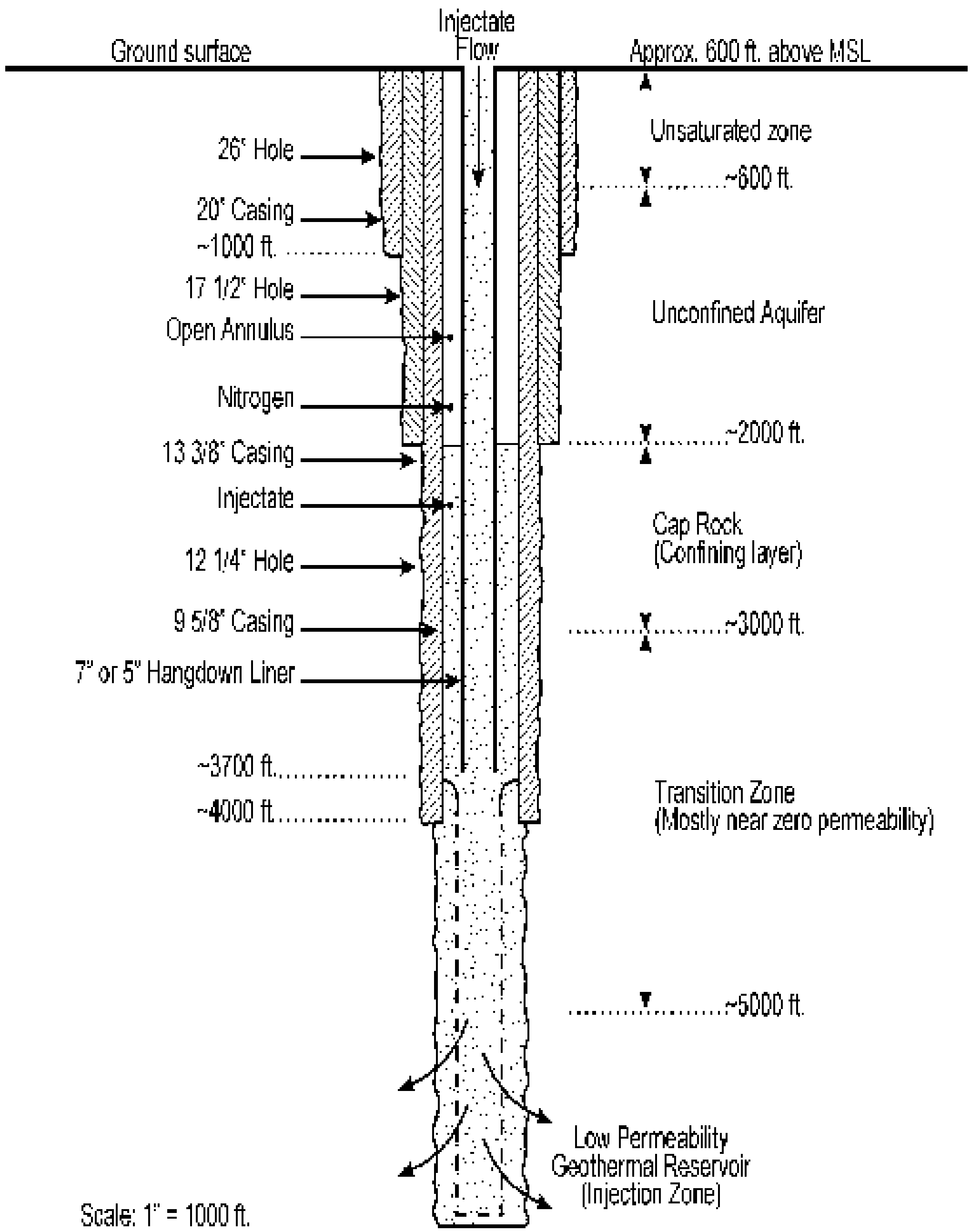
Proper design and construction of electric power geothermal injection wells is necessary to protect USDWs (where present). To protect ground water, wells should be designed with casing that runs from the surface to a depth below USDWs (Stock, 1990) when the geothermal reservoir occurs below the lowermost USDW. In addition, the well should have two casing strings, each sealed (e.g., cemented) its entire length (Crockett, 1990). The selection of casings, cements, and other materials used in well construction is dependent upon site-specific conditions, especially temperature, pressure, and the corrosivity of the geothermal fluids and formations through which the well passes. Appropriate material selection is facilitated by testing of the materials before construction (DiPippo, 1980).

Figure 8 provides an example of a well design that provides extensive provisions for prevention and detection of leaks and protection of ground water quality. Specifically, this well provides both multiple casing strings cemented through the USDW and a nitrogen "blanket" in the annulus. The nitrogen blanket is pressurized, and the pressure is monitored on an on-going basis to detect leakage of either the liner or the long string casing. While use of a cemented casing and a liner are common practice, nitrogen blankets are only used in Hawaii.

6.2 Operating Pressure and Injection Rate

Proper injection pressure is determined by site-specific factors. In some injection wells, injection occurs under vacuum (i.e., no pressure needs to be applied to achieve fluid injection), while other wells must inject under pressure to overcome formation pressures. When injection is accomplished under pressure, pressure monitoring aids in avoiding excessive pressure, thereby

Figure 8. Geothermal Well Casing Design,
Puna Geothermal Venture, Hawaii



Source: Puna Geothermal Venture, 1996

minimizing the likelihood of injection-induced seismic activity from increased subsurface pressure and the stresses on the injection well equipment.

Similarly, appropriate injection rates are determined by site-specific factors. In general, the maximum appropriate injection rate is less than a rate that will cause a pressure build-up in the formation or result in reduced fluid temperature at production wells. Monitoring of injection rates aids in avoiding the unwanted consequences of an excessively large flow volume and, in combination with pressure monitoring, provides an indication of casing integrity (Crockett, 1990; Halliburton,1996). For example, if flow rates increase and the injection pressure drops, this indicates that injection may have expanded to additional zones.

6.3 Maintenance

As with operating conditions, maintenance requirements are determined by site-specific factors such as the well design and the corrosivity of the injected fluids and the well environment. As discussed above, well design can minimize maintenance. For example, titanium casing is now used in many wells in the Salton Sea field to reduce the frequency of casing replacement. Some wells are designed and constructed with cellars around the casing wellhead. Experience in California and Nevada has shown that these cellars need to be kept dry or good drainage needs to be provided to prevent corrosion of the casing at the soil-air-water interface. There have been a number of instances in both Nevada and California (at the East Mesa field) where casing leaks have developed due to corrosion just below the ground level of the cellar (Land, 1999).

6.4 Mechanical Integrity

Well integrity is monitored on a continuous and periodic (e.g., every 1 to 5 years) basis as a routine part of injection management activities. Monitoring may be conducted to check the ability of the well to prevent both unintended release from within the well to the surrounding formations and interzonal migration of fluids between the casing and the formation. The type and frequency of monitoring performed is highly variable depending on site-specific characteristics, such as:

- Injection pressure (if any);
- Corrosivity and scaling properties of the injectate;
- Corrosivity of soils and formations that the well penetrates;
- Presence and characteristics of USDWs (if any); and
- Geothermal fluid temperatures, which may harm some instruments.

Continuous monitoring often includes monitoring of injection pressure, flow rate, and volume for changes that may signal a leak in the injection casing. In some cases, annulus pressure monitoring is also used on a continuous basis (Hawaii, 1998) to detect leakage of either the long string casing or injection tubing. In other cases, on-going monitoring also includes daily observations of surface conditions, as casing leaks may sometimes occur sufficiently close to the surface.

Periodic MIT is performed to detect actual and potential leaks, casing failures, and cementing problems. MITs are typically conducted prior to initial injection, after well workovers and repairs, and on a routine schedule during normal operations. Because geothermal injection wells are sometimes located in areas of seismic activity, casing integrity can be compromised by ground movement. In addition, casing and cement materials are susceptible to corrosion. Therefore, well materials and designs can vary, even within a single field. The appropriate use of MITs depends on the specific conditions of the geothermal field and the age and construction of the well. MITs may not be necessary in cases where an injection well does not penetrate a USDW (Radig, 1997).

MITs may involve performing a hydraulic pressure test or mechanic well logging to confirm that the well is functioning correctly and that confining fluid injection is to the intended zone. Hydraulic pressure tests check the integrity of long string casing and injection tubing by determining whether pressure applied to a gas or liquid in the annulus is adequately maintained for a specified length of time. For wells constructed without tubing and packer, pressure testing may be accomplished by setting packers above both the screen interval of the well and at the top of the casing, and pressurizing fluid in between. Alternatively, cementing pressure may be measured and used in combination with well log information (e.g., resistivity survey).

