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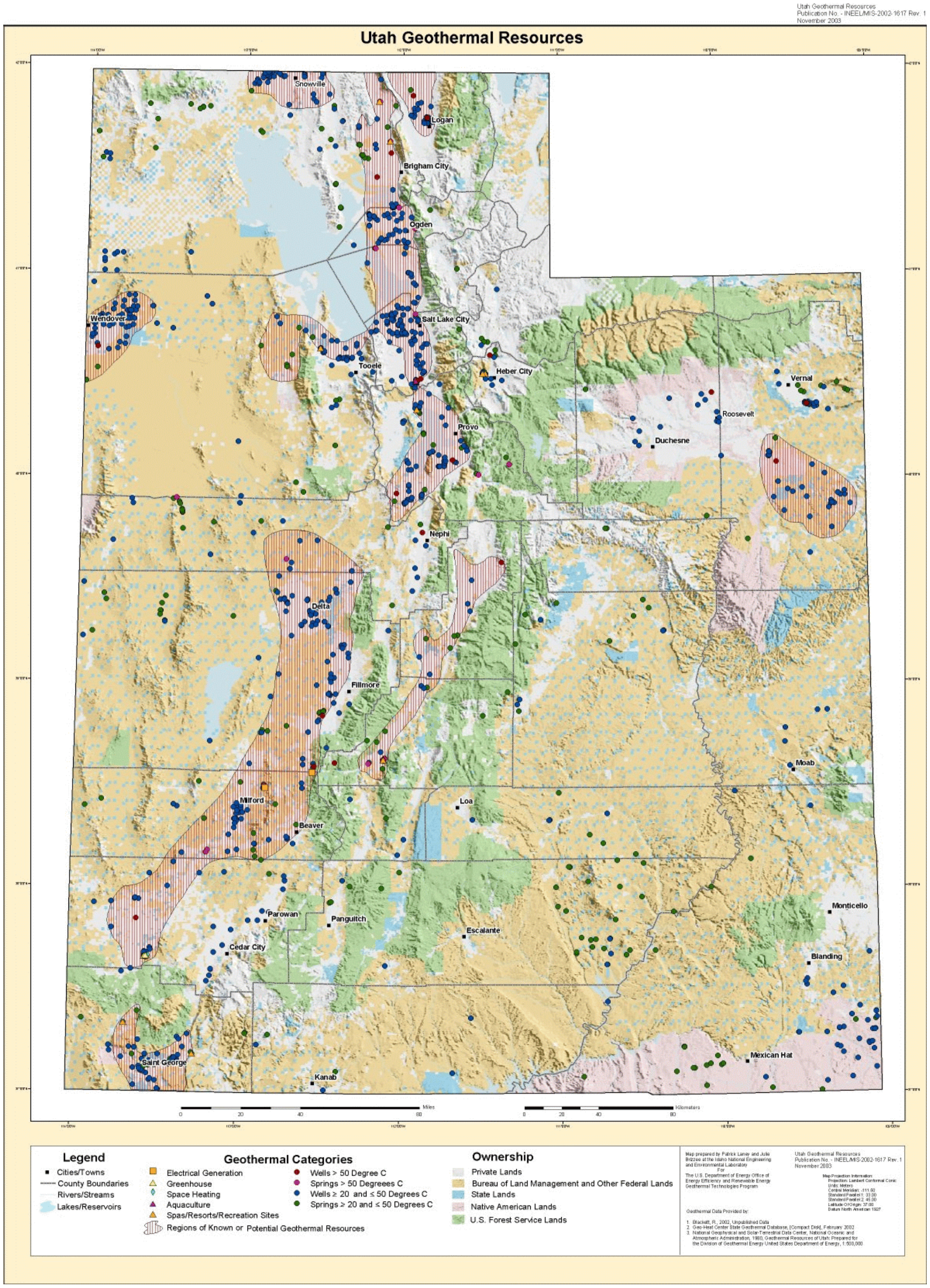

UTAH GEOTHERMAL RESOURCES & UTILIZATION

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A Quarterly Progress and Development Report
on the Direct Utilization of Geothermal Resources

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Oregon Institute of Technology
3201 Campus Drive
Klmath Falls, OR 97601
Phone: 541-885-1750
Email: geoheat@oit.edu

All articles for the Bulletin are solicited. If you wish to contribute a paper, please contact the editor at the above address.

EDITOR

John W. Lund
Typesetting/Layout - Donna Gibson
Graphics - Tonya "Toni" Boyd

WEBSITE http://geoheat.oit.edu

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GEOTHERMAL RESOURCES AND UTILIZATION IN UTAH

This issue of the *Geo-Heat Center Quarterly Bulletin*, is the third in our series of state summaries of their geothermal resources and utilization. Previous reports covered: South Dakota (Vol. 18, No. 4 - December 1997); and New Mexico (Vol. 23, No. 4 - December 2002). We also covered, in very general terms, direct-uses in California in Vol. 24, No. 1 (March 2003). This report on Utah, covers both electric power generation and direct-use - one of the four states that is presently producing power from geothermal resources. As can be seen from the cover map and the map in the following article, most of the geothermal resources in the state are located just to the west of the Wasatch Range, in an arc down through the middle of the state. This is the start of the Basin and Range physiographic province that extends all the way to southern Oregon and Klamath Falls.

Utah has one of the largest geothermally-heated greenhouses at Milgro near Newcastle, covering over 24 acres, growing crysanthiums, poinsettia, calilysis and tulips. The state also has a unique use, that of SCUBA dive pools, at three locations. These pools, two over 60 feet (18 m) deep, are used to certify divers, as there are no deep lakes or oceans that can be conveniently used. One of these pools, Bonneville Sea Base, also has 100 different types of fish, including sharks, to view while swimming. Another dive pool, The Crater at Homestead Resort near Midway, is inside a 55 foot high by 400 feet in diameter (17 m by 122 m) tufa (travertine) dome, with a 110-foot (33.5-m) tunnel cut in the side for access. It was originally called Schneitter's Hot Pot when used in the1860s. The third dive pool is in the very northern edge of the state north of Garland and Tremonton, formerly Belmont or Udy Hot Springs, is now run by Camperworld. The outdoor pond, only 30 feet (9 m) deep, is adjacent to areas where lobsters and crayfish were originally raised commercially in the geothermal water for the local market.

The three main sources of geothermal resource information and research are from the Utah Geological Survey (http://geology.utah.gov), the Utah Energy Office (www.energy.utah.gov), or the Energy and Geoscience Institute (formally Earth Sciences and Research Institute) at the University of Utah (www.egi.utah.edu), all in Salt Lake City. A new state geothermal map (reproduced on the cover of this issue) was recently published by the Idaho National Engineering and Environmental Laboratory (INEEL) for the USDOE. This 21- by 24-in. map, shows not only the various geothermal uses in the state, but also public land ownership, and areas that have a potential for geothermal electric generation and direct-use applications. Copies can be obtained at INEEL from Patrick Laney (email: ptl@ineel.gov; phone: 208-526-7468) or online at: geothermal.id.doe.gov/maps/ut.jpg.

I was fortunate to have the expert assistance of Bob Blackett of the Utah Geological Survey, during a week-long tour of the Utah geothermal use sites last summer. Much of the information and photographs in this issue are from that visit. Most of the geological descriptions of the various resources are based on compilations by Bob Blackett. Bob is also the contact person for the recently formed Utah Geothermal State Working Group established under the USDOE *GeoPowering the West* initiative. He provides frequent updates on geothermal activities in the state, and can be contacted at: Blackett@suu.edu.

