Examination and Evaluation of Geothermal Sites in the State of Idaho with Emphasis Given to Potential for Electrical Generation or Direct Use

Prepared for:

Idaho Department of Water Resources
1301 North Orchard Street, Boise, ID
208-327-7900
www.idwr.state.id.us

Prepared by:

Jim St. Marie
Idaho Water Resource Research Institute
University of Idaho – Boise
800 Park Blvd, Suite 200, Boise, ID

September, 2002

Funding provided in part by a grant from the U.S. Department of Energy

Table of Contents

	Page
List of Figures	4
Abstract	5
Section 1. Overview-Geothermal Power and Direct Use	7
Section 2. Regulatory Environment	9
Federal Leases	9
Geothermal Rights	9
Water Rights	9
Energy Regulation	10
Section 3. Electrical Generation	11
Dry Steam	11
Flashed Steam	11
Binary-Cycle	12
Section 4. Potential for Power Generation	15
Five Potential Sites for Power Generation	15
Crane Creek Hot Springs (Washington County)	16
Raft River KGRA (Cassia County)	19
Big Creek Hot Springs (Lemhi County)	20
Vulcan KGRA (Valley County)	22
Magic Hot Springs area (Blaine, Camas Counties)	23
Section 5. Potential for Direct-Use Projects	25
Three potential sites for direct-use applications.	25
Cascade (Valley County)	26
Lava Hot Springs (Bannock County)	29
Bruneau Dunes State Park (Owyhee County)	32
Summary for Direct Use	32
Section 6. Summary and Recommendations	35
Power Generation	35
Direct Use	36
Appendix 1. Temperature conversion	39
References	41

List of Figures

Figure	Description	Page
1	Overview map of the sites evaluated in this study	8
2	Schematic diagram of the dry-steam method of electrical generation	11
3	Schematic diagram of the flashed-steam method of electrical generation	12
4	Schematic diagram of the binary method of electrical generation	12
5	Warm water wells and a hot spring in the Cascade, Idaho Area.	26
6	Warm water wells and springs in the Lava Hot Springs Area, Idaho.	30

Abstract

Several geothermal occurrences in the state of Idaho were examined for their potential for electrical generation and direct use. Five sites were studied in detail with respect to their current conditions and developments, and the potential for future power generation projects: Crane Creek Hot Springs, Raft River, Big Creek Hot Springs, Vulcan Hot Springs KGRA, and the Magic Reservoir Hot Spring area. From this evaluation, Crane Creek Hot Springs was determined to be the best prospect for future development, in light of the current state of private-sector development at the Raft River site. The Vulcan KGRA and Big Creek Hot Springs are considered to be low priority candidates for electrical generation because of their remote locations and other conditions. Additional hydrogeologic information is needed for the Magic Reservoir area to determine the feasibility of a project in this area.

In terms of direct use of geothermal fluids, the cities of Cascade and Lava Hot Springs, and the Bruneau Dunes State Park were all determined to be suitable for new developments or expansions to existing developments. Cascade and Lava Hot Springs are prime candidates for district heating programs using geothermal resources. Bruneau Sand Dunes State Park is a prime candidate for the space heating of a proposed interpretive center using an existing geothermal well.

Idaho possesses a great number of geothermal occurrences, and future developments are not limited to the sites examined in this report. Additional potential, especially with respect to the wide range of direct-use applications, may be feasible in other geothermal resource areas throughout the state.

Section 1. Overview-Geothermal Power and Direct Use

Idaho has been gifted with a large geothermal resource, which is evidenced by the occurrence of 308 hot springs and 745 geothermal wells (IDWR, 2002). These resources were used for centuries by native Americans, and have been developed over the past 100+ years for recreation, district heating, domestic heating, aquaculture, and greenhouse operations. A geothermal power plant at Raft River in south-central Idaho generated electricity for a short time in the early 1980's as part of a United States Department of Energy test. This report describes some of the potential development projects, both power generation and direct use, that may be possible with the use of geothermal energy.

A number of sites in Idaho with geothermal power-generation potential have been examined in the past by governmental and private organizations. A literature search was conducted in the beginning phase of this study to develop initial rankings for the potential geothermal sites in Idaho.

Sites examined included areas where there are hot springs, but no geothermal wells (such as the Big Creek Hot Springs area in Lemhi County) and areas with surface occurrences and very hot wells (such as the Crane Creek area in Washington County, and the Raft River area in Cassia County). The data examined for this report included water temperature at surface and in wells, as well as geochemical data, most notably the thermometric calculations based upon the water chemistry.

The sites examined for their electricity-generation potential in the first phase of this study are (Figure 1):

- Crane Creek Hot Springs area in Washington County
  ~176° Celsius (°C) reservoir estimate, power estimates to 179 megawatts (MW).
- Raft River Known Geothermal Resource Area (KGRA) in Cassia County
  ~140°C reservoir, proven 5 MW producer.
- Big Creek Hot Springs area in Lemhi County
  ~160°C reservoir estimate, power estimates 20-50 MW
- Vulcan KGRA in Valley County
  ~150°C reservoir estimate, power estimates to 50 MW
- Magic Reservoir area in Blaine and Camas Counties
  ~149°C reservoir estimate

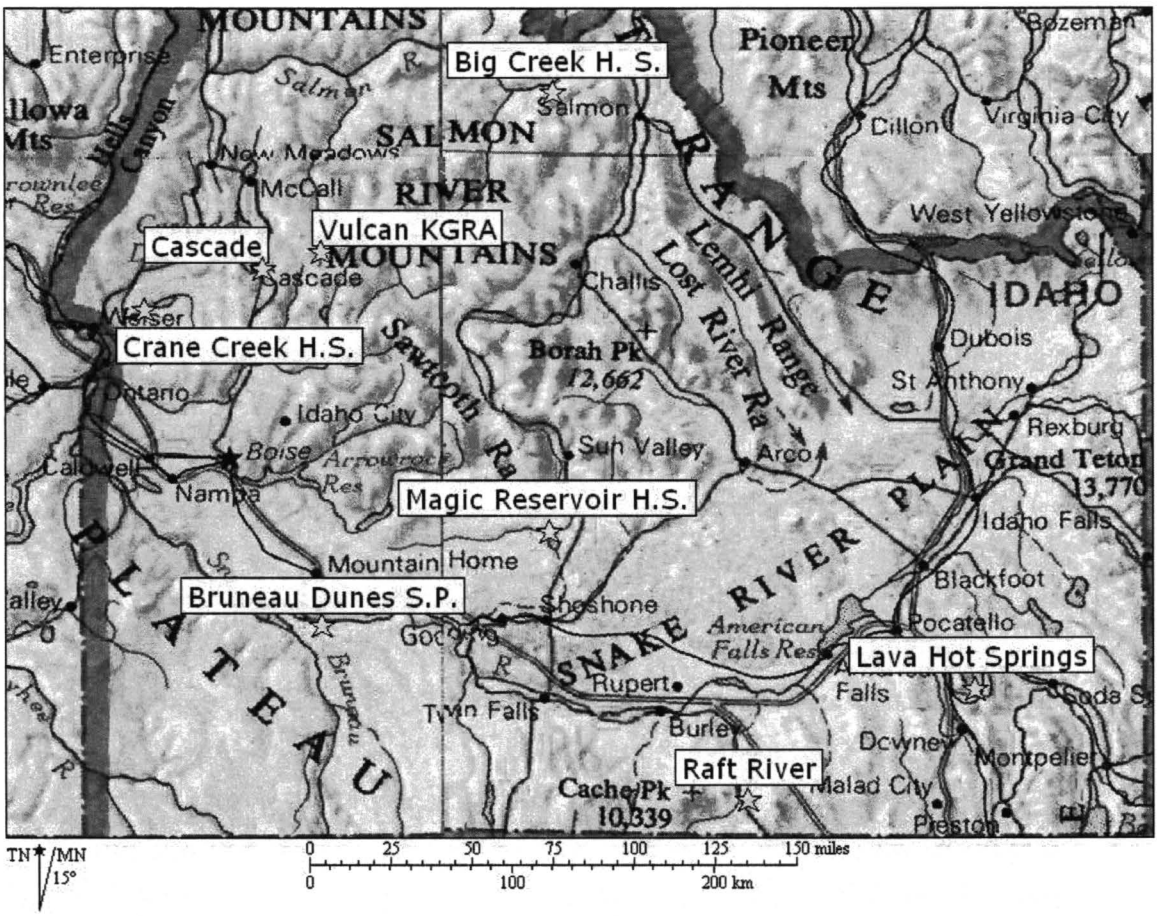


Figure 1. Location of sites examined in this study for electrical generation and direct use.

There are many sites in Idaho that have the potential for direct-use facilities. In this study, three potential sites were selected on the basis of a combination of current use, local interest, or both. The locations that were examined include (Figure 1):

- Cascade in Valley County.
- Lava Hot Springs in Bannock County.
- Bruneau Dunes State Park in Owyhee County

The sites were examined for their respective resources, and the accessibility of those resources.