A wide range of well logging approaches are available for use in assessing the integrity of an injection well, including measurements of temperature, noise, radioactive tracers, flow, and casing thickness (using electromagnetic sensors or callipers), and inspection using a borehole televiewer or other device. Method suitability for a specific well depends on factors such as reservoir temperature, availability, cost, and past experience. For example, temperature, radioactive tracer, and flow (spinner) surveys are used to check the integrity of most injection wells in the Heber field in Imperial County, California. [Periodic pressure tests are used on some older wells instead, and all of the periodic tests are also supplemented with pressure tests following workovers or well casing repairs for all wells.] At the nearby East Mesa field, however, electromagnetic surveys are used instead to check integrity, due to past occurrences of near-surface casing leaks that were not detected using the methods employed at the Heber field, where problems with near-surface leaks have been relatively infrequent.

In contrast, measurement of static water levels is commonly used in combination with caliper surveys (and sometimes other logging techniques) at The Geysers field to check for protection of USDWs. At The Geysers, injection wells operate without applied pressure due to the characteristics of the geothermal reservoir. Injected fluids meet essentially no resistance to downward flow in the well until they reach the static water level in the well. Thus, injected fluids will flow down at least to the static water level essentially independent of the condition of the casing, making releases to formations above that level highly unlikely. Ground water has been found to occur in localized areas of Quaternary landslides and stream channel deposits and generally at relatively shallow depths (i.e., a few hundred feet) at The Geysers (Johnson, 1990). Thus, CDOG uses 500 feet below ground surface (bgs) as a benchmark for evaluating water level survey results, such that protection of ground water is assumed if the static water level in a well is below that depth. Caliper surveys are also used to evaluate the integrity of well casing throughout its length to ensure that fluids are being injected into the intended zone (Crockett, 1990).

7. CURRENT REGULATORY REQUIREMENTS

As discussed below, several federal, state, and local programs exist that manage or regulate electric power geothermal injection wells.

7.1 Federal Programs

On the federal level, management and regulation of electric power geothermal wells fall primarily under the UIC program authorized by the Safe Drinking Water Act (SDWA). Depending on the location of the well, the Geothermal Steam Act may also apply.

7.1.1 SDWA

Class V wells are regulated under the authority of Part C of SDWA. Congress enacted the SDWA to ensure protection of the quality of drinking water in the United States, and Part C specifically mandates the regulation of underground injection of fluids through wells. USEPA has promulgated a series of UIC regulations under this authority. USEPA directly implements these regulations for Class V wells in 19 states or territories (Alaska, American Samoa, Arizona, California, Colorado, Hawaii, Indiana, Iowa, Kentucky, Michigan, Minnesota, Montana, New York, Pennsylvania, South Dakota, Tennessee, Virginia, Virgin Islands, and Washington, DC). USEPA also directly implements all Class V UIC programs on Tribal lands. In all other states, which are called Primacy States, state agencies implement the Class V UIC program, with primary enforcement responsibility.

Electric power geothermal injection wells currently are not subject to any specific regulations tailored just for them, but rather are subject to the UIC regulations that exist for all Class V wells. Under 40 CFR 144.12(a), owners or operators of all injection wells, including electric power geothermal injection wells, are prohibited from engaging in any injection activity that allows the movement of fluids containing any contaminant into USDWs, “if the presence of that contaminant may cause a violation of any primary drinking water regulation . . . or may otherwise adversely affect the health of persons.”

Owners or operators of Class V wells are required to submit basic inventory information under 40 CFR 144.26. When the owner or operator submits inventory information and is operating the well such that a USDW is not endangered, the operation of the Class V well is authorized by rule. Moreover, under section 144.27, USEPA may require owners or operators of any Class V well, in USEPA-administered programs, to submit additional information deemed necessary to protect USDWs. Owners or operators who fail to submit the information required under sections 144.26 and 144.27 are prohibited from using their wells.

Sections 144.12(c) and (d) prescribe mandatory and discretionary actions to be taken by the UIC Program Director if a Class V well is not in compliance with section 144.12(a). Specifically, the Director must choose between requiring the injector to apply for an individual permit, ordering such action as closure of the well to prevent endangerment, or taking an enforcement action. Because electric power geothermal injection wells (like other kinds of Class V wells) are authorized by rule, they do not have to obtain a permit unless required to do so by the UIC Program Director under 40 CFR 144.25. Authorization by rule terminates upon the effective date of a permit issued or upon proper closure of the well.

Separate from the UIC program, the SDWA Amendments of 1996 establish a requirement for source water assessments. USEPA published guidance describing how the states should carry out a source water assessment program within the state's boundaries. The final guidance, entitled *Source Water Assessment and Programs Guidance* (USEPA 816-R-97-009), was released in August 1997.

State staff must conduct source water assessments that are comprised of three steps. First, state staff must delineate the boundaries of the assessment areas in the state from which one or more public drinking water systems receive supplies of drinking water. In delineating these areas, state staff must use "all reasonably available hydrogeologic information on the sources of the supply of drinking water in the state and the water flow, recharge, and discharge and any other reliable information as the state deems necessary to adequately determine such areas." Second, the state staff must identify contaminants of concern, and for those contaminants, they must inventory significant potential sources of contamination in delineated source water protection areas. Class V wells, including electric power geothermal injection wells, should be considered as part of this source inventory, if present in a given area. Third, the state staff must "determine the susceptibility of the public water systems in the delineated area to such contaminants." State staff should complete all of these steps by May 2003 according to the final guidance.[11]

7.1.2 Geothermal Steam Act

The federal BLM regulates use of geothermal resources on federal lands administered by the Department of the Interior or the Department of Agriculture, on lands conveyed by the U.S. where geothermal resources were reserved to the U.S., and on lands subject to Section 24 of the Federal Power Act, as amended (16 U.S.C. 818) with concurrence from the Secretary of Energy. Guidance on geothermal classification, leasing, exploration, operations, and resource protection and utilization is provided in 43 CFR parts 3200, 3210, 3220, 3240, 3250, and 3260. The BLM can issue geothermal resource operational orders, under the Geothermal Steam Act of 1970, for nationwide requirements; notices to lessees for statewide or regional requirements; and other orders and instructions specific to a field or area. The BLM can also issue permit conditions or approval and verbal orders.

Permitting Requirements

In order to use federal lands for access to geothermal resources, a site license and construction permit must be issued before starting any site activities. To get approval for drilling operations and well pad construction the following must be submitted to BLM: a completed drilling permit application, a

[11] May 2003 is the deadline including an 18-month extension.

completed operations plan, a complete drilling program, and an acceptable bond. A drilling program describes the operational aspects of the proposed drilling, completion, and testing of the well. The drilling program requires numerous items, including the casing and cementing program, identification of the circulation media (mud, air, foam, etc.), a description of the logs that will be run, and a description and diagram of the blowout prevention equipment that will be used during each phase of the drilling. An operations plan describes how to drill and test for the geothermal resources. The BLM then reviews these materials and decides on the issuance of a permit and license to proceed with work.

Within 30 days of completion of the well, a geothermal well completion report, form 3260-4, must be submitted to BLM.

Operational Requirements

The rules establish general standards that apply to drilling operations. They include meeting all environmental and operational standards, preventing unnecessary impacts to surface and subsurface resources, conserving geothermal resources and minimizing waste, protecting public health, safety and property, and complying with the requirements of 43 CFR 3200.4. Federal regulations 43 CFR subparts 3260 through 3267 establish permitting and operational procedures for drilling wells, conducting flow tests, producing geothermal fluids, and injecting fluids into a geothermal reservoir. Also included in these regulations are redrilling, deepening, plugging back and other well re-work operations.

BLM operational requirements for drilling include: keeping the wells under control at all times, conducting training during operation to ensure trained and competent personnel can perform emergency procedures effectively, and using properly maintained equipment and materials. Other requirements include employing sound engineering principles using all pertinent data, selecting drilling fluid types and weights, providing a system to control fluid temperatures, providing blowout prevention equipment, and providing a casing and cementing program.

Mechanical Integrity Testing

Generally, BLM requires that wells be tested once every two years unless problems have occurred with a well. Casing failures or other problems can lead to orders from BLM specifying more frequent MIT.