Finally, the most elementary use of geothermal energy that I saw on my trip, was a transient sitting on a rock in a geothermal stream in sight of the State Capitol Building at Wasatch Warm Springs (on the northern edge of Salt Lake City), shaving. The hot water was free.

-- The Editor

GEOTHERMAL RESOURCES OF UTAH
- AN OVERVIEW -

PHYSIOGRAPHIC REGIONS

Utah comprises parts of three major physiographic provinces (Fenneman, 1931), each with characteristic landforms and geology (Figure 1). These include the Basin and Range Province, the Middle Rocky Mountains Province, and the Colorado Plateau Province. An overlapping of two of these provinces essentially forms a fourth distinctive physiographic region. The Basin and Range-Colorado Plateau Transition Zone extends through central and southwestern Utah, and contains physiographic and geologic features similar to both the Basin and Range and Colorado Plateau Provinces. The physiographic regions of Utah are also shown in Figure 2.

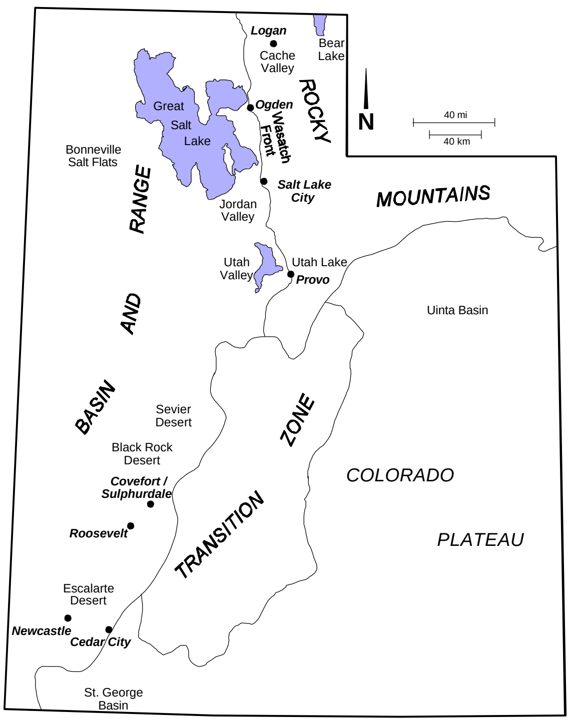

Figure 1. ***Physiographic provinces of Utah (Utah Geological Survey, Open File Report 311, 1994).***

The Middle Rocky Mountains Province in northeastern Utah consists of mountainous terrain, stream valleys, and alluvial basins. It includes the north-south trending Wasatch Range, comprising mainly pre-Cenozoic sedimentary and Cenozoic silicic plutonic rocks, and the east-west trending Uinta Mountains, comprising mainly Precambrian sedimentary and metamorphic rocks.

The Colorado Plateau is a broad area of regional uplift in southeastern and south-central Utah characterized by essentially flat-lying, Mesozoic and Paleozoic sedimentary rocks. Scattered Tertiary and Quaternary volcanic rocks are present on the western margin of the Colorado Plateau in south-central Utah, and some Tertiary intrusive bodies are present in southeastern Utah. Plateaus, buttes, mesas, and deeply incised canyons exposing flat-lying or gently warped strata distinguish the Colorado Plateau of southeastern Utah. Bedrock units are spectacularly exposed, while surficial deposits are sparse.

The Basin and Range Province is noted for numerous north-south oriented, fault-tilted mountain ranges separated by intervening, broad, sediment filled basins. The mountain ranges are typically 20 to 50 km (12 to 31 mi) apart, 45 to 80 km (28 to 50 mi) long and are bounded on one, or sometimes two sides by high-angle, often listric, normal faults. Typical ranges are asymmetric in cross section, having a steep slope on one side and a gentle slope on the other. The steep slope reflects an erosion-modified fault scarp and the range is a tilted fault block (Hintze, 1988). Rocks within the Basin and Range vary widely in age and composition. Older rocks consist mostly of a variety of Mesozoic and Paleozoic sedimentary units and their metamorphic equivalents. Proterozoic-age rocks have limited exposures in the region. Cenozoic volcanic rocks and valley-fill units generally overlie the sedimentary and metamorphic rocks. Valley-fill deposits consist mostly of late Cenozoic lakebeds and alluvium as much as 3,000 m (10,000 ft) thick.

The Transition Zone is a broad region in central Utah containing structural and stratigraphic characteristics of both the Basin and Range Province to the west and the Colorado Plateau Province to the east. The boundaries of the Zone are the subject of some disagreement, resulting in various interpretations using different criteria (Stokes, 1988). Essentially, extensional tectonics of the Basin and Range has been superimposed upon the adjacent coeval uplifted blocks of the Colorado Plateau and Middle Rocky Mountains. The result is that block faulting, the principal feature of the Basin and Range, extends tens of kilometers into the adjacent provinces forming a 100-km- (62-mi-) wide zone of transitional tectonics, structure, and physiography (Hecker, 1993; Black, et al., 2003).

LATE CENOZOIC TECTONICS IN UTAH

Comprising essentially the western half of Utah, the Basin and Range Province is separated from the Middle Rocky Mountains by the Wasatch Fault Zone in northern Utah, and from the Colorado Plateau by the Transition Zone in central and southern Utah (Figure 2). Within the Basin and Range and the Transition Zone, east-west structural extension is thought to have taken place over the past 17 million years (Hintze, 1988) creating numerous north-south-oriented, fault-bounded blocks. Prior to Basin and Range extension (during