Section 2. Regulatory Environment

As with any large development project, ownership of the property in question, or the permission to use the property in question, is necessary. In the case of privately-owned property, this requirement may be easily fulfilled. However, in the case of publicly-owned lands, permission must be obtained in the form of permits and leases issued by the federal agency responsible for the lands being developed. In addition to leasing issues, water rights to divert the resource must be acquired through the Idaho Department of Water Resources (IDWR).

Federal Leases

The Geothermal Steam Act of 1970 (United States Code, Title 30 Chapter 25, Sections 1001-1025) requires that geothermal leasing on National Forest System lands be subject to the consent of the United States Department of Agriculture (USDA), Forest Service, rather than the Department of Interior (Bureau of Land Management). The leases are subject to conditions prescribed by the USDA to protect the lands for the purpose for which they were withdrawn or acquired. The Department of the Interior is not authorized to issue prospecting permits for geothermal resources that might occur in National Forest System lands, but the Forest Service may issue a prospecting permit. According to the Boise office of the Bureau of Land Management, as of February 2002, there are currently no geothermal leases or claims on federal lands filed in Idaho. A check with the U.S. Forest Service in Idaho confirms that there are no geothermal leases on Forest Service land in the state.

Geothermal Rights

The Geothermal Resources Act (Idaho Code Title 42, Chapter 40) defines any ground water having a bottom-hole temperature of greater than 100°C as a "geothermal resource." Geothermal resources are put into a classification separate from water resources or mineral resources, and permits separate from those resources must be obtained for their extraction and use.

Water Rights

Article 15 of the Idaho Constitution declares that all waters within the State, both surface and ground, are "subject to the regulations and control of the state in the manner prescribed by law". In addition to leases for any development on federal land, any proposed power-generation facility would also require that water rights be conveyed by the State of Idaho. These rights would have to include any non-

thermal ground water and/or surface water used for cooling or other applications in addition to the geothermal rights.

If the surface water rights to a potential development have not been established prior to 1971 or not adjudicated in the Snake River Basin Adjudication (SRBA), the owner or developer must apply for a water right with the Idaho Department of Water Resources. If a ground water right has not been established prior to 1963 or not adjudicated in the SRBA, the owner or developer must apply with IDWR for the ground water rights. It is unlikely that any potential development would have the water rights in place considering the length of these "grandfather" periods, so the necessary water rights (surface and ground water) for potential developments must be obtained from the IDWR through an application and permitting process.

Energy Regulation

The Public Utility Regulatory Policies Act of 1978 (PURPA), Sections 201 and 210 (since amended), encourages the generation of electricity by small producers (those with a capacity of less than 80 MW), including those utilizing geothermal energy to generate electricity. Under the regulations set forth by PURPA, electric utilities are required to sell electric energy to qualifying cogeneration and small power production facilities and to purchase electrical energy from such facilities.

This 80 MW threshold should not be a problem with any of the sites examined in this study. Indeed, most estimates for electrical generation at potential Idaho sites are lower than this, although the Crane Creek area does have one estimate that is nearly two times the threshold (Bloomquist et al., 1985). Any estimates higher than the PURPA limit of 80 MW are likely to be optimistic, perhaps unreasonably so, and the actual, sustainable level of power generation will probably be much lower than estimated.

A small number of companies manufacture modular geothermal (both flash and binary-cycle) generators that can be installed quickly. Several such geothermal power plants in California and Nevada were constructed in under a year. Some companies, such as Ormat, will build and operate an electrical plant and sell the electricity to the local utility company as provided under PURPA. Other companies, such as Barber-Nichols, will provide design, manufacturing, installation, and testing services, but do not operate the finished plant. Either of these options could be attractive for a development company or a small, rural power cooperative that may or may not want to operate its own generating facility.

Section 3. Electrical Generation

There are three general methods for the geothermal generation of electricity: dry steam, flashed steam, and binary.

1. Dry Steam

The dry steam method taps an underground reservoir of high-temperature steam. The steam expands under the reduced pressure and drives a steam-turbine generator like conventional thermal power-generation plants (Figure 2). The steam is then vented or cooled, condensed, and returned to the underground reservoir via injection wells. Such a power-generation scheme requires large underground steam-filled aquifers or very hot (>260°C) water. The only dry-steam power-generation facility currently operating in the United States is The Geysers complex in California.

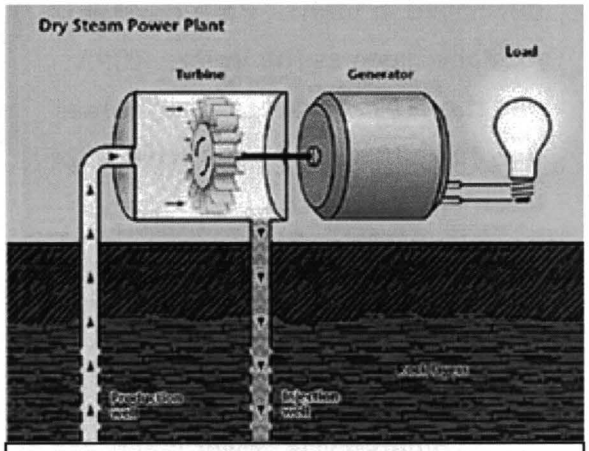


Figure 2. Dry steam electrical generation. (From DOE Geothermal Energy Program web site).

Yellowstone National Park contains dry steam reservoirs, but its status as a national park guarantees that those reservoirs will not be exploited. No such aquifers have been identified in Idaho, although the region near Yellowstone National Park, including the Island Park Caldera region in Fremont County, might contain such a resource. However, this region is sparsely populated, and few thermal wells have been drilled. Even if such a steam aquifer were discovered in the region, the proximity to Yellowstone National Park would probably preclude any development. As a result, the likelihood of developing resources using the dry steam method in Idaho is currently very low. The cost of electricity produced in this manner is approximately 4¢ and 6¢ per kilowatt-hour (kWh) (U.S. Dept. of Energy, 2001), or $40 to $60 per MW.

2. Flashed Steam

Flashed-steam power generation taps a reservoir of high-temperature (>182°C) water (U.S. Dept. of Energy, *Geothermal Today*, 1999). The decreased pressure at the surface allows some of the water to spontaneously convert (i.e., "flash"), into steam. The steam expands, is separated from the water, and is used to drive a steam-turbine generator. The steam may then be vented, or it may be cooled,

condensed and returned to the aquifer with the remaining water via injection wells (Figure 3). It is possible that a geothermal reservoir suitable for flashed steam generation could be identified and developed in Idaho. Hotter systems in Idaho, such as the Vulcan KGRA and the Big Creek Hot Springs areas may have this potential. The cost of electricity produced in this manner is approximately 4¢ to 6¢ per kWh (Dept. of Energy, 2001), or $40 to $60 per MW.

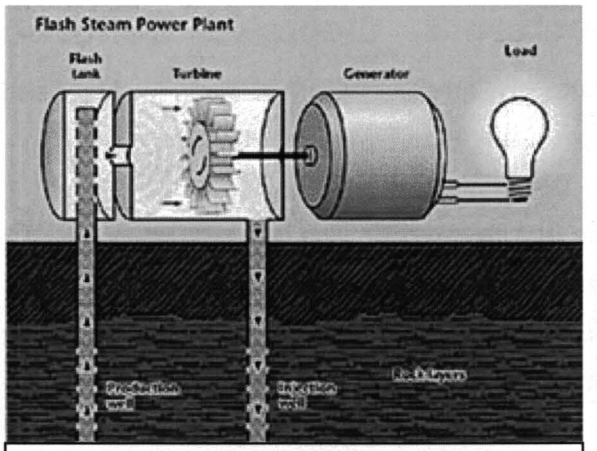


Figure 3. Flashed Steam method of generation. (From DOE Geothermal Energy Program Web Site).

3. Binary

Binary-cycle power plants are designed to use water with temperatures between 107° and 182° C (U.S. Dept. of Energy, *Geothermal Today*, 1999). The heat from the geothermal water is used to boil a second fluid, which is usually an organic compound or a mixture of compounds with a low boiling point. This "working fluid" vaporizes, expands, and drives a turbine generator. The geothermal water is injected back into the aquifer, and the working fluid is cooled, condensed, and recycled (Figure 4). Another method of binary production is to use two working fluids, one of which is pumped down a well to extract the heat from the reservoir through a down-hole heat exchanger, which is then brought back to the surface to boil the second working fluid.

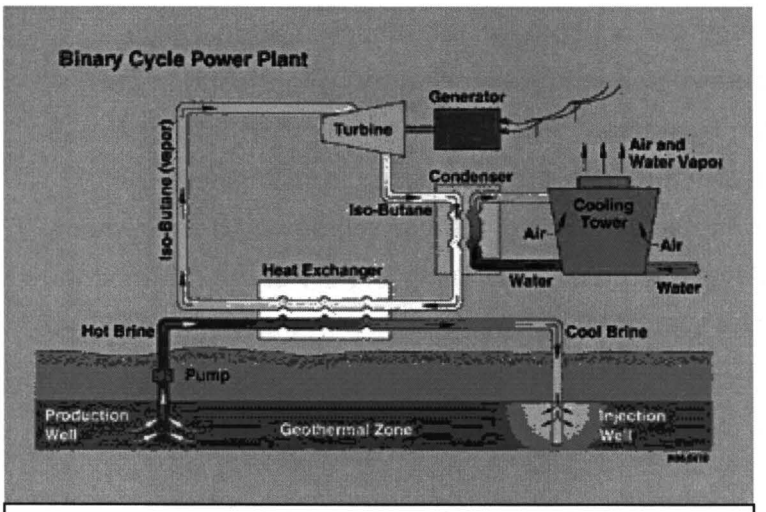


Figure 4. Binary electrical generation method. (From DOE Geothermal Energy Program Web site).