BLM also may specify particular types of MITs, such as hydraulic pressure tests and electronic casing log tests, or approve other methods proposed by operators on a case-by-case basis. Hydraulic pressure tests require a bridge plug to be placed as close as possible to the injection zone and the casing tested to a surface pressure of 1,000 psi or 200 percent of the maximum injection pressure, whichever is greater. However, this is not to exceed 70 percent of the minimum internal yield. If pressure declines more than 10 percent in 30 minutes, corrective action must be taken. Electronic casing log tests are run every two years and require injection well casing thickness to be no less than 75 percent of new nominal wall thickness. If the well fails this test, it must be placed out of service until BLM approves reactivation.

Well Abandonment

In order to abandon a well, a notice that documents the proposed plugging and abandonment program must be approved before closure begins. The local BLM office must also be notified before beginning abandonment so that they can witness the closure. Furthermore, a well abandonment report must be submitted to BLM within 30 days after completion of abandonment. The abandonment report should include a description of each plug, including the amount and type of cement used, the depth that the drill pipe or tubing was run to set the plug, the depth to the top of the plug, if the plug was verified, whether pressure testing or tagging was used, and a description of the surface restoration procedures.

Geothermal Resources Operational Order Number 3, effective February 1, 1975, states specific requirements for well plugging and abandonment. Cement used to plug any geothermal well, except surface plugging, must be placed into the well hole through a drill pipe or tubing. Plugging cement should consist of a high temperature resistant admix, unless waived by the site Supervisor. In uncased portions of the well, as well as in production perforations, cement plugs must be placed to protect all subsurface mineral resources including fresh water aquifers. These plugs must extend a minimum of 100 feet below and, if possible, 100 feet about the aforementioned zones. Intervals of the hole not filled with cement must be filled with good quality heavy mud. All open annuli extending to the surface must be plugged with cement and the innermost casing string which reaches ground level must be cemented or concreted to a minimum depth of 50 feet measured from 6 feet below ground level. All casing strings must be cut off at least 6 feet below the ground level and capped by welding a steel plate on the casing stub. The surface area must be restored as specified by the site supervisor.

Financial Responsibility

Before initiating any operation, operators are required to deposit a security or personal bond, subject to approval by BLM.

7.2 State and Local Programs

As discussed in Section 3, all the documented and estimated electric power geothermal injection wells in the nation, under either state or federal jurisdiction, exist in 4 states: California, Hawaii, Nevada, and Utah. Attachment B of this volume describes how each of these states currently regulate these wells. This section summarizes the regulatory requirements for electric power geothermal injection wells of the four states with such wells. Each of these states uses its geothermal resources in a variety of ways, and consequently has set up a special regulatory framework for geothermal wells, including injection wells. In California and Hawaii, USEPA Region 9 directly implements the UIC program for Class V injection wells. However, both California and Hawaii also have enacted, and implement, their own requirements for geothermal electric power return flow wells. Nevada and Utah are Primacy States for UIC Class V wells. Both of these states also have special regulatory standards for geothermal return flow wells, in addition to their UIC Class V programs.

- A Memorandum of Agreement between USEPA and CDOG assigns responsibilities to CDOG for regulating geothermal electric power return flow wells under its state-wide geothermal regulations. CDOG individually permits geothermal electric power return flow wells, after securing detailed information in permit applications about the entire plan of operations. California's regulations also contain well construction and operating requirements; mandate the use of MITs; contain procedural and technical requirements for plugging and abandonment; and require the operators to file indemnity bonds with CDOG guaranteeing financial responsibility for compliance with the requirements. In addition, Regional Water Quality Control Boards may prescribe requirements for discharges into waters of the state.

- In Hawaii, geothermal electric power return flow injection wells are permitted by USEPA Region 9. In addition, the Hawaii Department of Health also regulates geothermal injection wells under rules governing the use of geothermal resources. A state permit under the geothermal program may be issued only after a demonstration that the new or modified geothermal well has complete integrity and effluent will be confined to the intended zone of injection and will not impact a USDW. The geothermal requirements include monitoring of injectate and surveys to ensure that all injected fluid is confined to the intended zone of injection. The state geothermal well requirements also specify plugging and abandonment requirements.

- Nevada requires electric power geothermal injection wells to satisfy both its UIC Class V requirements and its geothermal well requirements. Geothermal wells are required to obtain an individual permit under the UIC requirements and also are permitted by the geothermal program. Substantial information is required in support of both permit applications, with the geothermal program specifying a greater level of detail. Both the UIC and the geothermal programs also have siting and construction requirements; require detailed monitoring of injection operations; require mechanical integrity testing; and specify plugging and abandonment requirements. Both require demonstrations of financial responsibility.

- Utah regulates wells used for geothermal energy production under its water rights code. Wells are individually permitted, on the basis of a detailed application. The code and permits address siting and construction; contain operating requirements; require MITs; specify the actions that must be taken to plug and abandon a well; and require owners to supply bonds indemnifying the state.

ATTACHMENT A
FACTORS INFLUENCING INJECTATE

The chemical characteristics exhibited by the injected fluids are primarily (although not exclusively) determined by the characteristics of the geothermal resource, the technologies used to produce the power, the chemicals used in conjunction with power plant operations (e.g., for treatment of steam or geothermal fluid), and the characteristics of supplemental water sources (in any). Each of these four factors is discussed in this attachment.

Composition of Geothermal Fluids

Researchers have identified four distinct water types commonly found within geothermal resource areas: alkali chloride waters, acid sulfate waters, acid sulfate-chloride waters, and bicarbonate waters (Ellis, 1977). In general, chloride waters are found in deeper, hotter geothermal systems, and bicarbonate waters are found in shallow geothermal systems and ground water. The composition of the geothermal fluid will, to a large extent, determine the composition of the injectate.

C Alkali chloride waters usually contain dissolved salts with high sodium and potassium chloride contents. Additional compounds in these waters include silica, sulfate, bicarbonate, fluoride, ammonia, arsenic, lithium, rubidium, cesium, and boric acid.

C Acid sulfate waters are low in chloride content with the constituents found in these waters mainly leaching from surrounding reservoir rocks.

C Acid sulfate-chloride waters exhibit properties of both alkali chloride waters and acid sulfate waters. Mechanisms for the formation of these waters include simple mixing of alkali chloride and acid sulfate waters; oxidation of sulfide waters at depth, with subsequent acidification of bisulfate ions upon rising; and interaction of high temperature chloride waters at depth with sulfur-bearing rocks.

C Bicarbonate waters have variable sulfate concentrations, high sodium concentrations, and neutral pH values. Bicarbonate waters of greater complexity are also common at great depths within geothermal systems in metamorphic or sedimentary rocks.

Geochemical differences among liquid-dominated systems and vapor-dominated systems also affect injectate quality. Hot water systems are nearly always characterized by relatively high amounts of chlorides, silica, boron, and arsenic (White, 1971). Vapor-dominated systems usually have lower levels of the common metal chlorides, because of their negligible volatility and solubility in low-pressure steam. Also, vapor-dominated systems usually have lower silica concentrations, as silica is more soluble at lower temperatures and pressures in the presence of liquid than it is in vapor.

Effect of Technology

The technology used to produce electric power from geothermal fluids affects the characteristics of fluid available for reinjection in two ways. First, it affects the extent to which non-condensible gases are removed and water is evaporated from the geothermal fluids prior to injection. Second, technology affects the need for treatment of the produced fluid prior to injection. The technology used is largely determined by the characteristics of the geothermal system. The three types of geothermal systems used to generate electric power are:

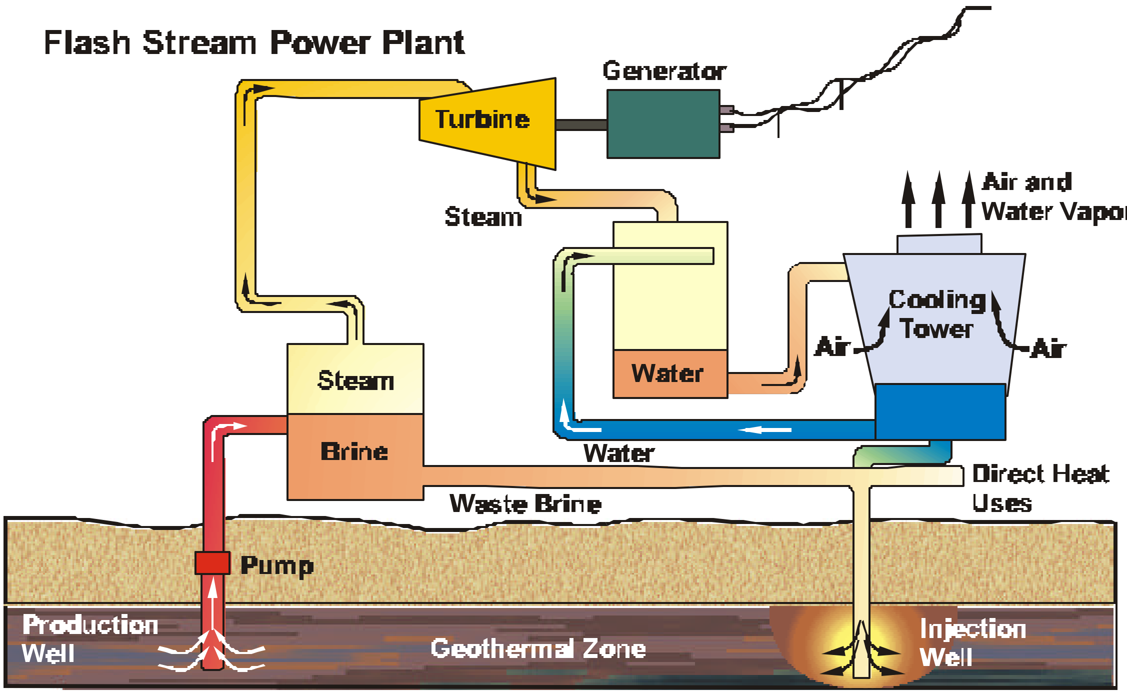
- steam or vapor dominated systems,
- high temperature water (liquid dominated) systems, and
- low to moderate temperature water (liquid dominated) systems.

At steam or vapor-dominated geothermal fields, the produced steam is used to power a turbine to generate electricity. The steam is then normally condensed and the resulting condensate is injected back into the same formation from which the geothermal fluid was produced. Condensing and injecting the spent steam (rather than venting to the atmosphere) serves to reduce emissions, allows for convenient disposal of spent fluids, and extends the life of the geothermal reservoir. The amount of condensate available for injection depends in part on the power plant technology used. Regardless of the specific technology used, however, these types of systems result in the evaporation of a much larger fraction (and, thus, condensation of a smaller fraction) of the produced geothermal mass than the systems using water-dominated resources. As a result, some facilities inject water from supplemental sources, which further affects injectate characteristics.

The second type of geothermal system used for power production is the high temperature water or liquid geothermal system, which contains high pressure water and steam mixtures at temperatures exceeding approximately 200°C (400°F). Steam used to power a turbine generator can be produced from high temperature water-dominated geothermal systems by "flashing" a portion of the geothermal fluid into steam. Flashing results from the reduction of pressure as the high temperature water is brought to the surface, which allows a portion the water to vaporize, or "flash," into steam. Figure A-1 shows a typical example of a flow diagram for a flash-steam power cycle.

As shown, fluids that remain after flashing of the steam are reinjected along with condensate and blowdown from the cooling tower. These spent liquids may contain higher concentrations of dissolved solids and less gas in solution than the original geothermal fluids. Decreased temperature, in combination with this change in concentrations, creates a need for treatment of the spent liquids at some facilities to prevent excessive scaling of piping, injection wells, and other equipment. Treatment of the geothermal fluid, when required, normally consists of pH reduction by addition of acid (such as hydrochloric acid) or controlled precipitation and

Figure A-1. Single-stage, Flashed-Steam Power Plant



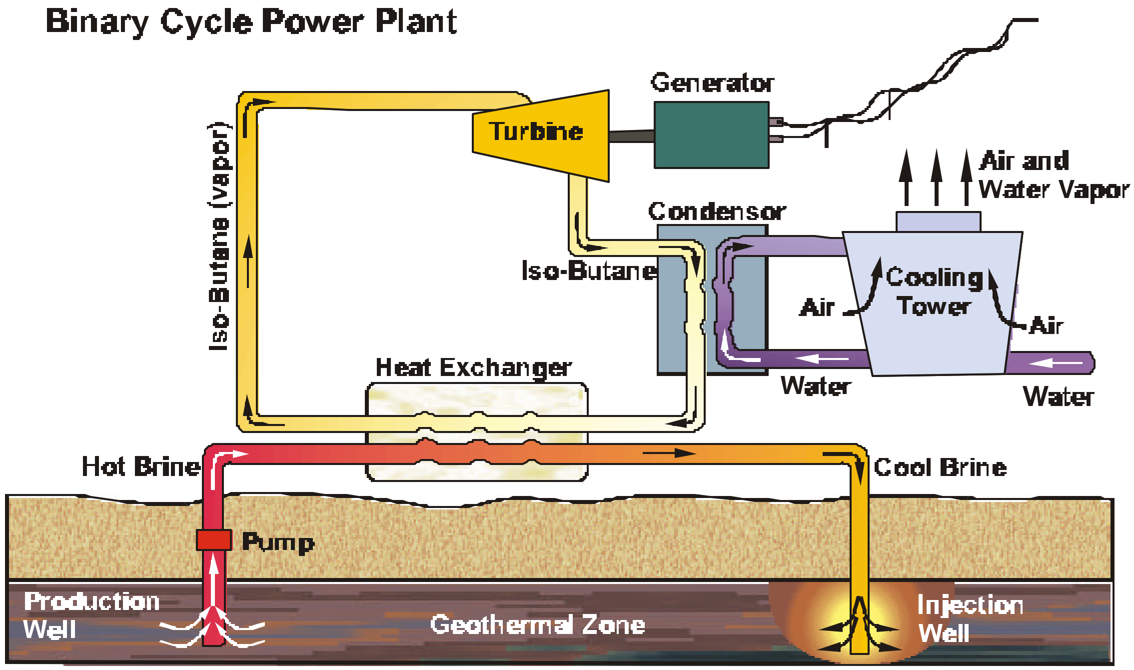
Source: U.S. DOE, 1998b

settling/clarification for removal of excess solids (e.g., carbonates, silicates) from the fluid stream.[12]

The third type of geothermal system--low to moderate temperature water-dominated geothermal systems--is developed for power production using a binary cycle or system. In a binary cycle, the hot reservoir water is kept under pressure and run through a heat exchanger, boiling a secondary fluid with a low boiling point, such as isopentane, pentane, butane, ammonia, or a fluorocarbon refrigerant. The geothermal waters are then re-injected after being run through a heat exchanger. Because the geothermal fluid is not exposed to the surface environment, the composition of the injected geothermal fluid is essentially the same as the produced fluid. Figure A-2 shows a flow diagram for a binary power cycle.

[12] In this context, "excess solids" are solids that precipitate due to the reduced solubility caused by reduced pressure, temperature, and fluid mass.

Figure A-2. Typical Flow Diagram of a Binary Cycle Power Cycle



Source: U. S. DOE, 1998b

Geothermal Fluid and Gas Treatment Chemicals

Geothermal steam and fluids contain non-condensible gases to varying degrees depending on formation pressure, temperature, and mineralogy (Mahon, 1980). The non-condensible gases most commonly encountered in geothermal fluids are carbon dioxide, hydrogen sulfide, ammonia, hydrogen, nitrogen, oxygen, and methane (Ellis, 1977). Gas handling practices vary by plant and affect injectate gas composition and overall characteristics. At some geothermal power plants, especially binary plants, these gases are not separated from the geothermal fluid and, thus, are reinjected along with the geothermal fluid. At other plants, especially some flash plants, non-condensible gases are collected, repressurized, and reinjected with the geothermal fluids. Other flash plants and steam plants vent non-condensible gases to the atmosphere and/or remove them through treatment . Hydrogen sulfide (H_2S) is the primary target of chemical or biological gas treatment efforts that convert H_2S to elemental sulfur.

Chemicals not native to the formation are introduced into the injected fluids as a result of the use of additives to control biofouling, corrosion, and scaling of the plant equipment. The type of chemicals used for these purposes are illustrated by a list of active ingredients for additives provided in the UIC permit for injection wells at Pahoa, HI, which includes (USEPA Region 9, 1998):

- sodium sulfite,
- benzoic acid,
- sodium hydroxide,
- sodium gluconate,
- dimethyldioctylammonium chloride,
- soya amine polyethoxylate,
- cychlohexlamine,
- polyamidoamino acetate,
- POE (15) tallow amine,
- sodium metabisulfite,
- cobalt compounds,
- sodium chloride,
- phosphoric acid derivative,
- magnesium nitrate,
- 5-chloro-2-methyl-4-isothiazoline-3-one,
- magnesium chloride,
- 2-methyl-4-isothiazolin-3-one,
- cupric nitrate,
- disodium ethylenebis-dithiocarbamate,
- dimethylamine,
- ethylene diamine,
- ethylene thiourea, and
- sulfuric acid.