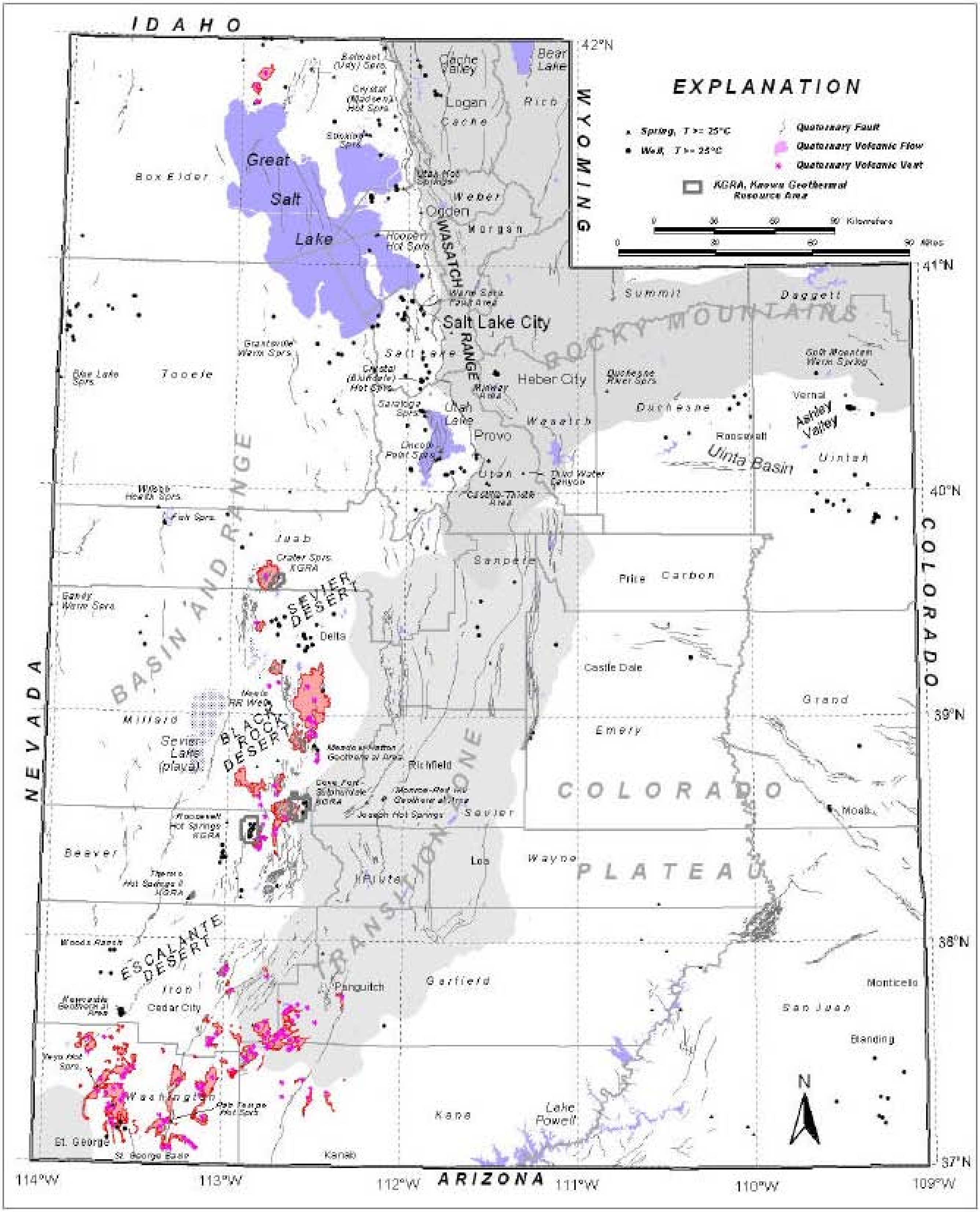

Figure 2. *Geothermal resources of Utah showing thermal wells and springs. Quaternary tectonic and volcanic features, and major physiographic regions.*

mid-Cenozoic time), voluminous silicic volcanism with associated hydrothermal activity took place within several east-west trending belts (Stewart, et al., 1977). Patterns of volcanism changed during the latter stages of the Basin and Range development to less-voluminous basalt and rhyolite (bimodal assemblage), spatially controlled by north-south Basin and Range faults.

Quaternary Faults

Tectonically active regions typically have abundant active geothermal systems as fault movement fractures bedrock, thereby opening potential fluid pathways. In areas of active tectonism, meteoric water has more opportunity to circulate deep and absorb thermal energy from the surrounding rocks. Hecker (1993) presents a detailed review of the Quaternary tectonic activity in Utah and describes the potential for earthquake-related hazards in the state. Utah is in a tectonically active region where the Intermountain Seismic Belt (ISB), a north-trending zone of historical seismicity, bisects the state. The ISB coincides with the broad transitional eastern margin (including the Transition Zone) of the Basin and Range Province, extending from southern Nevada, through Utah, southeastern Idaho, western Wyoming, and into central Montana. It includes the major active faults of Utah, such as the Wasatch fault system in northern Utah, and the Hurricane and Sevier faults in southern Utah and northern Arizona (Figure 2).

Quaternary Volcanic Rocks

Recent igneous activity may provide local, high-level, heat sources for geothermal systems. As a result, the distribution and timing of volcanic events is important for assessing the geothermal potential of a region. Hecker (1993) summarizes previous work (Best,et al., 1980; Hoover, 1974; Clark, 1977; Lipman, et al., 1978; Nash, 1986; Anderson, 1988; and Anderson and Christenson, 1989) to describe the distribution and timing of Quaternary volcanic rocks in Utah.

Clusters of young volcanic rocks (generally less than 2 Ma) extend from northwestern Arizona through southwestern and west-central Utah. These units consist of a bimodal assemblage of mainly basaltic rocks and less voluminous rhyolitic rocks. In southwestern Utah, several clusters of mostly basaltic rocks are oriented northeast-southwest, subparallel to the Basin and Range-Transition Zone margin. This package of volcanic rocks consists of series of basaltic flows and vents that do not seem to coincide with mapped faults. Rather, some vents lie adjacent to major faults, such as the Hurricane and Sevier faults, localized on the footwall or hanging-wall block, but not appearing to have used the fault as a conduit for magma. Cinder cones and mounds, which generally form alignments parallel to the faults, appear to have formed along steep joints.

In west-central Utah, another cluster of young basaltic rocks, with lesser quantities of rhyolite form a narrow belt generally aligned with the eastern margin of the Basin and Range. This volcanic assemblage formed in an intra-graben area between the Pavant and Tushar Mountains on the east, and the Mineral and Cricket Mountains to the west. The region is referred to as (from south to north) the northern part of the Escalante Desert, the Black Rock Desert, and the southern part of the Sevier Desert. Volcanism here appears to have been concurrent with east-west extension across numerous, small-scale intra-basin faults. Vents and cinder cones mostly lie along high-angle normal faults, suggesting that the faults provided the conduits for movement of magma. Basaltic eruptions began in this region about 2 Ma and have continued intermittently since then.

A small volcanic field of Pleistocene age is located just north of Great Salt Lake in the southern Curlew Valley in Box Elder County. Basaltic rocks comprise the field and have been dated between about 0.7 and 1.15 Ma. Although the field is aligned generally parallel to Basin and Range faults, it does not appear to be spatially associated with any mapped Quaternary faults.

GEOTHERMAL RESOURCES IN UTAH

Previous Workers

The earliest implied reference to geothermal systems in Utah is by Gilbert (1890), who described Fumarole Butte and the nearby Crater (Abraham) Hot Springs. Stearns and others (1937) and Waring (1965) summarized data for about 60 known thermal occurrences. Mundorff (1970) prepared a comprehensive report on the thermal springs of Utah that included data on individual springs. Swanberg (1974) made estimates of subsurface temperatures using chemical analyses of water samples and employing geothermometry. Goode (1978) and Rush (1983) both produced summaries of geothermal occurrences in Utah. Various workers from the University of Utah Department of Geology and Geophysics, Utah Geological Survey, Utah Energy Office, and the University of Utah Energy and Geoscience Institute have published details on geothermal systems and geothermal applications in Utah.

Budding and Bugden (1986) compiled a bibliography of this early work up through the mid-1980s. Since then, several authors (Blackett, 1994; Blackett and Moore, 1994; Blackett and Ross, 1992;) have published more recent compilations and research on geothermal systems in Utah. Mabey and Budding (1987, 1994) compiled detailed geological, geochemical, and geophysical information, including previously unpublished data on seven individual systems within the "Sevier thermal area," an area of central and southwestern Utah containing all of Utah's known high-temperature geothermal systems. Budding and Sommer (1986) gathered field data and published a study of low-temperature geothermal resources in the St. George area of southwestern Utah. Wright and others (1990) summarized geothermal resources and developments in Utah up through the 1980s, and discussed how factors such as regional low energy costs resulted in relative low growth of geothermal energy in the state. Blackett and Ross (1992) published the results of geochemical and geophysical studies for geothermal systems within the Escalante Desert of southwestern Utah.

Geothermal Occurrences in Utah

With few exceptions, the higher temperature geothermal areas in Utah occur either in the Basin and Range Province or within the Transition Zone (Figure 2). In central and western Utah, most thermal areas are located in valleys near the margins of mountain blocks, and are probably controlled by active Basin and Range faults. Other geothermal systems occur in hydrologic discharge zones at the bottoms of valleys. A few thermal areas are situated in mountainous regions.