Binary generation does not require fluids as hot as the steam methods, so this method will probably be the one most widely used in the future. Binary generation is not as efficient as the steam methods, but this can be partially countered in that the geothermal fluids can be reduced to a lower working temperature, getting as much energy possible per unit volume (Armstead and Christopher, 1976). Moreover, the potentially corrosive geothermal fluid does not come into contact with the power-generating system and there is no risk of damage to the turbines. One potential problem associated with using hydrocarbon working fluids is that plants may be classified as hazardous-chemical facilities, raising insurance costs. The cost of the generated electricity runs between 5¢ and 8¢ per kW (U.S. Dept. of Energy, 2001), or $50 to $80 per MW.

Even though current Idaho residential electrical rates are lower than this rate (Idaho Power Web Site – www.idahopower.com), there would be a market for geothermally-generated electricity, because it qualifies as "green energy" (i.e., electricity generated by renewable methods with a minimum of environmental damage, which includes geothermal, as well as solar and wind power).

Size and space requirements for binary plants vary, but recently constructed plants (in Bloomquist et al., 1989, Appendices) indicate that one acre per megawatt is a good general estimate. This area includes the plant, well field, and support facilities. If cooling ponds are used instead of cooling towers for condensing the working fluid, space requirements may increase by a factor of two or more. Roughly one production well is required to provide two to three MW of electricity. Approximately one re-injection well is required for every two production wells. Actual numbers will vary depending on reservoir temperature, flow rate, etc.

Section 4. Potential for Power Generation

Several potential power-generation sites were examined in this study. The sites listed in this section were examined on the basis of the following factors:

- Location
  - Proximity to markets and/or power grids
  - Approximate population served
- Potential for electrical generation
  - Water temperature
  - Water flow rates
  - Aquifer geology
  - Sustainability of geothermal flows

These sites are presented in their ranked order with the highest potential candidate listed first. It should be noted that various estimates for total power potential have been put forth for a number of these sites in previous reports and publications, and some estimates are quite high (the highest being 179 MW for Crane Creek). However, the criteria for these estimates are rarely documented. Therefore, it is assumed that the authors of these previous reports have given their most optimistic estimates, or estimates of the potential if the entire field were to be developed. It may also be assumed that the likely sustainable power-generating capacity of these sites is some fraction of the previously estimated capacity. Significant fieldwork (geophysics, geochemical, and drilling) would be required in the pre-development and development stages to determine the true sustainable capacity of the field in question.

Five Potential Sites for Power Generation

Previous studies have centered around a small number of sites in the state which have the potential for electrical generation. These sites are considered to have potential based on their surface temperature, as well as estimates of the temperature of the reservoir using geochemical analyses. The sites examined for this study included the following:

- The Crane Creek Hot Springs area east of Weiser in Washington County
- The Raft River area southeast of Burley in Cassia County
- The Big Creek Hot Springs area west of Salmon in Lemhi County
- The Vulcan Hot Springs KGRA east of Cascade in Valley County
- The Magic Reservoir area in Camas and Blaine Counties

1. Crane Creek Hot Springs area (Washington County)

Overview

The Crane Creek Hot Springs area of Washington County is located 12 miles east of the city of Weiser in a predominantly agricultural area (Figure 1). The area was formerly designated as a KGRA with an approximate size of seven square miles (mi^2) . The springs' surface temperature has been reported at various times ranging from 74° to 77° C. Measurements at the Crane Creek Hot Springs in 2002 yielded a surface temperature of 81° C and an approximate discharge of 30 gallons per minute (gpm). McClain (1979) reported the discharge to be approximately 50 gpm, and that both the silica and Na-K-Ca geochemical thermometers suggest the reservoir temperature is 166° to 176° C. There are at least two other lower temperature hot springs in the immediate vicinity. A watering hole for cattle has been excavated over at least one spring to the west of Crane Creek Hot Springs, and another spring is being used on an adjacent property to the southwest of Crane Creek Hot Springs.

The rocks underlying the Crane Creek area are faulted and gently folded by a north-south trending fault zone (Dansart et al., 1994). In general, the geology consists of tilted blocks of older metavolcanic and metasedimentary rocks with infillings of Miocene basalt and interbedded arkosic sandstone. The aquifer supplying Crane Creek Hot Springs is likely fracture-dominated, and a combination of these different rock formations. Bloomquist et al. (1985 vol.2) calculated the aquifer volume to be 9.3 cubic miles (mi^3). A previous geophysical (audio-magnetotelluric) study by the USGS (Hoover et al., 1976) indicated the presence of a shallow conductive zone under Crane Creek Hot Springs (Young and Whitehead, 1975). This may indicate that there is either a substantial reservoir of geothermal water containing significant dissolved ions underlying the area, or that there is a large deposit of conductive minerals, probably deposited by the geothermal system. Either of these scenarios is possible, but Young and Whitehead (1975) describe the geochemistry of the thermal spring waters at Crane Creek as being Na-Cl-SO_4^{2-} with pH values of 7.1 to 8.0. It is unlikely that these waters would be responsible for large-scale metallic deposits, and so it is more likely that the conductivity anomaly below Crane Creek is due to the ionic nature of the reservoir. This study also indicated the presence of a structural "break" that trends roughly north-south, which is interpreted as a fault and is likely the conduit for the geothermal fluids.

McClain (1979) estimated the power potential to be 100 MW and Bloomquist et al. (1985, vol. 2) suggested 179 MW as the field's potential. If these estimates are accurate, the development could require between 100 and 200 acres for the

plant site; it is unknown if this much land is available for development. Additional geologic work will be required to determine the actual field potential.

Mitchell et al. (1984) performed a $\delta D/\delta^{18}O$ isotopic study that indicated the water in the springs may be of Pleistocene age. This could indicate a regional or intermediate groundwater recharge system and possibly slow recharge compared to the area's non-thermal springs. If this is the case, the suitability of the reservoir may be brought into question. However, development using a heat-exchange system as opposed to a fluid-extraction system may still be a very attractive possibility.

Site development:

The Crane Creek area is one of the best choices for a new geothermal power development project in Idaho. The location is convenient to major highways (I-84 and US-95) and to a well-developed power transmission system because of the proximity to the Idaho Power hydroelectric dams on the Snake River. The area is close to the Idaho Power electrical transmission lines coming out of the Hells Canyon dam complex. This is a series of 500kV lines emanating from the dam sites in Hells Canyon. These lines cross the region approximately 7 miles to the west-northwest while running southeast from Brownlee Dam to the Boise metropolitan area. The closest transmission substation on this series of lines is at Midvale, 11 linear miles to the north-northwest of the Crane Creek Hot Springs. The closest transmission substation to the area is in Weiser, approximately 10 linear miles to the west-southwest. However, the capacity of the power lines at the Weiser substation is only 69kV and may not be sufficient for the electric power generated at Crane Creek.

Interwest Development owns 226 acres around Crane Creek Hot Springs, including water rights on Crane Creek. This area abuts BLM land which has no current geothermal leases or claims. Interwest is currently allowing the land to be used for grazing and hopes to use the land as a game bird hunting reserve. Interwest apparently has all of the access required for development, as well as the ability to purchase the adjoining private land. Interwest is strongly favorable to development of this site for electrical generation as well as some kind of cogeneration facility (e.g., ethanol production or food processing) (Leon Blaser, personal communication).

Recommendations

1. Updated geochemistry: The temperature of the reservoir underlying Crane Creek Hot Springs has been estimated to be 160° to 170° C, depending upon the study and the geochemical thermometer used (Young and Mitchell, 1973; Young and

Whitehead, 1975). It would be advisable to conduct new chemical measurements on the water from Crane Creek Hot Springs and to re-calculate the reservoir estimate using the most recently published geothermometer formula. Even though the silica and the Na-Ca-K methods produced similar estimates for the Crane Creek Hot Springs, both methods should be used in the new study for verification purposes.

2. Geologic mapping: The area surrounding Crane Creek Hot Springs has never been geologically mapped in detail. A potential fault zone is visible in the hillside to the southwest of the hot springs in the adjoining property, and may be the fault responsible for Crane Creek Hot Springs. The area should be mapped at a scale of 1:24,000 or smaller in an attempt to reveal any structures that may be allowing geothermal fluids to flow to, or near to, the land surface. This project may be an attractive subject for a graduate-student thesis, and the possibility of graduate research support at the master's degree level should be examined.