Supplemental Water Sources

At most geothermal fields used for electric power generation, the injected fluids consist of spent geothermal fluid in combination with other fluids generated onsite by plant operations, such as cooling tower blowdown. At a few geothermal power plants, however, fluids in addition to those produced from geothermal reservoirs are routinely injected along with spent geothermal fluids to supplement fluid recharge in the geothermal resource.

At The Geysers, for example, fluids injected down some of the 29 active injection wells in 1997 (CDOG, 1998a) included storm water runoff from power plant sites, water from Big Sulfur Creek and Clear Lake, treated wastewater effluent from the Lake County Sanitation District (LACOSAN), and treated sanitary wastes generated at the power plant sites (Crocket, 1990; Dellinger, 1998). The largest volume supplemental source of injection water at The Geysers is the 7.8 mgd from Clear Lake and LACOSAN that is delivered to The Geysers through a 29-mile pipeline and then distributed to selected injection wells within the field. Injection of waters from some supplemental sources occurs seasonally (i.e., storm water runoff during the winter "rainy season" and waters from Big Sulfur Creek) while other sources do contribute year round. The relative contribution of the various sources to aggregate characteristics of the injected fluid varies also seasonally because the amount of geothermal steam condensate available for injection varies seasonally (due to higher evaporation rates during the warmer summer months).

At the Dixie Valley Geothermal Project in Nevada, shallow ground water is injected (in addition to geothermal fluids) into the geothermal reservoir to counteract the loss of mass from the geothermal system due to condensate evaporation. The ground water is not mixed with the geothermal fluids prior to injection (Land, 1999).

Other examples of additional fluid sources are provided in the USEPA UIC permit for the injection wells at Pahoa, Hawaii. For the wells covered by this permit, the following fluids are allowed to be injected along with geothermal fluids (USEPA Region 9, 1998):

- steam turbine seal water,
- rinsate from water softener system,
- sulfatreat heat exchanger cooling water,
- raw/quench water,
- production well bleed system,
- abatement fluids,
- sulfatreat system vacuum pump seal water,
- condensate from the sulfatreat system,
- periodic drilling fluids, and
- fluids from the plant water storage tank and the emergency steam release facility.

ATTACHMENT B
STATE AND LOCAL PROGRAM DESCRIPTIONS

This attachment addresses the four states with electric power geothermal injection wells: California, Hawaii, Nevada, and Utah.

California

USEPA Region 9 directly implements the UIC program for Class V injection wells in California. However, the State of California also regulates these wells and has substantial responsibilities set forth in a Memorandum of Agreement between USEPA and CDOG (USEPA, 1991). CDOG is the state agency with direct responsibility for geothermal electric power return flow wells under Chapter 4 of Division 3 of the California Public Resources Code (PRC) (Sections 3700 - 3776). The Department has enacted state-wide geothermal regulations in Title 14, Chapter 4 , Subchapter 4 of the California Code of Regulations (CCR). The PRC explicitly covers "any special well, converted producing well or reactivated or converted abandoned well employed for reinjecting geothermal resources or the residue thereof" (3703 PRC). The regulations define an injection well as "a service well drilled or converted for the purpose of injecting fluids" (1920.1(e) CCR). They also state that injection wells are those used for the disposal of waste fluids, the augmentation of reservoir fluids, pressure maintenance of reservoirs or for any other purpose authorized by CDOG. New wells may be drilled and/or old wells may be converted for water injection or disposal service (1960 CCR).

Under California's Water Quality Control Act (WQCA), the state is divided into nine regions, and Regional Water Quality Control Boards, which are organizations separate from CDOG, are delegated responsibilities and authorities to coordinate and advance water quality (Chapter 4 Article 2 WQCA). A Regional Board can prescribe requirements for discharges (waste discharge requirements or WDRs) into the waters of the state, including ground water[13] (13263 WQCA). A WDR can pertain to an injection well (13263.5 and 13264(b)(3) WQCA) and at least one Regional Board has issued a WDR for geothermal wells.

Permitting

Under the state geothermal regulations, injection well operators must file a Notice of Intent to Drill, post a bond or surety prior to injection operations, and pay an application fee (3724 PRC, 1931 CCR). Operations may not commence until the CDOG reviews and approves the application (3724.3 PRC; 1931 CCR). Applicants must provide a letter setting forth the entire plan of operations that includes analysis of reservoir conditions, method of injection (i.e., through casing, tubing, or tubing with a packer), source of injection fluid, and estimates of the daily amount of water to be injected. The application must include a map of the well field along with one or more cross sections showing the wells involved and a copy of any environmental documents created in support of the operations. Notice is

[13] The WQCA defines "waters of the state" as "any surface water or ground water, including saline waters, within the boundaries of the state."

also required when operators convert an existing well to an injection or disposal well, even if there will be no change in mechanical condition as a result of the conversion. In addition, applicants must provide chemical analyses of injectate and injection zone fluids. Finally, the application must contain copies of the letter of notification sent to neighboring operators, if required by CDOG (3724, 3724.1 PRC). Officials set permit conditions on a case-by-case basis.

Regional Water Quality Control Boards can include special monitoring and reporting requirements in a Waste Discharge Requirement's monitoring and reporting program (3724 PRC) and at least one Regional Board has done so for a geothermal well.

Siting and Construction

The CDOG geothermal regulations contain specifications for well construction. All wells must be cased in a manner that protects or minimizes damage to the environment, surface and ground waters, geothermal resources, life, health, and property (1935 CCR). Conductor pipe must be cemented with sufficient cement to fill the annular space from the shoe to the surface (1935.1 CCR). Surface casing must provide for control of formation fluids, protection of ground water, and prevention of blowouts. Intermediate casing must be cemented solid to the surface whenever possible (1935.2 CCR). Similarly, production casing may be set above or through the injection zone and cemented above the objective zones (1935.4 CCR). The specific casing design criteria are determined on a case-by-case basis, depending on the hydrogeological conditions at each well field (3740 PRC).

State regulations also contain standards for blowout prevention. Each well must be equipped with blowout prevention equipment (BOPE) that includes high temperature-rated packing units and ram rubbers. This equipment must have a working-pressure rating equal to or greater than the lesser of (a) a pressure equal to the depth of the BOPE anchor string in meters multiplied by 0.2 bars per meter, (b) a pressure equal to the rated burst pressure of the BOPE anchor string, or (c) a pressure equal to 138 bars (2,000 psi). The state generally prohibits drilling in unstable geothermal areas, including areas with fumaroles, geysers, hot springs, and mud pots. However, if drilling in these areas is approved, drilling operations must be monitored by state officials until the surface casing has been cemented and the BOPE has been pressure-tested satisfactorily (1941-1942.2 CCR).

Operating Requirements

Completed and operating geothermal injection wells must be maintained and tested to prevent loss of or damage to life, health, property, and natural resources. All surface and wellhead equipment and pipeline, and subsurface casing and tubing must be examined periodically for corrosion. Operators must show complete casing integrity upon completion of a new injection well, when converting a production well to an injection well, or when reactivating an idle well. The geothermal regulations also require monitoring of injection well operations on a "continuing" basis to establish that all injectate is confined to the intended injection zone. Casing integrity tests must be performed within 30 days after injection starts and every two years thereafter, unless otherwise specified by CDOG. In addition, CDOG staff (well supervisors) conduct onsite inspections periodically to note surface conditions and determine action needed to address problems, if any. Operators must examine, document, and report injection pressures to CDOG, and CDOG may rescind injection approval if it appears damage is being done (1966 CCR).

Mechanical Integrity

State regulations mandate the use of MITs to prevent damage to life, health, property, and natural resources; to protect geothermal reservoirs from damage; and to prevent the infiltration of detrimental substances into underground or surface water suitable for agricultural, industrial, municipal, or domestic use. Casing tests must be performed, which may include spinner surveys, wall thickness, pressure, and radioactive tracer tests. Cementing tests are also required, which may include tests on cementing of the casing, pumping of plugs, hardness of plugs, and depths of plugs. Finally, regulations require equipment testing of gauges, thermometers, surface facilities, lines, vessels, and BOPE. The CDOG well supervisor determines the type and frequency of these tests on a case-by-case basis (1941, 1942, and 1966 CCR).