The most significant known occurrence of geothermal water in eastern Utah is from oil wells of the Ashley Valley oil field, which yield large volumes of nearly fresh water at temperatures between 43EC and 55EC (109EF and 131EF) as a byproduct of oil production. In 1981, the Ashley Valley field yielded 5.42 million m^3 (26.1 million barrels) of water (Goode, 1985).

Using geothermometry and other information, Rush (1983) suggested that six areas in Utah are probably high-temperature geothermal systems with reservoir temperatures above 150EC (302EF). He also suggested that ten other areas could be classified as moderate-temperature geothermal systems with reservoir temperatures between 100EC and 150EC (212EF and 302EF). Known high-temperature systems include the Roosevelt Hot Springs and Cove Fort - Sulphurdale Known Geothermal Resource Areas (KGRA). Other potential moderate- to high-temperature systems are Thermo Hot Springs, Joseph Hot Springs, the Newcastle area, and the Monroe-Red Hill area.

Geothermal Use in Utah

Presently, electric power is generated at the Roosevelt Hot Springs and the Cove Fort - Sulphurdale KGRAs. Commercial greenhouses, that use thermal water for space heating, operate at Newcastle in Iron County, at Crystal Hot Springs near Bluffdale in Salt Lake County, and at Utah Hot Springs near Pleasant View in Weber County. Ten resorts use geothermal water for the heating of swimming pools, small space-heating applications, and therapeutic baths. Three of the newer direct-use geothermal developments consist of commercial SCUBA-diving and aquaculture facilities near Grantsville in Tooele County, near Plymouth in Box Elder County, and at Midway in Wasatch County.

Power Plants

Utah Power, a PacifiCorp company that merged with Scottish Power in 1999, has operated the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area near Milford in Beaver County since 1984. Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from wells that tap a geothermal resource in fractured, crystalline rock. The resource depths range generally between 640 and 1,830 m (2,100 and 6,000 ft). Resource temperatures are typically between 271 and 316EC (520 and 600EF). Wellhead separators are used to "flash" the geothermal fluid into liquid and vapor phases. The liquid phase, or geothermal brine, is channeled back into the reservoir through gravity-fed injection wells. The vapor phase, or steam fraction, is collected from the production wells and directed into the power plant at temp-
eratures between 177 and 204EC (350 and 400EF) with steam pressure approaching 7.66 kilograms per square centimeter (109 psi). The plant produces 26 MW_e gross (23 MW_e net).

At Sulphurdale in Beaver County in 1985, Mother Earth Industries, in cooperation with the city of Provo, installed a geothermal binary-cycle power system and a steam-turbine generator. In 1990, Provo City and the Utah Municipal Power Agency (UMPA) dedicated the Bonnett geothermal power plant, becoming the third geothermal power unit to go on-line at Sulphurdale to provide electricity for Provo City. The estimated net output capacity from the power units is about 10 MW_e. Because hydrogen sulfide (H_2S) gas is produced, the plant includes a sulfur abatement system designed to extract up to 1.36 metric tons (1.5 short tons) per day of sulfur. In 2003, Recurrent Resources acquired the Sulphurdale geothermal properties and facilities of Provo City/UMPA. Recurrent has presently shut down the operation and plans to reconstruct the facility, eventually building a 30 to 40 megawatt binary power plant. Production wells primarily tap a shallow, vapor-dominated part of the geothermal system at depths between 335 and 366 m (1,100 and 1,200 ft). A deeper well (~ 730 m [2,400 ft]), however, reportedly taps the liquid-dominated part of the system.

Commercial Greenhouses

Various research organizations and energy companies became interested in the Newcastle area of Iron County in the 1970s after farmers accidentally discovered a relatively shallow hydrothermal system while drilling a irrigation well. The well had encountered a hot-water aquifer with a maximum temperature of 108EC (226EF) between depths of 75 and 94 m (245 and 310 ft). Subsequent studies by the Utah Geologic Survey (UGS) suggest a model of hot water rising along a range-bounding fault and discharging into an aquifer in unconsolidated Quaternary sediments, forming a broad outflow plume. Temperatures within the outflow plume generally range between 82E and 104EC (180E and 220EF). Several commercial greenhouses, covering about 100,000 m^2 (25 acres), use the geothermal fluid from shallow production wells (152 m [~ 500 ft] deep) to produce high-quality flowers, vegetables, and ornamental plants year-round.

Crystal (Bluffdale) Hot Springs is located at the southern end of the Salt Lake Valley where Bluffdale Flower Growers (formerly Utah Roses) operates a geothermal-heated greenhouse complex. The facility covers about 11,700 m^2 (2.9 acres), and produces cut roses as its primary product. Hi-Tech Fisheries, Inc. located at the nearby Utah State Prison uses thermal water cascaded from the prison geothermal production well for raising tropical fish commercially. Surface spring temperatures are about 62EC (144EF). Subsurface temperatures of 88EC (190EF) have been reported in one of two 122-m (400-ft) deep production wells. The springs normally issue from valley alluvium into several ponds. When production wells are in operation, the surface springs and ponds reportedly dry up.

Therapeutic Baths, Resorts, and Aquaculture

Bonneville SeaBase is a SCUBA-diving facility developed at Grantsville Warm Springs located about 66 km (40 mi) west of Salt Lake City along Interstate Highway 80 in Tooele County. SeaBase consists of several dive pools fed by warm springs and stocked with tropical marine fish. The facility is associated with Neptune Divers of Salt Lake City, a business devoted to SCUBA diving and related-product sales.

At Belmont (Udy) Hot Springs in northeastern Box Elder County, about 50 hot springs and seeps issue along the Malad River at about 52EC (125EF). In addition to a golf course and camping facilities, the resort has therapeutic hot tubs, a swimming pool, and a SCUBA diving pool. The resort also operated a commercial aquaculture facility, raising lobsters and crayfish for distribution out of the local area, which is now closed.

Crystal (Madsen) Hot Springs Resort, near Honeyville along Interstate Highway15 in Box Elder County, uses cold springs and hot springs at the same facility. The springs are situated along the northern extension of the Wasatch fault, which traverses along the western side of the Wellsville Mountains. A cold spring (11EC [52EF]) is used to help fill a 1.1-million liter (300,000-gallon) pool, while hot springs 60EC (140EF) fill therapeutic hot tubs, mineral pools, and also flow into the swimming pool. Pool temperatures range from 29E to 44EC (85E to 112EF).

Thermal springs in and around the community of Midway in Wasatch County issue from several widespread, coalescing travertine mounds covering an area of several square kilometers. Temperatures in the springs generally range from 35E to 46EC (95 to 115EF). Thermal water at Midway probably originates from deep circulation of meteoric water from recharge zones located to the north near Park City. The Mountain Spa Resort uses thermal water for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 35EC (95EF) thermal pool inside "the old hot pot," a large travertine mound.

The Monroe-Red Hill Hot Spring area is 16 km (10 mi) south of Richfield in Sevier County. The proprietors have named the resort "Mystic Hot Springs" and offer a geothermal-heated swimming pool, therapeutic baths, camping facilities, and tropical fish ponds. The Monroe and Red Hill Hot Springs issue at about 77EC (170EF) near the surface trace of the Sevier fault adjacent to the Sevier Plateau. The area was the focus of U.S. Department of Energy-sponsored geothermal studies in the late 1970s.