3. Geophysical study: The previous audio- magnetotelluric study (Hoover et al., 1976) indicated a shallow conductive zone and a probable fault underlying Crane Creek Hot Springs. This study was rather rudimentary, and further geophysical studies should be undertaken to more accurately determine the subsurface structure in this area. According to Spencer and Russell (1979), the hot springs in the Crane Creek area occur on the east side of the fault zone. Geophysical study could be a very cost-effective method for locating potential drill sites.

4. If the exploratory geophysical and field mapping indicate attractive sites for detailed exploration, one or more exploration wells should be drilled to determine lithologic, structural, geochemical, and temperature information. Interwest Development is concerned with only heat extraction from the reservoir via heat exchanger rather than geothermal fluids via pumping, and the most suitable sites may be at a distance from the springs. By the same token, the areas with the highest heat flow are likely to be those with the highest fluid flow. It is likely that several wells may have to be drilled to determine the site's suitability. The depth of the exploration wells is unknown, but may be predicted using an estimated geothermal gradient. An average gradient, as measured in boreholes or in underground mines, is 2 to 3° C per 100 meters (°C/100m) (Press and Siever, 1974). A lower gradient (e.g., 1.5° C/100m) would result in a lower temperature for a given depth, and a higher gradient (e.g., 5°C/100m) would result in a higher temperature for a given depth. It can be assumed that in the immediate vicinity of the hot springs, the geothermal gradient is higher than normal, but the exact value

cannot be known for certain. Brott, 1976 indicates that the geothermal gradient for three wells in Washington County is 6° to 8° C/100m. If a similar geothermal gradient exists for the Crane Creek area, maximum reservoir temperature may be reached with a 1000 meter well (approximately 3000 feet). This estimate is entirely dependent upon the nature of the temperature gradient. It is likely that one of the reasons for the temperature drop between the reservoir and the spring output is mixing with cool near-surface groundwater. If this hypothesis is true, drilling through this mixing zone may result in a marked increase in water temperature, perhaps close to the estimated reservoir temperature.

Well-drilling can be the most expensive portion of an exploration program, with drilling costs of $20 to $25 per foot (for 6-inch wells). Therefore, drilling should commence after suitable targets have been identified.

2. Raft River KGRA (Cassia County)

Overview

The Raft River KGRA lies in Cassia County of south-central Idaho, about six miles north of the Utah border and 15 miles south of the town of Malta. It is one of the most studied geothermal systems in Idaho. The Department of Energy Idaho National Engineering and Environmental Laboratory (INEEL) operated a 5 MW test plant from the fall of 1981 to the spring of 1982. U.S. Geothermal, Inc., of Boise, is in the process of purchasing the Raft River complex from Vulcan Power of Bend, Oregon, and intends to develop the site into a commercial power plant. A few low temperature geothermal springs occur in the area, but the resource was discovered primarily by the drilling of irrigation wells, which was followed by geophysical exploration (Chappell et al., 1978). Allen, et al. (1979) gave a range of bottom-hole reservoir temperatures between 133°-150° C.

The aquifer for the Raft River KGRA is a complex mixture of Tertiary alluvial sediments, sedimentary and metasedimentary rocks, and crystalline rocks which often occur in Basin and Range terranes. Fracturing in the rock is the primary control on the flow of water. Bloomquist et al. (1985 vol. 2) estimate the volume of the aquifer underlying the Raft River KGRA to be approximately 5 mi^3. Flows from wells drilled into the aquifer vary greatly. Production ranged from about 15 gpm to 1,250 gpm (Applegate and Moens, 1980).

Site Development

Raft River is the only proven geothermal electricity producer in Idaho. McClain (1979) suggested a 100 MW potential, while Bloomquist et al. (1985)

suggested 12 MW as their best estimate for the area's potential. Based on the work done by the DOE (Bliem and Walrath, 1983), approximately 10 MW can probably be considered a very likely estimate of the field's potential, although greater output may be possible. Much of the work needed prior to full development would be those procedures necessary to pass environmental and regulatory hurdles (e.g., environmental impact statements, water and geothermal rights, etc.).

Recommendations

From the standpoint of development, the Raft River area would likely be the most favorable site in Idaho for electrical production. Much of the necessary infrastructure, including the production and injection wells, is already in place. As stated above, U.S. Geothermal Inc., is planning to develop the Raft River site for electricity generation. As a result, very few (if any) state resources would need to be expended in the development of this resource.

3. Big Creek Hot Springs (Lemhi County)

Overview

Big Creek Hot Springs are located on United States Forest Service land in Lemhi County, approximately 24 miles west-northwest of Salmon, near the Frank Church River of No Return Wilderness. Access to the area is by unimproved and primitive roads.

Big Creek Hot Springs is one of the hottest geothermal systems in Idaho, with a surface temperature of approximately 93° C, (the boiling point of water at the springs' elevation) and a discharge from fifteen vents of approximately 75 gpm (McClain, 1979). Geochemical thermometers indicate that the underground reservoir temperatures are in the 137° to 179° C range (Dansart et al., 1994). Bloomquist et al. (1985 vol. 2) offered a reservoir temperature estimate of 159° C. As such, it is a prime candidate for electrical power development using binary-cycle generation, but the remote location, potential environmental implications, and the sparse population may not justify development.

The aquifer supplying geothermal water to Big Creek Hot Springs is altered granite of the Cretaceous Idaho Batholith, and water flow is controlled by fractures in the rock. Bloomquist et al. (1985 vol.2) gave an aquifer volume value of 0.8 mi^3, based on the estimated area and thickness values used in that study, and as such, cannot be relied upon as a meaningful value. Significant research into the thickness and areal extent of the Big Creek aquifer would be required to determine a more reliable volume.

Site Development

There have been numerous estimates of the electrical potential of the Big Creek Hot Springs area, such as 11 MW (for binary cycle generation) given by Struhsacker (1981), 23 MW from Bloomquist et al. (1985), and according to McClain (1979), the field has a 50 MW potential. All of these figures probably fall into the category of "best estimates," and as a result, the sustainable power that the field can be expected to produce is unknown. Again, significant geologic work would be required to determine the size of the geothermal resource.

Recommendations

The apparent geothermal potential of the Big Creek Hot Springs area alone would make it an attractive candidate for development. However, like Vulcan Hot Springs to the west, Big Creek Hot Springs lies in a scenic, remote, and publicly-owned area. Any power generation facility would be located approximately 10 miles from the closest transmission line to tie into the Idaho Power grid. This line runs from the city of Salmon to the Blackbird mine and is rated at 68 kV.

In order to more accurately delineate the geothermal aquifer, substantial exploration work is needed. Field mapping of the area is a prerequisite to subsurface exploration. However, the value of field mapping may be limited because the bedrock is all Idaho Batholith granite, and the fractures that serve as the fluid conduits may or may not have surface expressions. However, field studies could attempt to identify zones of geothermal alteration that may indicate points of future interest. Other work would most likely consist of geophysical work to determine the nature of the fractures that serve as the fluids' conduits, and hydrogeological studies including the drilling of a number of test wells to determine the production capacity of the aquifer.

The location of Big Creek Hot Springs is probably the main barrier that will be the most challenging to overcome for the development of a power plant. In addition to the construction of the generation facilities, transmission capacity would need to be established, as well as suitable access roads to the remote location. Extensive research is needed to determine the suitability of this site for development. This site would likely require a strongly favorable outlook in terms of the technical, political, and economic factors to drive development forward. The recommendation of this study is that Big Creek Hot Springs remain under consideration, but that other, more readily developable, sites should be considered with higher priority.

4. Vulcan KGRA (Valley County)

Overview

The Vulcan Hot Springs KGRA is located in a remote area of Valley County, over 20 miles east of Cascade. Access is by paved county highway, a Forest Service road, and a 0.75-mile hiking trail. The main vent at Vulcan Hot Springs discharges roughly 500 gpm at a surface temperature of 84° C, and 12 other nearby vents add 100 gpm (Dansart et al., 1994; McClain 1979). Geochemical analysis of the springs indicates a reservoir temperature of about 150° C (Mitchell and Young, 1973). The springs form a hot creek, which has been dammed with logs and tarpaulins at a number of points to create soaking pools.

The aquifer for Vulcan Hot Springs is Cretaceous granite of the Idaho Batholith, and flow is assumed to be fracture-controlled. Bloomquist et al. (1985 vol. 2) give an aquifer volume of 0.8 mi^3, which is based upon a "best estimate" of the area and thickness since there are few data for this area.

McClain (1979) estimated the area's electrical potential at approximately 50 MW, although space limitations imposed by the area's rugged topography may limit development potential. The general lack of research data also adds uncertainty to this estimate.

Site Development

Development of the Vulcan Hot Springs KGRA would require a great deal of research and effort. This effort would require geophysical study to determine the subsurface extent of the reservoir and the conduit structures which bring the geothermal water to the surface, geochemical study of the water to confirm reservoir temperature estimates, and well-drilling and reservoir testing to determine the suitability of the reservoir for electrical power generation. Some of this work, specifically the geophysics and drilling, would require the construction of an access road to the springs' discharge area, or would require that all necessary equipment be packed in or flown in by helicopter.