Financial Responsibility

Operators must file an individual indemnity bond that secures the state against losses, charges, and expenses incurred from assuring compliance with the state's geothermal resources regulations. The bond must be filed with CDOG at the time operators file the Notice of Intent to Drill. Bonds must be executed by the owner, as principal, and by an authorized surety company, as surety, on condition that the principal named in the bond will comply with all the provisions of the state's geothermal regulations. The bond's language must substantially conform to the language provided in California's Public Resources Code, Chapter 4, §3725. Operators may choose to file an individual indemnity bond of $25,000 for each well drilled, redrilled, deepened, maintained, or abandoned; or they may file a blanket bond of $100,000 to cover all operations statewide. Individual and blanket bonds may be terminated and canceled after the wells have been properly abandoned (3725.5 PRC). Liability for individual wells covered under a blanket bond may be terminated by consent of the CDOG supervisor (3728 PRC); (3725 PRC).

Plugging and Abandonment

Under the geothermal requirements of PRC, an operator must file for and obtain written approval to abandon, specifying the proposed method of abandonment. Furthermore, the operator must file the request at least 10 days before the proposed abandonment (3747 PRC). Unless otherwise approved, no person shall remove casing from a geothermal injection well without first giving written notice to the state oil and gas supervisor of the intention to do so. The notice shall be given at least 10 days before the proposed removal (PRC 3751). Within 60 days after the completion of abandonment of any well, the owner or operator of the well must provide a written report of completion. CDOG, in turn, must furnish the owner/operator with a written final approval or disapproval of abandonment (3748 PRC).

The regulations provide detailed requirements for plugging and abandonment. They include, for cased wells, including injection wells, a requirement that cement plugs must extend from the bottom of the geothermal zone or perforations to 30 meters over the top of the zone or perforations. Cement plugs must be placed from 15 meters below to 15 meters above liner tops. The requirements also address casing salvage, plugging of stubs and laps, shoe plugs, bridge plugs, surface plugs, and other specifications (1980 - 1981.2 CCR).

An example of a proposed plan, approval, and reporting for the well shown in Figure 9 is as follows (CDOG, 1998b):

Proposed Plugging and Abandonment Activities

1. Install blowout prevention equipment.
2. Rig up working platform and crane equipment.
3. Pick up 1-1/4" Hydril tubing.
4. Go in hole to 3,350'.
5. Set 300' cement plug from 3,350' to 3,050'.
6. Displace drilling mud into wellbore.
7. Locate and identify top of cement plug. CDOG to witness.
8. Set 50' cement plug at surface.
9. Rig down equipment.
10. Remove wellhead. Weld steel plate onto 9-5/8" casing.
11. Remove cellar and restore location. Notify CDOG.

Agency Approval of Plan

Approved provided that CDOG shall be notified:

1. To witness the location and hardness of the cement plug at 3,050'.
2. Upon restoration of the location to near original conditions so that a final environmental inspection can be made.

Agency Approval and Reporting of Plugging Operations

1. Plugged with cement from 3,320' to 3,105'.
2. Plugged with cement from 3,080' to 3,025'.
3. Plugged with cement 120' to surface.

Hawaii

USEPA Region 9 directly implements the UIC program for Class V injection wells in Hawaii. The Region requires that geothermal injection wells have a permit issued by USEPA. The Hawaii Department of Health also has enacted UIC requirements and issues permits for geothermal injection wells. Chapter 23 of Title 11 of the Hawaii Administrative Rules (HAR), effective July 6, 1984, amended November 12, 1992, establishes the state's UIC program. Class V wells are grouped into six subclasses. Subclass E consists of injection wells associated with the development and recovery of geothermal energy.

The Hawaii Board of Land and Natural Resources (HBL&NR) enacted special rules governing the leasing and drilling of geothermal resources, which are found in Title 13, Subtitle 7, Chapter 183 HAR. Subchapter 9 of Chapter 183 addresses use of injection wells. Injection wells are defined as those wells used for disposal of geothermal waste fluids, for the augmentation of geothermal reservoir fluids, for maintenance of reservoir pressures, or for any other purpose authorized by the HBL&NR.

Permitting Requirements

Underground injection through a Class V well is prohibited except as authorized by a UIC permit. A permit for injection into USDW is based on evaluation of the contamination potential of the local water quality by the injection fluids and the water development potential for public or private consumption. Class V Subclass E wells are defined by Hawaii's rules to consist of injection wells associated with the development and recovery of geothermal energy, provided that the geothermal effluent will be injected at a depth that will not be detrimental to USDW. For Subclass E geothermal wells, if injection is to occur below the basal water table, the receiving water must be tested, and injection will be allowed if the receiving water has either an equal or greater chloride concentration as that of the injected fluid or a TDS concentration in excess of 5,000 mg/l, or an equivalent or lesser water quality than the injected fluid (11-23-06 (b)(6)(A) HAR). Permits are issued for up to five years. Permit applications must include specified information (e.g., facility location, ownership, nature and source of injected fluid; description of injection system; details of proposed injection testing; well log; elevation section; results of injection testing; water quality data; and operating plans) (11-23-12, 11-23-13, and 11-23-16 HAR).

Under the geothermal requirements administered by HBL&NR, existing wells may not be modified for injection purposes until a permit has been applied for and received (13-183-78 HAR). The owner or operator of either a new or modified geothermal well must demonstrate that the casing has "complete" integrity by approved test methods, or establish that all injection effluent is confined to the intended zone of injection (13-183-79 HAR).

Permitting by HBL&NR is a two-step process. First, an Authorization to Construct is issued in response to receipt of an application. Once the well is constructed and tested, a Permit to Operate is issued by the Department of Land and Natural Resources. Under the geothermal requirements, if a well remains idle for a period of two years or longer, the permit may be rescinded (13-183-79 HAR).

Siting and Construction

The UIC rules require wells to be sited beyond an area that extends at least one-quarter mile from any part of a drinking water source, including not only the surface expression of the water supply well, tunnel, or spring, but also all portions of the subsurface collection system. Special buffer zones are required if the well is located in a caprock formation that overlies volcanic USDW under artesian pressure (11-23-10 HAR).

No injection well may be constructed unless a permit has been applied for and the construction has been approved. Construction standards for each type of well are not specified, due to the variety of injection wells and their uses. If large voids such as lava tubes or solution cavities are encountered, special measures must be taken to prevent "unacceptable" migration of the injected fluid (11-23-09 HAR).

Operating Requirements

A Class V well may not be operated in a manner that allows the movement of fluid containing a contaminant into a USDW, if the presence of that contaminant may cause a violation of any national or state primary drinking water rule or otherwise adversely affect the health of one or more persons. All wells must be operated in such a manner that they do not violate any rules under Title 11 HAR regulating water quality and pollution, including Chapter 11-20, relating to potable water systems, Chapter 11-62, relating to wastewater systems, and Chapter 11-55, relating to water pollution control. The state may also impose other limitations on quantity and quality of injectate as deemed appropriate. An operator may be ordered to take necessary actions to prevent a violation of primary drinking water standards, including cessation of operations (11-23-11 HAR).

Mechanical Integrity

All casing strings are required to be pressure tested after cementing and before commencing any other operations on the well (13-183-76 HAR).

Monitoring Requirements

Operating records generally are required for geothermal wells, including the type and quantity of injected fluids and the method and rate of injection (11-23-12 HAR).

Under the geothermal requirements, the operator must make "sufficient" surveys (not further defined by regulation), within 30 days after injection commences, to demonstrate that all the injected fluid is confined to the intended zone of injection. Subsequent surveys must be made at least every two years (13-183-79(b) HAR). Injection pressures and rates must be recorded, maintained, and reviewed to detect anomalies (13-183-79(d) HAR). If this process demonstrates ongoing damage, the permit may be rescinded. Detailed well records must be kept, and monthly reports of the amount of fluid injected must be submitted (13-183 Subchapter 12 HAR).

Financial Responsibility

The Hawaii Department of Health does not require a bond for closure of injection wells. However, USEPA Region 9 issued a permit to Puna Geothermal Venture/Puna Cost, Inc. that required a financial assurance mechanism to cover the anticipated cost of plugging and abandoning the injection wells.[14]

Plugging and Abandonment

An operator wishing to abandon a well must submit an application, and the well must be plugged in a manner that will not allow "detrimental" movement of fluids between formations (11-23-19(a) HAR).