Veyo and Pah Tempe Hot Springs resorts in southwestern Utah offer swimming and therapeutic baths. At Veyo Hot Springs Resort, located southeast of the town of Veyo along the Santa Clara River canyon, spring flows are channeled to a swimming pool at a temperature of about 32EC (89EF). At the Pah Tempe Hot Springs Resort springs flow from a number of vents along the Virgin River at about 42EC (108EF) near where the river crosses the Hurricane fault between the towns of Hurricane and La Verkin. The thermal water is channeled into a swimming pool and therapeutic baths.

SUMMARY OF GEOTHERMAL ENERGY USES IN UTAH

Two separate electric power plants using geothermal energy have been installed in the southern part of the state, at Cove Fort/Sulphurdale (Bonnett) and near Roosevelt (Blundell) (Table 1). The Bonnett plant is presently shut down and probably will be replaced with a 30-to 40-MWe plant. These two plants are described in more detail in subsequent articles in this issue.

Direct-use is more extensive in the state, where geothermal energy is used at 21 sites located along the entire central arc of geothermal resources in the state (Figure 2)(Table 2). Greenhouse heating is the largest use, followed by swimming pools. Many of the resorts and spas have closed throughout the state as detailed in an article by Susan Lutz in this issue. The direct-use amounts to a savings of about 162,000 barrels of oil (assuming 35% efficiency from electricity), and eliminating 21,700 tons of carbon and 42,000 of carbon dioxide.

ACKNOWLEDGMENTS

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Table 1. Utilization of Geothermal Resources in Utah

Type of Use	Name	Location	Temperature °F (°C)	Installed Capacity MWe	Annual Energy Use GWh(e)
Electric Power	Blundell	Roosevelt	271-316 (133-158)	26	200
Electric Power	Bonnett	Cove Fort/Sulphurdale	315-350 (157-177)	11	0*
TOTAL				**36**	**200**

* Plant presently not operating

Table 2. Utilization of Geothermal Resources in Utah for Direct-Use

Type of Use	Name	Location	Temperature °F (°C)	Installed Capacity MWt	Annual Energy Use 10^9 Btu(t)	TJ
Greenhouses	Castlevalley Greenhouses	Newcastle	210 (99)	1.76	13.1	31.8
Greenhouses	Milgro Nursery	Newcastle	192 (89)	14.94	93.0	98.0
Greenhouses	Milgro No. 2	Newcastle	203 (95)	1.05	6.6	6.9
Greenhouses	Milgro No. 3	Newcastle	203 (95)	0.86	5.3	5.6
Greenhouses	Bluffdale Flower Growers	Bluffdale	190 (88)	3.29	24.6	26.0
Greenhouses	Allan Plant Co.	Ogden	136 (58)	0.66	4.9	5.2
Aquaculture	Crystal Springs Fisheries	Bluffdale	80 (27)	0.73	14.7	15.5
Aquaculture	Hi-Tech Fisheries	Bluffdale	189 (87)	1.60	32.0	33.7
Space Heating	Hi-Tech Fisheries	Bluffdale	189 (87)	0.08	0.6	0.6
Space Heating	Utah State Prison	Bluffdale	178 (81)	2.05	15.3	16.1
Space Heating	LDS Wardhouse	Newcastle	132 (56)	0.04	0.2	0.2
Space Heating	Camperworld Hot Springs	Garland	127 (53)	0.08	0.6	0.6
Swimming Pool	Camperworld Hot Springs	Garland	127 (53)	0.59	13.2	13.9
Swimming Pool	Crystal Hot Springs	Honeyville	140 (60)	1.03	21.4	22.6
Swimming Pool	Mountain Spa Resort	Midway	110 (43)	1.03	4.6	4.8
Swimming Pool	Mystic Hot Springs	Monroe	168 (76)	0.29	7.8	8.2
Swimming Pool	Saratoga Homeowners Assoc.	Lehi	112 (44)	0.32	7.7	8.1
Swimming Pool	Veyo Hot Springs	Veyo	85 (29)	0.29	7.0	7.4
Swimming Pool	The Homestead Resort	Midway	104 (40)	0.59	13.2	13.9
Scuba Diving	Bonneville SeaBase	Grantsville	76 (24)	0.59	14.0	14.8
Scuba Diving	The Homestead Crater	Midway	96 (36)	0.59	13.2	13.9
Scuba Diving	Camperworld Hot Springs	Garland	127 (53)	0.59	13.2	13.9
TOTAL				**33.05**	**326.2**	**343.7**

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CLEANED UP AND CLEANED OUT
- RUINED HOT SPRING RESORTS OF UTAH -

Susan Juch Lutz
Energy and Geoscience Institute, University of Utah
Salt Lake City, Utah 84108

INTRODUCTION

Although there are currently nine resorts in Utah that use thermal water for swimming pools, spas, and baths, there have been many more of these "pleasure resorts" in the past. This article discusses the history, resources, and demise of three hot spring resorts in Utah; Wasatch (Beck's) Warm Spring in Salt Lake City, Castilla Resort at the mouth of Spanish Fork Canyon, and Pah Tempe Hot Springs in LaVerkin, southwestern Utah.

WASATCH WARM SPRINGS (BECK'S HOT SPRINGS, WASATCH SPRINGS PLUNGE)

Undoubtedly, the largest area in Utah with hot spring waters that are perfect for balneological use are the combined 50 or so springs in a 3 by 0.75 mile (5 by 1.2 km) area that make up the Wasatch Warm Springs in northern Salt Lake City. Although the original Mormon pioneers frequently bathed in the largest of these springs, the area is now overrun with an interstate highway, oil refineries, junkyards, and scrap metal recycling centers (Figure 1). The thermal water is still used to heat the old swimming pool building, currently (but not for long) housing the Children's Museum of Utah, but the rest of the water has been diverted or piped away from the wetlands area and is considered a nuisance rather than a resource. Bathing is no longer permitted in the natural spring pools north of the building; although, the city of Salt Lake has restored and developed "Warm Springs Park" for recreational use (i.e, picnic areas and soccer fields). What was once a veritable paradise for swimming, bathing, and boating enthusiasts is now Salt Lake City's "Vanishing Hot Springs" (Pearce, 1969).

Figure 1. ***Present-day map of northern Salt Lake City, Utah indicating the location of Beck's and Wasatch hot springs in the Warm Springs fault geothermal area. Beck's hot spring is now under Interstate Highway 15.***

History

Much of the following account of the history of the Wasatch and Beck's hot springs is taken from an article written by Louise Pearce of Salt Lake City for a Daughters of the Utah Pioneers (DUP) plaque dedication ceremony. Although Native Americans likely soaked in the thermal waters, the first written accounts of the springs were by the original Mormon pioneers in Utah. Thomas Bullock, a leader in the Latter Day Saints Church (LDS) and in 1847, one of the original members of the Pioneer Company, described the oldest swimming hole and her numerous sister springs that once drained into a large hot spring lake "*2 or 3 miles long upon which are several thousands of snipes or plover.*"

In 1860, Richard F. Burton described his entry into Salt Lake Valley as follows:

> *"Northward, curls of vapor ascending from a gleaming sheet- The Lake of the Hot Springs- set in a bezel of emerald green, and bordered by another lake-bench upon which the glooms of evening were rapidly gathering, hung like a veil of gauze around the mountains."*

Thomas Bullock was one of the first to dig out a place to bathe with the help of his "brethren." He wrote:

> "*those who once bathe there want to go again; the water is 109 degrees Fahrenheit, strong sulpher and salt taste…These springs, like the pool of Siloam, heal all who bathe, no matter what their complaints. The air is very salubrious, and with these warm springs, I can truly say we have found a healthy country. This will prove the greatest blessing to those poor Saints who are weak, sickly, and affected. Oh what a blessing to the rheumatic; cramps, sprains, bruises, itch, every skin disease, and almost every complaint will here be healed.*"

By the summer of 1850, a building was erected over the springs, with a boarded inner pool for women, and an outer zone for men and boys. A winter swimming pool, with hot baths for all, was also constructed. An adobe dance hall with a kitchen and dining room was build as a Social Hall. LDS President Brigham Young performed the original dedication of the Bath House (Figure 2), which was also the first public place in Salt Lake City where entertainments and dances were held.