Recommendations

It is unlikely that the Vulcan KGRA will ever be developed due to a number of barriers. First, it is on Forest Service land in a remote and scenic area of a sparsely populated region. Second, the springs are popular as a recreational destination, and development of the springs would probably meet with resistance from hunters, hikers, and campers. Third, the area is a salmon spawning drainage, and development may cause conflict with the Endangered Species Act and raise

objections from environmentalists. In addition, the closest transmission line to the area is about 18 miles to the north and according to an Idaho Power grid map, has a capacity of 69 kV.

Development of the Vulcan Hot Springs KGRA would likely require substantial efforts in road-building and power-transmission capacity, in addition to the actual construction of the generation facility. Any of these required elements would most likely meet with resistance from a number of interested parties, and obtaining the necessary permits would probably be extremely difficult. The recommendation of this report is that development of the Vulcan Hot Springs KGRA not be pursued at this time.

5. Magic Hot Springs area (Blaine, Camas Counties)

Overview

According to Ross (1971), Magic Hot Springs previously discharged near the north edge of Magic Reservoir at 36° C with a discharge of 130 gpm. In 1965, a 259-foot well was drilled near the site of the springs, which discharged 74° C water at a rate of 15 gpm. The springs ceased flowing after the well was completed. Geochemical analysis of the water in this well indicated a reservoir temperature of approximately 149° C (Struhsacker et al., 1984).

Local rock types are basalt, rhyolite, and sediments. The flow of water appears to be controlled by normal faults (Struhsacker et al., 1984). In general, wells drilled near major faults have higher temperature gradients and higher water yields (Dansart et al., 1994). The existence of a number of large geologic structures in the area may indicate the potential for a significant geothermal resource.

No estimates have been made with respect to the electric power potential of the Magic Hot Springs area. Additional geologic data are needed to assess the resource. This would require geophysical studies and the drilling of at least one exploration well determine flow and geothermal gradient information.

The location of the former Magic Hot Springs is approximately two miles from the closest power-transmission line, rated at 138 kV and owned by Idaho Power. The closest substation is also approximately two miles from the Magic Hot Spring location. Other power plants in the area include the Magic Dam hydroelectric project, a new gas-fired power plant, and a planned gas-fired power plant in the area.

Site Development

The Magic Hot Springs area is close to power transmission lines, and with the fossil-fuel power plants in the area, the capacity for additional generation exists. In addition to the generation facilities, the transmission lines necessary to connect the facility to the power grid would have to be erected.

Recommendations

1. Hydrologic study: The primary resource consists of a single well which dried up a single hot spring. Temperature estimates have been made for the reservoir, but there do not seem to be any data on the hydrologic qualities of the reservoir. Testing on the one thermal well should be performed to determine current flow and temperature.
2. Geophysical study: A shallow geophysical study should be performed to determine the subsurface structure, which may point the way to likely sites for exploration and/or production wells.

Section 5. Potential for Direct-Use Projects

In general, the direct use of geothermal fluids for heating, recreation, and aquaculture applications is appropriate when water temperatures are lower than those required for electrical power generation. This encompasses the entire range of low temperature geothermal resources (30 to 100° C), although heat can be extracted from fluids much cooler than that (Forcella, 1984). Of course, geothermal fluids can be extracted without utilizing the thermal energy in any way, such as irrigating crops or watering livestock. Even then, the water's heat can be an asset in the colder months. However, it can also be a detriment during the hot months.

Direct-use involves the removal of either the geothermal fluid (water + heat) from the aquifer, or just the geothermal energy (heat) itself. More complex uses, such as surface and down-hole heat exchangers and even refrigeration units also fall under this category. Some of the specific methods employed are as follows (Forcella, 1984):

1. Hydronic Heating Systems: Best when the geothermal fluid can be directly used, these heat-emitting systems (e.g., radiant panels, finned-tube baseboard convector units and forced-air systems) are commonly used for space heating. The primary drawback to these systems is that the geothermal fluid is pumped directly through the heating unit, and these fluids often contain dissolved minerals that can cause corrosion or scale deposition within the units.
2. Heat Exchangers: Heat exchangers work by extracting the heat from the geothermal fluid to warm a second fluid. The advantage to this method is that the potentially corrosive or scaling effects of the geothermal fluid are limited to one side of a system, while the radiant heating units on the other side are not affected. Heat exchangers can be operated by pumping water out of a well and into the exchanger, or down-hole exchangers can be used to remove only the heat from the water inside the well without extracting the water.

Three potential sites for direct-use applications.

It is impractical to list all of the sites in Idaho where direct-use applications could be feasible, or even attractive. There are literally hundreds of places where wells have encountered water ranging from a few degrees above mean annual surface temperature to near boiling. Many geothermal direct-use applications are already operating in the state, such as the geothermal heating of the Idaho Capitol Mall Complex, City of Boise buildings, the College of Southern Idaho in Twin Falls, Boise's Warm Springs Water District residential area, numerous greenhouses, resorts, and aquaculture facilities.

As a result, only three potential direct-use sites will be discussed in this report. The interested reader can refer to the Idaho State Geothermal maps (1978, 1994, 2002) or to the Idaho Department of Water Resources web page for information

about the resources throughout Idaho and the various uses of geothermal water in the state (www.idahogeothermal.org).

1. Cascade (Valley County)

Overview

The Cascade, Idaho area overlies a low temperature geothermal resource of unknown size. A number of wells in the vicinity have intersected geothermal fluids in the 29°-37° C range, and a number of other wells have produced water in the 20°-29° C range (Figure 5). All of the thermal wells occur in granite, west of a northeast-trending fault near the site of the now-closed Boise Cascade Corporation sawmill. A portion of the surface trace of a fault can be seen in the Payette River from the mill site. However, heavy glacial cover obscures the remainder of the trace and the orientation of the fault as it moves away from the river. It appears that the fault dips to the east-southeast, and that at least two of the hot wells occur in fractured, decomposed granite on the northwest side of the fault zone.

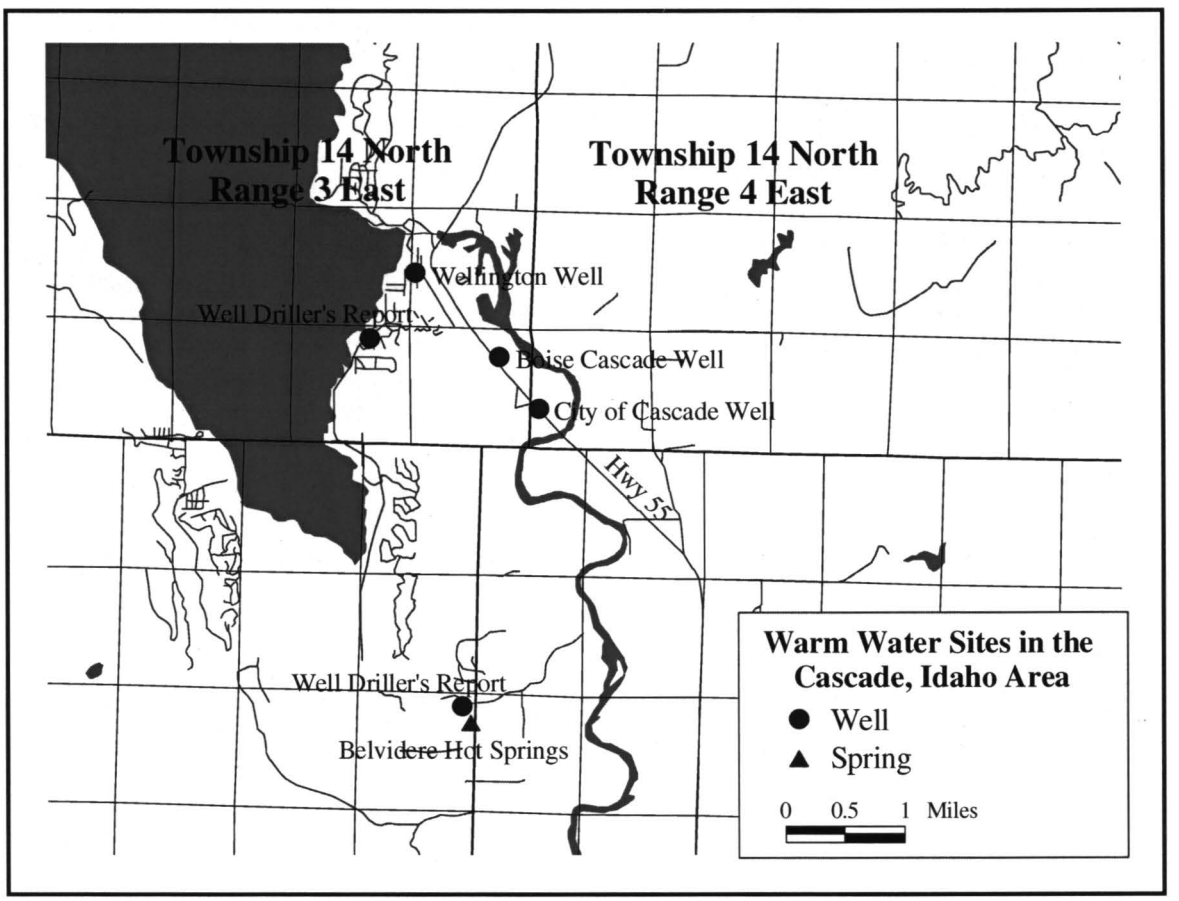


Figure 5. Warm water wells and a hot spring in the Cascade, Idaho Area.