Under the geothermal requirements, before abandonment of a well, an operator must file for and obtain a permit to abandon and specify the proposed method of abandonment. Unless otherwise approved, abandonment requires that approved heavy drilling fluid be used to replace any water in the hole, and all portions of the hole which are not plugged with cement be filled. The casing must be cut off at least 6 feet below the surface of the ground and the surface restored. Detailed cementing requirements are included in the rules requiring: 1) the cement to contain a high temperature resistant admix; 2) filling of all open annuli solid with cement to the surface; 3) placement of 100 lineal feet of cement straddling the bottom of the conductor pipe and at the shores of all casings; and 4) placement of cement across geothermal zones and extending 100 feet above and below the zones whether in a cased or uncased hole. Fifty feet of cement is required above the top of casing liners and below the surface of the well (13-183-81 to 13-183-83 HAR).

Nevada

Nevada is a UIC Primacy State for Class V wells in which the Nevada Division of Environmental Protection (DEP) administers the UIC program. Electric power geothermal injection wells must satisfy Nevada's UIC program requirements. Geothermal wells also must satisfy regulations of the State Engineer and the Division of Minerals (DOM).

UIC Statutes and Regulations

Nevada Revised Statutes (NRS) §§ 445A.300 - 445A.730 and regulations under the Nevada Administrative Code (NAC) §§ 445A.810 - 445A.925 establish the state's basic underground injection control program. The injection of fluids through a well into any waters of the state, including underground waters, is prohibited without a permit issued by the DEP, (445A.465 NRS), although the statute allows both general and individual permits (445A.475 NRS and 445A.480 NRS). Furthermore, injection of a fluid that degrades the physical, chemical, or biological quality of the aquifer

[14] The cost of plugging injection well KS-8 at the Puna Geothermal facility in Hawaii following a blowout in 1991 was more than $1 million.

into which it is injected is prohibited, unless the DEP exempts the aquifer and the USEPA does not disapprove the exemption within 45 days after notice of it (445A.850 NAC). The statute defines geothermal wells used in the generation of energy as Class V wells (445A.849 NAC).

Chapter 445A NAC, "Underground Injection Control," defines and elaborates these statutory requirements. First, they provide that any federal, state, county, or municipal law or regulation that provides greater protection to the public welfare, safety, health, and to the ground water prevails within the jurisdiction of that governmental entity over the Chapter 445A requirements (445A.843 NAC).

Permitting. The UIC regulations specify detailed information that must be provided in support of permit applications, including proposed well location, description of geology, construction plans, proposed operating data on rates and pressures of injection, analysis of injectate, analysis of fluid in the receiving formation, proposed injection procedures, and a corrective action plan (445A.867 NAC). The DEP may, however, request additional information be supplied in support of a permit application for a Class V well.

Siting and Construction. The state specifies, among other siting requirements, that the well must be sited in such a way that it injects into a formation separated from any USDW by a confining zone free of known open faults or fractures within the area of review. It must be cased from the finished surface to the top of the injection zone and cemented to prevent movement of fluids into or between USDWs (445A.908 NAC).

Operating Requirements. Monitoring frequency for injection pressure, pressure of the annular space, rate of flow, and volume of injected fluid is specified by the permit. Analysis of injected fluid must be conducted with sufficient frequency to yield representative data. Prior written authorization from DEP is required before an operator may use any chemicals (biocides, corrosion and scale inhibitors, etc.) in the injection or cooling systems.

Mechanical Integrity. MIT is required once every 5 years, by a specified method.

Financial Responsibility. Class V geothermal injection wells associated with the production of energy are charged graduated fees for permitting depending on the number of megawatts produced (445A.872 NAC). Such wells are specifically required to satisfy bonding requirements, and must be covered by a bond either equal to the estimated cost of plugging and abandonment of each well or, if approved by DEP, a sum not less than $50,000 to cover all injection wells of the permit applicant in the state.

Plugging and Abandonment. A plugging and abandonment plan and cost estimate must be prepared for each well, and reviewed annually. Before abandonment, a well must be plugged with cement in a manner that will not allow the movement of fluids into or between USDWS (445A.923 NAC).

Regulations on Geothermal Resources

In addition to Nevada's requirements pertaining to underground injection wells, electric power geothermal wells also must satisfy regulations of the State Engineer and DOM. These requirements are found in Chapter 534A NAC, "Geothermal Resources."

These regulations define a geothermal injection well as any well used to dispose of fluids derived from geothermal resources into an underground reservoir (534A.061 NAC). They further divide geothermal wells into three categories based on the use of the geothermal resource. Injection wells used to dispose of spent fluids from electric power generation are considered industrial geothermal wells, which are the most extensively regulated (534A.170 and 534A.180 NAC) and are described below.

<u>Permitting Requirements</u>. The state requires a permit to drill or operate an individual geothermal well. Geothermal operators are required to file a Notice of Intention to Drill with the State Engineer, including descriptions of the purpose, location, estimated depth, casing, blowout protection, and drilling rig. The application must include information concerning well ownership, including the name of the landowner where the well will be sited, the name of the geothermal resource owner, and the name and address of the well operator and drilling contractor. Each permit application must include the appropriate financial assurance bond described under "Financial Responsibility." Finally, the permit must include a description of the location by the quarter section, section, township, and range. If the area has not been mapped, the application must state the location by distance and direction from an established landmark. Operators may also apply to permit wells for an entire project area, and must submit all the information required for an individual permit (534A.190 and 534A.193 NAC).

In addition to geothermal well permit requirements that address production and injection wells alike, applications for geothermal injection wells must provide additional information for permit approval. This includes a description of the casings in the wells or proposed wells; the proposed method for testing the casings before injection; the estimated maximum injection pressure and temperature; and a description of the proposed pipelines, metering equipment, and safety devices used to prevent accidental pollution (534A.196 NAC).

<u>Siting and Construction</u>. Injection wells may not be drilled within 100 feet of the boundary of the land on which the well is sited or a public road, street or highway. Exceptions to these regulations may be granted by DOM after considering such factors as the topographic, hydrologic and geologic characteristics of the area; characteristics of the reservoir; protection of the environment; and any existing rights. All wells must be cased in a manner that minimizes damage to the environment, ground and surface waters, geothermal resources, and property. Completion equipment for the well must be attached to the surface casing, and all casing reaching the surface must provide adequate anchorage for BOPE. Also, surface casing must provide for control of formation fluids and protection of fresh water. The annular space must be filled by circulating cement up the annulus to the surface. If the cement does not circulate or falls back, the casing must be cemented at the surface (534A.200, 534A.260, 534A.270 NAC).

Operating Requirements. Unless otherwise approved, all geothermal fluids must be reinjected into the same reservoir from which they originated. Operators must take all necessary precautions to keep wells under control and operating safely at all times. BOPE capable of shutting in the well during blowout or failure of flow controlling equipment must be installed on the surface casing and maintained ready for use at all times. The equipment must be made of steel and have a pressure rating equal to the maximum anticipated pressure at the wellhead. BOPE is required for all wells where temperatures may exceed 250°F. Immediately after installation, BOPE and the casing must be tested under pressure. DOM personnel must be given adequate advance notice and must witness the tests before the guide shoe is drilled out of the casing (534A.270, 534A.420 NAC).

Industrial geothermal well operators must complete monthly reports of production and temperature, based on continuous metering of rate of flow of water, steam, and pressure and temperature of fluids (534A.400, 534A.410, 534A.460 NAC).

Mechanical Integrity Testing. Nevada geothermal regulations do not specify MIT. However, the code states that all equipment used or purchased for development and production of geothermal resources must meet the minimum standards generally accepted for geothermal well equipment. DOM may require additional testing or repairs to prevent waste and damage to the environment.

Financial Responsibility. Nevada requires operators to provide a sufficient bond of at least $10,000 per well to indemnify the state against costs of enforcing its geothermal regulations. Liability ceases upon proper well abandonment. Operators may also file blanket bonds of at least $50,000 to cover all wells to be operated statewide. Bonds must be in cash, issued by a surety authorized to do business in Nevada, or in the form of a savings or time certificate of deposit. If the certificate is used, it must be issued by a bank or savings and loan association operating in Nevada, and payable to the State of Nevada. Operators who deposited a surety bond guaranteeing performance with the federal government for wells drilled on federal land (see Section 7.1.2 above) must file a copy of the bond with DOM (534A.250 NAC).