Figure 2. ***Two historic photographs: the Warm Sulfur Springs Bath House, completed November 27, 1850 (top); and Beck's Hot Spring resort sometime before 1898 (bottom). At first, mule trains brought Salt Lake City residents without indoor plumbing to the bath house for washing and recreation. Later, trains of the Great Salt Lake and Hot Springs Railway Company brought Salt Lake visitors to Beck's.***

Because of the supposed healing qualities of the spring water and the location of the springs on the main north-south road through northern Utah, it also became a popular camping place for farmers, teamsters and pioneers entering the city from the north.

The Hot Spring Lake was used for launching boats on the Great Salt Lake, by way of the Jordan River. This was considered the safest place for yachting and for launching boats on the Great Salt Lake.

Being on the outskirts of the town, it was difficult for the majority of the settlers to get to the bathing and swimming pools. So in 1865, one of the first services of the Salt Lake Railroad (mule-driven cars) was to transport pleasure seekers to and from the municipal baths. The early railroads commonly owned and operated resorts on or at the end of their lines as a way of stimulating passenger traffic. When, for example, the Great Salt Lake and Hot Springs Railway Company began the construction of tracks from Salt Lake City to Ogden in 1891, they proceeded in stages, laying track first to the existing resort, Beck's Hot Springs, four miles to the north, then going as far as Bountiful, where they built Eden Park, then moving to Farmington, where they built Lagoon, and finally, in 1908, reaching Ogden.

In 1884, a German Mormon, John Beck spent some of the fabulous wealth he had accrued from his Bullion-Beck mine in the Tintic mining district to buy 1,000 acres of land on Utah Lake and to develop warm springs there into "Beck's Saratoga Springs" (Van Wagoner, 1989). The next year in 1885, Mr. Beck purchased the property with the largest and hottest of the springs in the Wasatch Warm Springs area. He built a large resort, "Beck's Hot Springs," on the property that became known as the "coming sanitarium of the West" (Figure 2). The resort included a "plunge" (i.e., deep) bath 30 by 75 feet, a private plunge 40 by 80 feet, and 12 private plunges 10 by 10 feet, with nicely furnished dressing rooms. The resort was a grand grassy area with lawns and shade trees, and covered areas with dance floors, billiard tables, and picnic tables. The hot spring water was bottled and sold as a medicinal beverage. But in September of 1898, tragedy struck at Beck's and a disastrous fire burned the hotel and swimming pool surrounds. The hotel was not rebuilt, but the old spring was expanded into a large swimming pool and plunge.

The years of 1899-1915 were declining years for the resort, and in May of 1915, upon the Board of Health recommendation, Hot Spring Lake was drained because it had become a prolific mosquito breeding area. Most of the surrounding wetlands and smaller springs were also drained by the deep ditch that ran from Hot Spring Lake into the Jordan River and then into the Great Salt Lake. Although the pretty lake was gone, the resort continued to be popular as a health spa and swimming area. One bad incident occurred in 1921--there was a robbery where all the bathers' checked valuables were stolen. One bather said afterward, "We were cleaned out, as well as cleaned up. It was one clean sweep!"

Another fire in 1924 destroyed the covered bathhouse, and a new open-roofed structure was built to replace it. The resort experienced financial difficulties through the Depression years and was fairly rundown in the 1930s. By 1942, it went into foreclosure. A new owner, Harvey C. Woodbury, a research chemist, bought the resort in 1943 and started to replace the corroded piping and concrete with newer materials. In 1951, new regulations by the State Health Department required chlorination of all swimming pools, and all but seven swimming resorts in the state had been closed down the previous summer. It would be very expensive to chlorinate the continuous flow of fresh water into Beck's large swimming pool. The Woodbury family had plans to develop a health center with smaller flow-through pools when they received notice that the Utah State Highway Commission was to build a new highway in this narrow transportation corridor between the western escarpment of the Wasatch Mountains and the Great Salt Lake. The resort's demise became conclusive March 3, 1953, when the State of Utah acquired title to the property under threat of condemnation. Louise Pearce put it this way, "… so ends the story of Beck's Hot Springs."

The few areas of remaining openly flowing thermal water are still attractive for bathing, especially for those without their own luxury bath or hot tub. As far back as the 1950s, "Hobo Springs" was a place of bathing for railroad transients. Today, homeless people still illegally bath in the springs and bars of soap and discarded blankets from the rescue missions dot "Hot Springs Park."

Resource and Local Geology

The fifty or so springs in the Warm Springs area occur along the trace of an active normal fault, the "Warm Springs fault." The Warm Springs and Hobo faults associated with the springs are local names for segments of the Wasatch fault zone, which forms the boundary between Salt Lake Valley and the Wasatch Range. Wasatch Warm Springs is the southernmost of four major hot springs, located along three miles (5 km) of the Warm Springs fault zone. From south to north, the individual springs are Wasatch, Clark, Hobo and Beck's. There are also two shallow warm water wells used by local quarry operators. Collectively this area is known as the Warm Springs fault geothermal area. The thermal springs occur at the intersections of the Wasatch fault and other structures that are perpendicular to the fault zone (Murphy and Gwynn, 1979). Discharge temperatures range from 81EF (27EC) at Clark Warm Springs, to 131EF (55EC) at Beck's Hot Spring (Klauk and Davis, 1984; Blackett and Wakefield, 2002).

Water temperature of Wasatch Warm Springs fluctuates seasonally between 100E and 108EF (38 and 42EC). Assuming a thermal gradient of 93EF per mile of depth (32EC per km) and an average annual outside temperature in the Wasatch Range of 40EF (4.5EC), the water must reach a depth of approximately 0.75 mile (1.2 km) to obtain the maximum temperature of 108EF (42EC) (Milligan, 2003). This is, however, a minimum estimate of the depth of circulation because the upwelling geothermal waters likely mix with cooler ground waters on their way to the surface.

Measured outflow from Beck's hot spring is about 228 gpm (870 liters/minute), and at Wasatch about 63gpm (240 liters/minute; Cole, 1983). Chemical analyses of water samples collected in January of 1981 indicate high Ca+Mg and high SO_4 +Cl (Cole, 1983). The chemistry is consistent with mixing between low-temperature near-surface ground waters high in Ca and HCO_3, and an upwelling geothermal fluid that has become enriched in Na and Cl by water-rock interaction during deep circulation along the Wasatch fault zone (Cole, 1983). Cole also noted cyclical changes in the chemistry of the spring waters throughout the year; chemical enrichments were noted during the summer months and depletions during the fall and early winter months. The hot springs exhibit their highest surface temperatures during the summer months at times of maximum flow. Based on the chemistry of the hot spring waters and surrounding ground waters in the Warm Springs area, Cole (1983) estimated a four-to-six month time period between recharge from melting mountain snow packs in April-May and discharge as diluted spring water in September-October.