While there are few surface hot springs in the immediate vicinity of Cascade (apart from one submerged in Cascade Reservoir), the region is home to eleven thermal springs within twelve miles of the city that are fault controlled according to Wilson et al. (1976).

Site Development

The city of Cascade has two potential sources of low temperature geothermal water for direct use applications. The first is a well drilled in the 1980's for municipal drinking water in the southern half of the city. According to Mayor Larry Walters of Cascade, this well encountered thermal water of approximately 38° C, was subsequently capped and has not been used since. This well would need to be tested for hydrologic and temperature parameters to determine if it is capable of provide heating water to the city.

The second potential resource is the thermal well on the site of the now-closed Boise Cascade corporation mill. The mill site is being decommissioned, and the future status of the mill site and its property is currently unknown. Negotiations would have to be undertaken to secure the well and its water rights for a city and/or county project.

The Valley County Recreation District is in the early stages of developing a recreation center in Cascade, including a swimming pool complex. At present, the center's projected location is at the north end of the city, near the Payette River's outflow from Cascade Reservoir. This site is approximately 1.5 miles north of the City of Cascade's hot well and 0.8 miles north of the Boise Cascade mill low temperature geothermal well. The original proposed location for the recreation center was in the city park just west of the Boise Cascade mill. This location is within 2,000 feet of the city's low temperature geothermal well and only a few hundred feet from the Boise Cascade well. The temperatures recorded in these wells would be sufficient to heat a swimming pool and associated recreational buildings if the flow is adequate and sustainable.

Another possible use for the geothermal fluids is a district heating program in the city of Cascade. The wells could serve as the head of a trunk line of geothermal fluid that would run down the central business district of Cascade where State Highway 55 passes through the city. Businesses could tap into the geothermal trunk line for heating. If there is sustainable discharge at an adequate temperature, this line could even be continued to the site of the proposed recreation center, where it could be used for space heating, and/or for use in heating the swimming pool, most

likely through a heat exchanger. At this point, the water could be discharged into the Payette River or re-injected into the aquifer system.

In addition to recreation and district heating, the potential for other applications in the Cascade area also exist. These may include greenhouse operations, aquaculture operations (e.g., tropical fish), or food dehydration.

Recommendations

The City of Cascade is a prime candidate for a district-heating program utilizing the low temperature geothermal wells in the area. This could include a business district heating program, the space heating of a proposed recreation center, or both. However, the geothermal system underlying the city seems to be rather "hit or miss," in that one well may tap a geothermal reservoir while a nearby (and deeper) well will produce cool water. Also, while most of the hot wells are close to the river, at least one well has intersected geothermal fluids at about 800 feet depth distant from the river (Ben Wellington, pers. comm., 2002). This disparity would make the development of a system of geothermal wells challenging. Also, it is unknown whether an injection well would be effective in recharging the low temperature aquifer. A study would need to be completed to determine if re-injection would benefit aquifer pressures and the possibility for thermal breakthrough at the production wells.

Exploratory geophysical work should be performed near the existing low temperature geothermal wells in order to determine if there are any structural similarities that may be used to locate and drill other geothermal wells. Each of the low temperature geothermal wells appears to be associated with a fault, but geophysical study may indicate what relationship they have to the faults, and whether they are related to the same fault or separate ones. This geophysical work would likely only need to examine the shallow subsurface (500-1000 feet), as the geothermal wells drilled so far are generally less than 350 feet deep. A widespread geophysical survey may indicate sites attractive for potential production or injection wells.

In addition to geophysical work, reservoir testing needs to be performed on the low temperature geothermal wells belonging to the City of Cascade and the Boise Corporation. This is necessary to determine if the reservoirs intersected by the wells are connected hydrologically. Seeing as how some wells in Cascade have elevated temperatures and others do not, it may be that there are a number of disconnected sources of geothermal fluids underlying Cascade. In addition, injection tests may be

performed to determine if injection of spent fluids after use would positively affect head levels in the geothermal reservoir, and if they would affect water temperatures in the production wells.

Temperature profiles are needed on the existing low temperature geothermal wells in Cascade to determine if there is a specific horizon producing the geothermal waters (although this is probably an unlikely scenario) or to determine if the temperature seen at the wellhead is a result of mixing with colder water from a different level in the well. Temperature profiles could be useful for predicting if the temperature of water from a well might be increased through the judicious use of well casing.

2. Lava Hot Springs (Bannock County)

Overview

The City of Lava Hot Springs (population ~500) is located in Bannock County approximately 30 miles southeast of Pocatello. One of Idaho's truly historic resort areas, Lava Hot Springs centers around the renowned geothermal soaking pools that were used for centuries by Native Americans and which were deeded to the state in 1902 as a health and recreation facility. The State of Idaho, through the Lava Hot Springs Foundation, currently owns and operates the springs (Figure 6). These soaking pools, along with the geothermally-heated Olympic swimming pool complex (also operated by the Lava Hot Springs Foundation), are the basis for the town's resort status. According to the IDWR water rights, the soaking pools utilize 3 cubic feet per second (cfs), which is equivalent to 1346 gpm. The water in the pools is approximately 41° C. Because the sand bottom of the soaking pools covers the spring vents, a direct temperature measurement is not practical. The well that feeds the heat exchanger for the Olympic-size swimming pool has a water right for 0.5 cfs (224 gpm). According to Mark Lowe, director of the Lava Hot Springs Foundation, this water is used only for heating the water in the swimming pool, and discharges into the Portneuf River after it is used.

A number of local businesses, primarily hotels and motels, divert geothermal water from local hot springs and from shallow (less than 100') wells for space heating and for soaking tubs and pools for their guests. In addition, many private residences have soaking tubs built over geothermal springs and wells. The majority of these sites seem to be within a couple hundred feet of the Portneuf River (Figure 6).

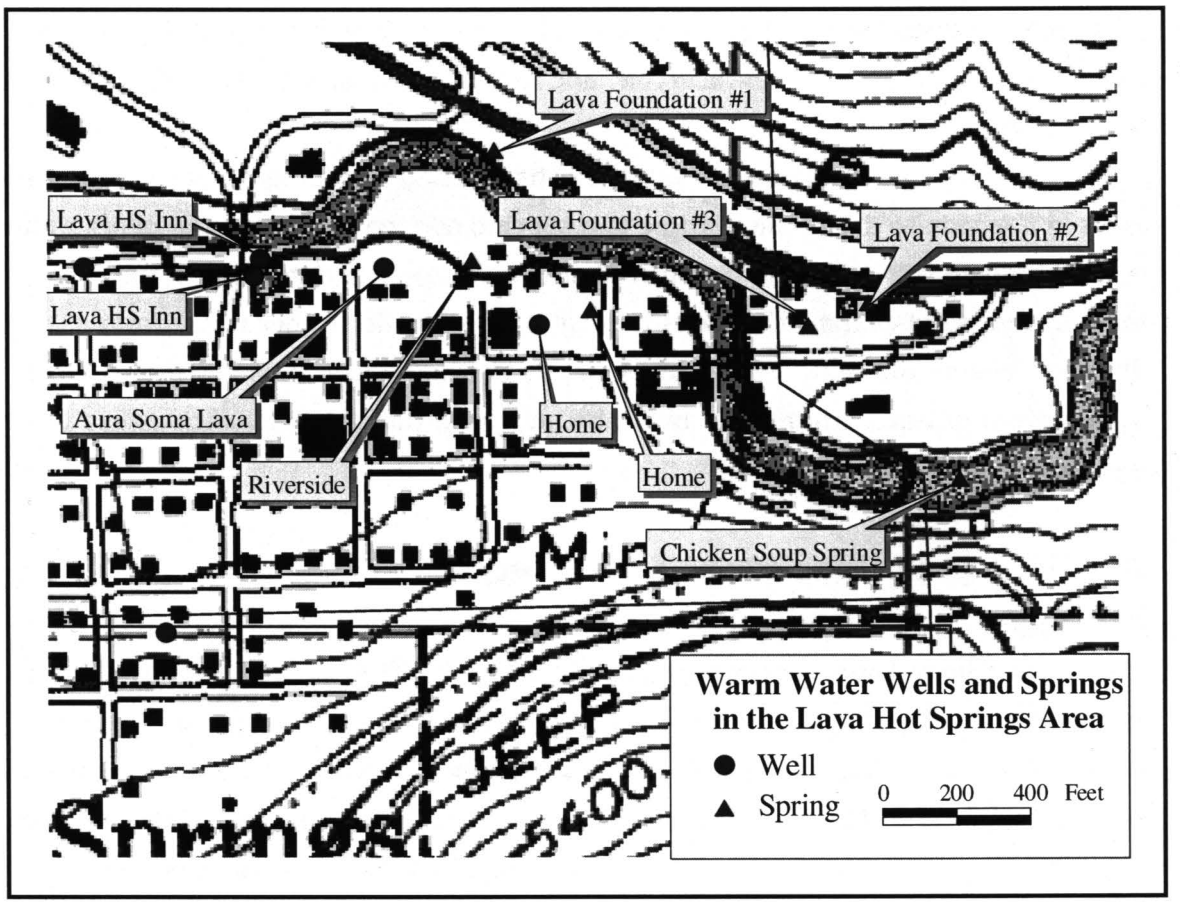


Figure 6. Warm water wells and springs in the Lava Hot Springs Area, Idaho.