Plugging and Abandonment. Operators must file a request to abandon a well with DOM, including a detailed statement of the abandonment activities. Cement used to plug the well, except for surface plugging, must be placed in the hole by pumping through drill pipe or tubing. The cement mix must be able to withstand high temperatures. Cement plugs must be placed in the uncased portion of wells to protect all subsurface resources. The plug must extend a minimum of 100 lineal feet above and below the producing formations, or the total and 100 lineal feet below the producing formations, or to the total depth drilled, whichever is less. Where there is an open borehole, a cement plug must be placed in the deepest casing string.

If there is a loss, or anticipated loss, of drilling fluids into the formation or if the well has been drilled with air or another gaseous substance, a permanent bridge plug must be set at the casing shoe and capped with a minimum of 200 lineal feet of cement. Cement plugs must also be placed across perforations, extending 100 lineal feet below, or to the total depth drilled, whichever is less, and 100 lineal feet above the perforations. If using a cement retainer to plug perforations, it must be placed a minimum of 100 lineal feet above the perforations. DOM must approve cutting and recovering the casing. All annular spaces extending to the surface must be plugged with cement, and the innermost string of casing that reaches ground level must be cemented to a minimum depth of 50 feet below the top of the casing. Any interval not cemented must be filled with good quality, heavy drilling fluids. Finally, the surface should be restored as near as practicable to its original condition, including cutting all casing strings below ground level, capping casing strings by welding a steel plate on the stub, and removing all structures and other facilities (534A.490 NAC).

Utah

Utah is a UIC Primacy State for Class V wells. Utah's Division of Water Rights (DWR) has regulatory authority over wells used for geothermal energy production under Chapter R655 of the Utah Administrative Code (UAC), "Water Rights." Geothermal injection wells are defined as any special wells, converted producing wells, or reactivated abandoned wells used to maintain geothermal reservoir pressure; provide new material; or re-inject any material medium, residue, or by-product of geothermal resource exploration/development.

Permitting Requirements

Any person or operator who wishes to construct an injection well must submit an application form to DWR. This requirement extends to modifying an existing injection well and converting another well type to an injection well (even in cases where mechanical condition does not change). The application must contain information detailing location, elevation, and layout; lease identification and well number; a list of tools and equipment to be used; expected depth and geologic characteristics; drilling, mud, casing, and cementing plans; logging, coring, and testing plans; waste disposal plans; environmental considerations; and emergency procedures. Information contained in permit applications may be shared with other state agencies having interest in or jurisdiction over injection issues. To the extent possible, DWR will eliminate duplicative application efforts with other interested agencies, including the Bureau of Pollution Control. DWR conditions permits on a case-by-case basis (UAC R317-7-6 thru R317-7-9).

Siting and Construction

Injection wells used in geothermal operations must be located more than 100 feet from the boundary of the parcel on which the well is situated. In addition, injection wells must be more than 100 feet from a public road, street, or highway dedicated prior to the commencement of drilling. The State Engineer must approve all well spacing proposals, giving consideration to topographic characteristics of the area, hydrogeological characteristics, well interference, economic considerations, and environmental protection. Regulations also allow DWR to approve directional drilling for parcels of one acre or more whose surface is unavailable for drilling. In such cases, the surface well location may be on another property that may or may not be contiguous to the property containing the geothermal resource.

Regulations governing well construction require that all wells be cased in a manner that protects or minimizes damage to the environment, usable ground waters, geothermal resources, life, health, and property. Permanent wellhead completion equipment must be attached to the production casing or to the intermediate casing if production casing does not reach the surface. Casing strength specification is determined on a case-by-case basis. All casing reaching the surface should provide adequate anchorage for BOPE, hole pressure control, and protection of natural resources. In addition, casing should reach below all known or reasonably estimated ground water levels to prevent blowouts or uncontrolled flows (UAC R655-1-5.1).

In all areas, the operator must continuously record the drilling mud temperature, drilling mud pit level, drilling mud pump volume, drilling mud weight, drilling rate, and hydrocarbon and hydrogen sulfide gas volume. This information must be monitored after drilling out of the shoe of the conductor pipe until the well has been drilled to the total depth.

Operating Requirements

Utah's regulations also address BOPE requirements (UAC R655-1-3). For operations using mud as the drilling fluid in unexplored or unstable areas, the minimum annular BOPE working pressure is 2,000 psi, and equipment must be installed on the surface casing (UAC R655-1-3.2). The well must also have a system that shuts down all the hydraulic well components to prevent blowouts. The system should use an accumulator of sufficient capacity and a high pressure auxiliary back-up system with dual controls that allow operation at the driller's station and at least 50 feet away from the well head (UAC R655-1-3.2(c)). Operations must include a Kelly cock and standpipe valve, a fill-up line installed below the BOPE, and a blowdown line fitted with two valves installed below the BOPE (UAC R655-1-3.2(d), (g)). All lines and fittings should be steel and have a minimum working pressure of at least that required of the BOPE (UAC R655-1-3.2(h)).

In areas where dry steam exists at depth or formation pressures are less than hydrostatic, a rotating-head installed at the top of the BOPE stack is required (UAC R655-1-3.3(a)). Regulations also require a pipe-ram/blind-ram BOPE with a minimum working-pressure rating of 1,000 psi, installed below the rotating-head to facilitate shut-in at any time (UAC R655-1-3.3(b)). A banjo-box or mud-cross steam diversion unit should be installed below the BOPE and fitted with a muffler to reduce sound emissions to within state standards (UAC R655-1-3.3(c)).

In explored areas, each well must be equipped with BOPE that include high temperature-rated packing units and ram rubbers. This equipment must have a working-pressure rating equal to or greater than the lesser of: (a) a pressure equal to the depth of the BOPE anchor string in meters multiplied by 1 psi per foot, (b) a pressure equal to the rated burst pressure of the BOPE anchor string, or (c) a pressure equal to 2,000 psi. Additional requirements may be set by DWR.

Mechanical Integrity Testing

MIT is required at the discretion of DWR to prevent damage to life, health, property, and natural resources; to protect geothermal reservoirs; or to prevent the infiltration of detrimental substances into underground or surface waters suitable for beneficial uses. The regulations list the various tests that are required, including casing tests, cementing tests, and equipment tests.

Operators must conduct casing integrity testing upon completion of a new well or before converting a production well to injection, showing that the casing has "complete" integrity (UAC R655-5.2.1). Testing must be completed within 30 days after injection operations commence, and thereafter every two years. The test must "prove that all injected fluid is confined to the intended zone of injection." Operators must notify DWR 48 hours prior to testing should the department wish to observe the testing. In addition, operators must test for corrosion of well materials. Other regulations require operators to provide monthly reports of injection operations (UAC R655-5.2).

Financial Responsibility

Utah requires owners to file a bond with DWR indemnifying the state against costs of enforcing its geothermal regulations and the improper abandonment of any permitted wells. Amount of the bond is not to be less than $10,000 for each individual well, or $50,000 for statewide operations. These bonds remain in force for the life of the well(s) and will not be released until properly abandoned or substituted by another bond. Any person who acquires ownership or operation of any well is subject to the bonding requirements and must tender his own bond, or assume responsibility under an existing blanket bond.

Plugging and Abandonment

Utah's regulations pertaining to plugging and abandonment of injection wells specify that the actions taken must block interzonal migration of fluids that may contaminate fresh water and other natural resources, prevent damage to geothermal resources; prevent reservoir energy loss; and protect life, health, the environment, and property (UAC R655-1-6.1). Written notification is required 5 days before abandonment efforts commence, as well as a history of well operations within 60 days of abandonment completion (UAC R655-1-6.2 (b) and (n)). All abandoned wells must be monumented by 4-inch diameter pipe 10 feet in length, of which 4 feet are above ground. Name, number, and location of the well shall appear on the monument. When filling the wells, operators should use good quality heavy drilling fluid to replace any water in the hole and to fill all portions of the hole not plugged with cement (UAC R655-1-6.2 (i)). All cement plugs should be pumped into the hole through drill pipe or tubing, and all open annuli should be filled solid with cement to the surface. A minimum of 100 feet of cement should be emplaced straddling the interface or transition zone at the base of ground water aquifers (UAC R655-1-6.2(g)). In addition, 100 feet of cement should straddle the placement of the shoe plug on all casings, including conductor pipe. Other requirements include a surface plug of neat cement or concrete mix in place from the top of the casing to at least 50 feet below the top of the casing (UAC R655-1-6.2(i)). All casing should be cut off at least 5 feet below land surface and cement plugs should extend 50 feet over the top of any liner installed in the well (UAC R655-1-6.2(j),(k)); (UAC R655-1-6.1-- thru R655-1-6.2).

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