CASTILLA HOT SPRINGS

Castilla Hot Springs are located about 8 mi (13 km) southeast of Spanish Fork in Spanish Fork Canyon, along the north side of U.S. Highway 6/89 in Utah County (Figure 3). During the early part of the twentieth century there was a thriving hot spring resort that attracted trainloads of visitors. Most of the following historical account of the Castilla Hot Springs resort is taken from an article in a Utah State Historical Society Publication, "Beehive History," written by Linda Thatcher (1981).

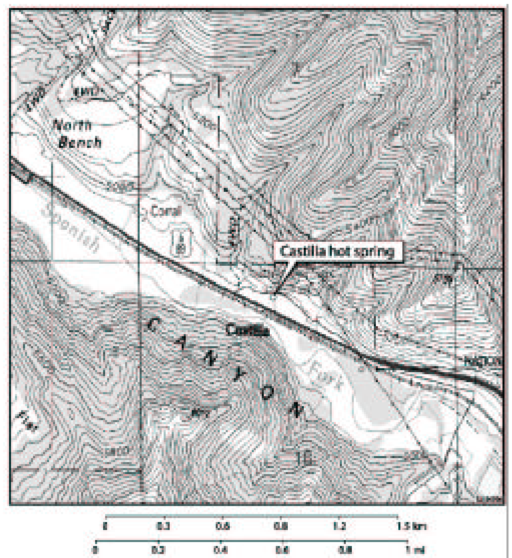

Figure 3. ***Present-day map of Castilla in Spanish Fork Canyon, site of the Castilla Hot Springs resort in the early 1900s. Trainloads of visitors used to arrive by train for a day of diving, dining, drinking, and dancing.***

History

Spanish Fork Canyon was named for the Spanish priest-explorers Escalante and Dominguez who discovered the springs in September 1776 as they followed the Spanish Fork River down the canyon. They called it Rio de Aguas Calientes ("River of Hot Waters") because of the hot springs flowing into the river. The name Castilla may have been suggested by the castle-like rock formations nearby.

In 1863, heavily armed Mormon troops traveling through Spanish Fork Canyon noted the presence of "unfriendly Indians" living around the hot springs (Jeffers, 1972). But by 1889, the Native Americans were gone and William Fuller had filed for a patent on the hot springs property with the U.S. government. He built a small house that contained a wooden tub for bathing in the mineral water. Later that year, a Mrs. Southworth felt that her health had been improved by bathing in the spring water, and she urged her two sons to buy the springs and "make a resort for people who have hopeless afflictions, that they may come and be cured." They filled the swampy area with gravel and built a three-story, red sandstone hotel from sandstone quarried in a nearby canyon (Figure 4). Other structures included indoor and outdoor swimming pools, a store, a dance pavilion, private bathhouses, several private cottages, and a saloon. Picnic areas, a baseball diamond, and stables were also provided.

Figure 4. ***Two historical photographs of the Castilla Hot Springs resort in about 1917. Elderly ladies may have come to Castilla for their rheumatism rather than recreation.***

During the summer months, the Denver and Rio Grande Railroad ran excursion trains to Castilla, and it was a regular passenger stop for many years. One of the more popular runs was the "moonlight excursion" from the Tintic Mining District in Juab County to Castilla. The train stopped at stations along the way to pick up passengers for an evening of dining and dancing.

Besides providing recreation for many Utahans, the resort was the site of several "direct-use" enterprises, including a cigar factory and a quarry that furnished silica used as a flux by the Columbia Steel Company in Ironton, Utah. However, the main attraction was still the warm, sulfuric water. Bathers come from far and wide for the relief of their rheumatism and arthritis. The springs' water also became popular as a cure for other ailments such as alcoholism, chain-smoking, moral dissipation, and the "tendency to use profane language."

In 1912, a noted sculptor with local ties, Cyrus Dallin bought the resort, but he had to rely on relatives to run it as he lived in Boston. The resort enjoyed a brief renewal of popularity in the 1920s, but by the 1930s, it had fallen into disuse. Work in a nearby rock quarry slowed the flow to the springs and the hotel fell into disrepair. In the 1940s, a fire destroyed most of the hotel. What remained was eventually torn down.

By the 1970s, all that was left of the old resort was a concrete tank or cistern build over the hot sulfur spring. Sometime in the 1980s, the spring was blown up by local authorities because they had trouble controlling the visitors that frequented the springs. Nowadays, there is only a small railroad sign that says "Castilla," and in a grassy area nearby, the remains of the soaking tubs and bits of foundation from the hotel.

Resource and Local Geology

The Castilla springs are located at an elevation of about 5,000 ft (1,525 m) within the Wasatch Mountains, not far from hot springs in the Thistle and Diamond Fork (Fifth Water) areas (Blackett and Wakefield, 2002). Klauk and Davis (1984) presented thermal and chemical data on two springs at Castilla. Temperature in both springs was 97EF (36EC). Cole (1983) measured temperatures of 108EF (42EC) and fluid discharges of 21 gpm (80 liters/minute) for the larger spring, and noted the location of the spring at an outcrop of faulted Paleozoic quartzite. The water chemistry generally appears to be of the Ca-Na-SO_4 type. Cole (1983) reports that the isotopic composition of the Castilla spring water lies on the local meteoric water, indicating that not much mixing, evaporation, or high-temperature water-rock interaction has occurred during the evolution of the thermal fluid. Not much more is known about the geology of this forgotten hot spring area.

PAH TEMPE (DIXIE, LAVERKIN) HOT SPRINGS

Pah Tempe Hot Springs Resort is located between the towns of Hurricane and LaVerkin in southwestern Utah. The springs flow from travertine mounds along the Virgin River and into the river where it cuts the Hurricane Cliffs (Figure 5). The LaVerkin (Pah Tempe) hot springs have been an active resort from pioneer times until two years ago (January 2002) when pipelines put in to divert water from the Virgin River into the Quail Creek reservoir disrupted the natural flow of hot spring water to the resort. This is not the first time that pipeline construction has damaged the geothermal resource, Pah Tempe was out of business from 1992 to 1995, and also in July of 2000 and May of 2001 when heavy equipment work in the river bed shut down the flow of hot spring water. Ken Anderson, current owner of the resort, has raged a 10-year legal war with the Washington County Water Conservancy District for damages and business losses. The Conservancy District says it owns the water rights to the Virgin River and that the Quail Creek pipeline is critical to the growing population of Washington County (*The Spectrum*, January 18, 2002). The district also claims that the high salinity spring water is polluting the Virgin River, hurting her native fish population, and decreasing the water quality of the Colorado River into which she drains. The district also suggests that even the early pioneers considered the springs to be "poison water." Mr. Anderson states that up to 20,000 people a year have enjoyed soaking in these revered hot spring waters, and claims losses of $1,000 a day in revenue from disappointed bathers and resort lodging (previously geothermally heated). Mr. Anderson has prepared a document entitled "Summary History of Pah Tempe Mineral Hot Springs, 1984 to the Present" dated July 1, 2001, and has put together a comprehensive website that can be viewed on-line (www.infowest.com/pahtempe).