At one time, the City of Lava Hot Springs piped geothermal water from the Chicken Soup Spring (the name used by local residents) just east of town. A well was drilled at the Chicken Soup spring to provide water for the city. This well was washed out when the Portneuf River flooded some years ago (none of the local residents spoken to during the reconnaissance trip were able to remember the exact year). The spring discharges from the riverbank with an estimated flow of 1.5 cfs (673 gpm). The temperature of the water was 47° C in August, 2002. The spring is at the end of a dirt road and a dilapidated chain-link fence partially surrounds the site. Schwarze (1960) describes a series of north-south trending normal faults in the area. These faults are likely candidates for the geothermal fluid conduits. However, the hydrogeology of the geothermal system in the Lava Hot Springs area has not been studied in detail and, therefore, is poorly understood.

Site Development

The city of Lava Hot Springs has potential for a space heating project and a district heating program. Mark Lowe indicated that the Community Center, located

on the north side of the river, might be re-fitted for geothermal heat. The line from State Pump House #1 runs north of the Community Center and into the Olympic swimming pool. It may be possible to tap into this line and deliver geothermal water to heat the Community Center.

The Chicken Soup spring, which was previously used for recreation and snow melt, could again be used as a source of geothermal fluids for the town for heating a small number of buildings in the city's downtown area, depending upon the water rights that could be obtained for the spring. The City of Lava Hot Springs has constructed a pipeline from the Chicken Soup Springs to the Lava Spa Motel, and has a lease with this facility to deliver 40 gpm to be used in hot tubs. However, the Lava Spa Motel has not purchased hot tubs so the water is currently returned to the river from the pipeline.

It is strongly recommended that any new development does not divert more water than is currently being discharged by the spring. Any additional development of the geothermal resource underlying the city must be prefaced with a thorough hydrogeological study of the resource. The reason for this is plain: The economic survival of the city is intimately tied to the geothermal resource. Any alteration, however minor, to the geothermal resource could result in an economic damage to the city and its residents, especially if the flow to the soaking pools of the Lava Hot Springs Foundation were reduced. A technical study would require the drilling of a number of test and monitoring wells and the performance of well-interference tests. If such a study shows that additional water can be withdrawn without damaging the flow to the resort, hotels, and local residents, then further exploitation of the resource may be feasible.

Recommendations

The city of Lava Hot Springs sits on a highly attractive geothermal resource. However, the intimate economic ties that the city has to that resource make it difficult to recommend further development because of the potential effects on the existing uses. This is not a simple case of conflicting water rights, but a potential irreversible damage to the city's livelihood. However, the water discharging into the Portneuf River from Chicken Soup Spring is presently unused, and utilization at its current discharge rate would not adversely affect the city's geothermal resource. The discharge should be enough to heat at least one building, if not several buildings, in the downtown area. Candidates for heating may include City buildings, the Lava Hot Springs Museum, or other public buildings. A hydrogeologic study of

the geothermal resource in this area must be conducted as an initial phase of a district-heating project.

A study of the resource was performed by G. Bloomquist of Washington State University, but the results of that study have not yet been received by the IWRRI or the IDWR.

3. Bruneau Dunes State Park (Owyhee County)

Overview

The Idaho Department of Parks and Recreation (IDP&R) operates the Bruneau Dunes State Park in Owyhee County. A low temperature geothermal well in the park is currently being used for irrigation. The IDP&R would like to develop this resource for heating a new interpretive center. The well is 990 feet deep, and has a temperature of approximately 37° C. The discharge listed on the IDWR Well Driller's Report is 132 gpm.

Aaron Boston, IDP&R Engineer, indicated that this well is prone to severe drawdown during the summer months, with subsequent recharge to "normal" levels during the winter and spring; this seasonal fluctuation may affect the discharge rate. According to Mr. Boston, the temperature of the well does not seem to vary greatly through this cycle. There may be reasons for this pattern. First, the IDP&R may be pumping too much water from the well. Therefore, use of the water from this well for heating may require the drilling of another well for irrigation. Second, the aquifer may be unconfined, with significant surface recharge due to infiltration of rainwater and snowmelt in the wet months. This may indicate a source of geothermal heat that is independent of the source of the water. If so, a system of down-hole heat exchangers might be used to heat the park buildings.

Recommendations

According to IDP&R Engineer Aaron Boston, the Department of Parks and Recreation is not currently ready for this type of development. However, some preliminary work could be accomplished now in preparation for future development. The use of geothermal by a state agency in a scientific interpretive center would project a favorable image of geothermal heat in Idaho.

Summary for Direct Use

The Cascade, Lava Hot Springs, and Bruneau Sand Dunes sites are the leading candidates for direct-use development projects in Idaho. The potential for development at these sites is fair to excellent. However, each site has barriers to development that will have to be overcome before district heating or other direct use

applications become a reality. In addition to these three sites, a number of other places in Idaho have been studied for district heating projects. Contact the Idaho Department of Water Resources (208-327-7900 or geothermalinfo@idwr.state.id.us) for a listing of these sites, or for additional information about the potential for geothermal direct use in your area of interest.

Section 6. Summary and Recommendations

Power Generation

Idaho has one site, Raft River, where power generation was successful for a short time in the 1980's. Raft River and four other sites were studied for their current power generation potential.

1. Crane Creek

The Crane Creek site in Washington County has high potential for a future power generation facility, but much technical work is needed to prove the resource.

Recommendations for Technical Work:

a. Cost benefits analysis for determining the feasibility of a power plant, and secondary (direct) use of the geothermal resources.
b. Updated geochemical study of the waters of Crane Creek Hot Springs.
c. Geophysical studies of the Crane Creek Hot Springs area.
d. Detail geologic mapping of the Crane Creek Hot Springs area.
e. Exploratory drilling in the Crane Creek Hot Springs area **if** prior geophysical work and mapping indicate a favorable situation.

2. Raft River

The Raft River site in Cassia County is being developed by U.S Geothermal, Inc. No technical work needs to be done by the State of Idaho at this time at the Raft River site.

3. Big Creek Hot Springs

The Big Creek site should remain under consideration for electrical development, but no technical work should be directed toward this site until the higher-priority Crane Creek site has been investigated.

4. Vulcan Hot Springs KGRA

No technical work should be pursued at the Vulcan KGRA at this time by IDWR.

5. Magic Reservoir Area

The Magic Reservoir site in Blaine and Camas Counties has very limited hydrogeologic information available at this time. Additional studies to determine the potential of this area can commence after the higher-priority Crane Creek area has been investigated.

Recommendations for Technical Work:

a. Hydrologic study of the Magic Reservoir Hot Springs area.
b. Geophysical study of the Magic Reservoir Hot Springs area.

Direct Use

Direct use projects are common throughout southern Idaho. District heating, domestic heating, heating of commercial businesses, recreation, and aquaculture are all current uses of low temperature geothermal resources. Three sites were examined in detail for potential new or expanded developments.

1. Cascade

The Cascade area has proven geothermal resources as evident by the existence of several wells with water temperatures in the 29°-37° C range. However, the capacity of the reservoir system is unknown at this time. The Cascade area has the highest development potential for direct use at this time, and investigations should begin as soon as possible due to a possible window of opportunity with the decommissioning of the Boise Cascade site.

Recommendations for Technical Work:

a. Cost Benefits analysis to assist the City with planning for new development.
b. Geophysical study of the Cascade area.
c. Determination of the availability of resources by thorough reservoir testing (pump tests, temperature profiles, re-injection potential, thermal breakthrough investigations).

2. Lava Hot Springs

The Lava Hot Springs area has proven geothermal resources that are currently being used for heating and recreation. Additional development of the resources could be accomplished by using both the existing Lava Hot Springs Foundation pipeline, and the unused Chicken Soup Spring. This development will not require any new withdrawals from the aquifer system, but would use existing water rights. Technical work with respect to the reservoir is not needed unless additional withdrawals are proposed. However, technical work is needed to determine how to use the water from the Lava Hot Springs Foundation and the Chicken Soup Spring to heat local buildings

Recommendations for Technical Work:

a. Determine the infrastructure changes needed to provide geothermal heat to the Community Center.
b. Determine the infrastructure changes needed to supply geothermal water from the Chicken Soup Springs to downtown buildings on the south side of the river.

3. Bruneau Dunes State Park

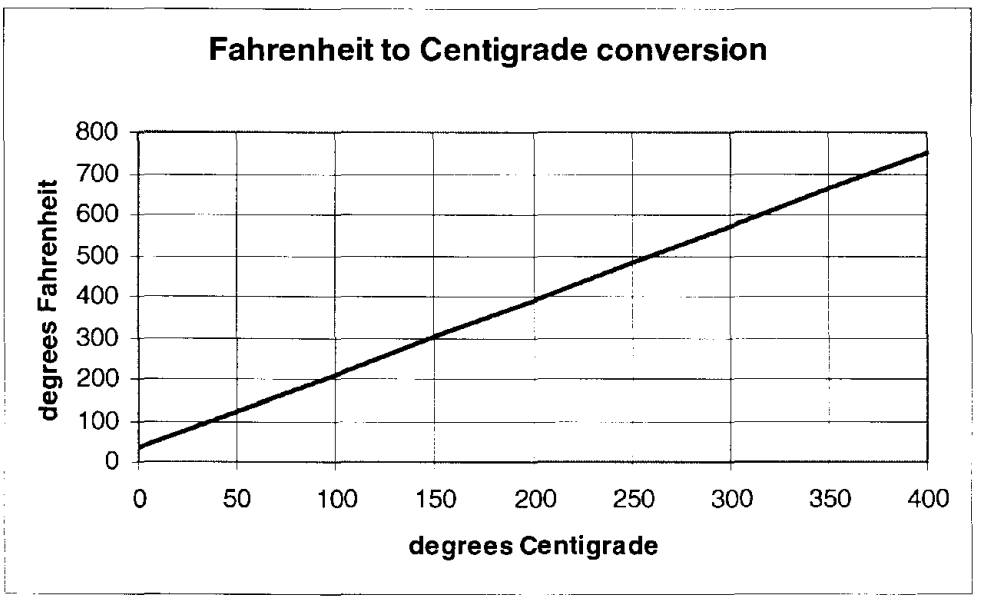
The Bruneau Dunes State Park has a proven low temperature geothermal resource and a desire to use that resource for heating a proposed new interpretive center.

Recommendations for Technical Work:

Investigate heating methods which would be best used in conjunction with the existing low-temperature thermal well in the park and with the new interpretive center.

Appendix 1. Temperature Conversion

Temperatures are given in various reports and publications in either Centigrade or Celsius (metric) scale or in Fahrenheit (imperial) scale. In this report, temperatures are reported in Centigrade. Conversions are based upon the relation **°F = 1.8°C + 32**. The chart below depicts the temperature relations. The boiling point of water is 100°C, or 212°F. The elevated pressure below the surface of the earth inhibits boiling, and the temperatures of subsurface geothermal fluids can be far in excess of the boiling point of water.



References

Allen, C.A., Chaney, R.E., and McAtee, R.E., 1979, Geochemical Modeling at Raft River, *in* Transactions of the Geothermal Resources Council (Volume Three) Annual Meeting, pp. 1-4.

Applegate, J.K. and Moens, T.A., 1980, *Geophysical Logging Case History of the Raft River Geothermal System, Idaho*, Los Alamos Scientific Laboratory Informal Report, 30 pp.

Armstead, H. and Christopher, H., 1976, Summary of Section VII Electricity Production, *Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources* (San Francisco), pp. ciii-cx.

Bloomquist, R.G., Black, G.L., Parker, D.S., Sifford, A., Simpson, S.J., and Street, L.V., 1985, *Evaluation and Ranking of Geothermal Resources for Electrical Generation or Electrical Offset in Idaho, Montana, Oregon and Washington*, Bonneville Power Administration Resource Assessment, 2 volumes.

Bloomquist, R.G., Geyer, J.D. and Sifford B.A., 1989, Innovative Design of New Geothermal Generating Plants, Bonneville Power Administration.

Bliem, C.J. and Walrath, L.F., 1983, Raft River binary-cycle geothermal pilot plant final report: EG&G Idaho, Inc. Report EGG-2208.

Boston, Aaron, 2002 personal communication.

Brott, C.A., Heat Flow and Tectonics of the Snake River Plain, Idaho, Geothermal Investigations in Idaho, Part 8, Idaho Department of Water Resources Water Information Bulletin No. 30, 195 pp..

Chappell, R.N., Griffith, J.L., Knowles, W.R., and Schultz, R.J., 1978, The Multi-Purpose Geothermal Test and Experimental Activities at Raft River, Idaho, *in* Geothermal Resources Council, TRANSACTIONS, Vol. 2, pp. 83-85.

Dansart,, W.J., Kauffman, J.D., and Mink, L.L., 1994, Overview of Geothermal Investigations in Idaho, 1980 to 1993, Idaho Water Resources Research Institute research technical completion report, 79 pp.

Forcella, L.S., 1984, *Low Temperature Geothermal Resource Management*, Oregon Department of Energy Report, 28 pp.

Gawlik, K. and Kutscher, C., 2000, Investigation of the Opportunity for Small-Scale Geothermal Power Plants in the Western United States (Draft), National Renewable Energy Laboratory, 49p.

Hoover, D.B., Brougham, G.W., and Clark, J.C., 1976, Station and traverse location map, audio-magnetotelluric data log, and telluric profiles for Crane Creek Known Geothermal Resource Area, Idaho, United States Geological Survey Open-File Report #76-409.

Idaho Code, Article 42, Chapter 40.

Idaho Department of Water Resources, 2002, Geothermal Resources: Idaho Department of Water Resources website, (http://www.idwr.state.id.us/planpol/techserv/gwmon/geotherm.htm)

Idaho State Constitution, Article 15.

Idaho State Geothermal Map, 1978, 1994, 2002

Lowe, M., 2002, personal communication.

Mabey, D.R., 1983, Geothermal resources of southern Idaho: U.S. Geological Survey Circular 866, 24 p.

McClain, D.V., 1979, Geothermal Energy in Idaho: Site Data Base and Development Status, OIT Geo-Heat Utilization Center & Idaho Energy Office.

Mitchell, J.C., Johnson, L.L., and Anderson, J.E., 1980, *Geothermal Investigations in Idaho Part 9:* Potential for Direct Heat Application of Geothermal Resources, Idaho Department of Water Resources Water Information Bulletin No. 30.

Mitchell, J.C., Bideganeta, K., and Palmer, M.A., 1984, Stable Isotopic Evaluation of Thermal Water Occurrences in the Weiser and Little Salmon River Drainage Basins and Adjacent Areas, West-Central Idaho with Attendant Gravity and Magnetic Data on the Weiser Area, Idaho Department of Water Resources Water Information Bulletin No. 30.

Muffler, L.J.P. (editor), 1979, Assessment of geothermal resources of the United States – 1978: United States Geologic Survey Circular 790, 163 pp.

Press, F., and Siever, R.R., 1974 *Earth*, W.H. Freeman, 649 pp.

Ross, S.H., 1971, Geothermal potential of Idaho, Idaho Bureau of Mines and Geology Pamphlet No. 150, 72 pp.

Schwarze, D.M., 1960, *The Geology of the Lava Hot Springs Area, Idaho,* Occasional Papers of the Museum of Idaho State College, No. 4, 51pp.

Spencer, S.G. and Russell, B.F. (eds.), 1979, *Crane Creek KGRA: An Environmental Analysis*, EG&G Idaho, 117 pp.

Spencer, S.G. and Russell, B.F., 1979, *Vulcan Hot Springs KGRA: An Environmental Analysis*, EG&G Idaho, Inc., 125pp.

Struhsacker, D.W., Jewell, P.W., Zeisloft, J., and Evans, S.H., Jr., 1984, The Geology and Geothermal Setting of the Magic Reservoir Area, Blaine and Camas Counties, Idaho.

United States Code, Title 30 Chapter 25, Sections 1001-1025 (Geothermal Steam Act of 1970)

United States Department of Energy, 1999, *Geothermal Today* (1999 Geothermal Energy Program Highlights), 36 pp.

United States Department of Energy, Geothermal Energy Program World Wide Web Site, 2001. (www.eren.doe.gov/geothermal/)

Walters, Larry, 2002, personal communication.

Wellington, Ben, 2002, personal communication.

Wilson, M.D., Applegate, J.K., Chapman, S.L., and Donaldson, P.R., 1976, *Geothermal Investigation of the Cascade, Idaho area*, Department of Geology and Geophysics, Boise State University, 44 pp.

Young, H.W., 1985, Geochemistry and Hydrology of Thermal Springs in the Idaho Batholith and Adjacent Areas, Central Idaho, USGS Water-Resources Investigations Report 85-4172.

Young, H.W., and Mitchell, J.C., 1973, *Geothermal Investigations in Idaho Part 1, Geology and Geochemistry*, Idaho Department of Water Resources Bulletin No. 30.

Young, H.W., and Whitehead, R.L., 1975, Geothermal Investigations in Idaho, Part 3, An evaluation of thermal water in the Weiser area, Idaho, Idaho Department of Water Resources Water Information Bulletin No. 30.

Cost associated with this publication are available from
the Idaho Department of Water Resources
in accordance with Section 60-202, Idaho Code.
IDWR, 10/02