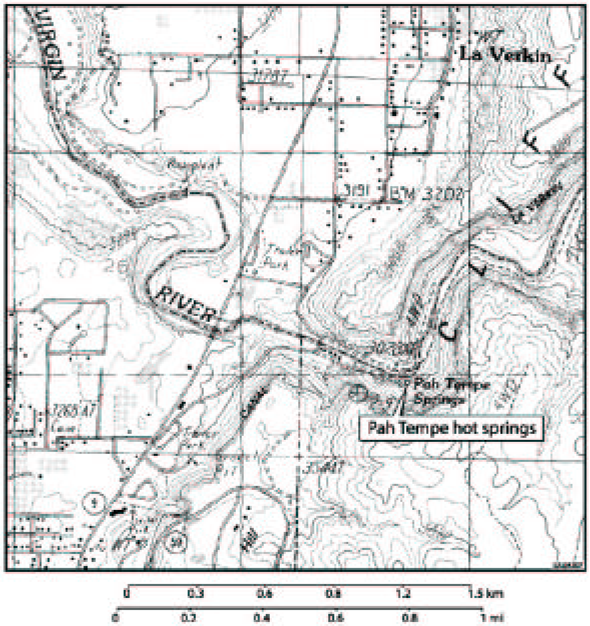

Figure 5. ***Map of present-day Pah Tempe Hot Springs, near LaVerkin in southwestern Utah. The Washington County Water Conservancy District's pipeline runs through the Virgin River in the vicinity of the hot springs.***

History

The earliest human history of the LaVerkin (Pah Tempe) hot springs starts with the Native Americans. A cave located above the hot springs contained two pots in perfect condition and a broken bowl. A cave located downstream from the springs on the north side of the river, contained "the most varied trove, including a war club with two stone points cemented to the wood handle" (Hall, 2003). There was also a wood-handled dagger, a "tump strap" or head band made of braided hair and rawhide for carrying loads, a digging stick used for gardening, lots of bone awls, and a "duck jar" made by hollowing out a sandstone rock. These items are now in possession of the University of Utah. Hall (2003) also writes the following:

> "The hot springs were considered sacred by the Indians and were a neutral zone. If enemies met there, they avoided conflict while together. Presumably, Navajos respected the sacredness, and wouldn't steal a child if they encountered a Paiute family."

The Dominguez-Escalante party went through this area in 1776. They recorded the first historical account of Indians (Paiutes) utilizing irrigation to grow food and named the river "Rio Sulfureo" for the sulfur smell near the hot springs. Jedediah Smith stopped by in 1826, and the first Mormons visited in 1849. Most of the following pioneer history of the springs comes from "A Brief History of the LaVerkin Hot Springs and the LaVerkin Canal," compiled by Ruby Webb (Daughters of the Utah Pioneers, 1986).

Thomas Judd, the first owner of the hot springs, acquired them in about 1889. The springs were used by the early settlers for recreation and for performing baptisms. The builders of the original Hurricane Canal built walls and dammed up the springs in order to soak their sore muscles at the end of the day, and for frolicking when wives (think plural, this is Utah!) came to visit on weekends. One of the wives, Rosalba Fuller recounted, "Since we had no bathtubs in those days, we really loved the sulfur springs."

Like the Monroe hot springs near Richfield, Utah, the pioneers also used the hot waters to wash sheep. The sheep were doused in the sulfur water to prevent scabies.

Hundreds of baptisms were performed at the LaVerkin hot springs from about 1915 until into the 1940s. Thoughtful parents brought their babies to be baptized in the warm water during winter months. Later, when bathing and swimming facilities had been built, many baptisms were performed on Sunday mornings in the main enclosed pool. Sometimes the young person got to swim for a few minutes afterward. As Ruby Webb recounts, "There is an additional zest to the pleasure of swimming when it's done at a time that's normally forbidden." Sundays were generally reserved for more sacramental activities.

A swimming pool 15 feet wide and 45 feet long was completed in 1918 by the LaVerkin Sanitarium and Resort Company. Two immediate tasks of the company were to sell additional company stock and to establish a code of decency for bathing suits. The LDS bishops of the towns of LaVerkin, Hurricane and Toquerville reached a decision; the codes for ladies called for elastic in sleeves and legs that reached below elbows and knees, plus a skirt. Men's suits could be sleeveless, but legs were to reach below the knees. A local seamstress made the suits for 15 cents a piece; they were sold by the company for $1.50 each or could be rented for 25 cents. Rules of conduct prohibited naked bathing, dunking, throwing water, and diving from the walls. The pool was a popular attraction for individuals, families, school, scout and church groups (Figure 6); many arriving by wagon.

The resort became more of a public service than a cash cow. Though some facility improvements were made (such as the installation of electrical lighting to surprise late-night skinny-dippers), the pool eventually became privatized. In 1952, new owners gave it the name "Pah Tempe."

The current owner, Ken Anderson, bought the resort in 1985, and made many improvements to the grotto area and pools. He created an inviting tree-lined spa with camping and bed-and-breakfast lodging. Even in these modern times, the pool continued to be used for "sulfur spring baptism" by the local people. But the Pah Tempe Hot Springs are perhaps better known internationally than they are locally. There were eighteen thousand guests from thirty-five countries during 1997. Now, the tragic story is that the resort is closed. This rare natural gem, that has provided peace, health and sanity to so many, has been ruined, but hopefully not for long. Somewhere in the riverbed and in the fractured limestone bedrock beneath it, the hot water still flows.

Figure 6. ***Historical photograph of the LaVerkin (Pah Tempe) hot spring pool (top; used by permission from the City of LaVerkin). Empty grotto pools at the Pah Tempe Mineral Hot Springs (bottom), the resort has been closed since January 21, 2002 (images from Ken Anderson's Pah Tempe website).***

Resource and Local Geology

The Pah Tempe Hot Springs, also known as the LaVerkin or Dixie Hot Springs, flow from a number of vents along the Virgin River at about 108EF (42EC) near where the river crosses the Hurricane fault (Blackett and Wakefield, 2002). The springs issue from multiple vents in the fractured Permian Toroweap Limestone. Besides deep circulation along the Hurricane fault zone, there are also some very young (1,000 years B.P.) basalt flows in the vicinity of the springs which may provide local heat sources for the thermal water (Blackett and Wakefield, 2002). When the resort was open, the thermal water was channeled into a swimming pool and several therapeutic baths. The hot spring water was also used to heat the resort buildings through heat exchangers.

In 1937, the hot water was described as flowing from beneath the cliffs at the rate of 11 cubic feet per second (about 4908 gpm or 18,700 liters/minute), at a temperature of 108EF (42EC)(Webb, 1986). Measured flow rates range from 4490 gpm (17,000 liters/minute) in 1970 (Mundorff, 1970), to 4755 gpm (18,000 liters/minute) in 1978 (Cole, 1983), and 4800 gpm (18,169 liters/minute) in 1986 (Budding and Sommer, 1986). Flow rate, chemistry and temperature have varied with time. Mundorff (1970) and Budding and Sommer (1994) indicate that measured temperatures have ranged over the last one hundred years between 100 to 133EF (38 to 56EC). Total dissolved solid (TDS) contents have ranged from 8390 to 9340 mg/liter (ppm).

Before disruption by pipeline construction in 1984, the springs had artesian outflow to small caves (grottos) along the canyon wall. Damage was done to the main upwelling hot spring conduit by the blasting of trenches in the Virgin River during the pipeline installation. The blasting resulted in cracks in the limestone bedrock, rupturing the springs so that the natural artesian outflow ceased to flow from the grottos. New springs emerged at lower bank-levels along the Virgin River (Blackett and Wakefield, 2002). Flows to the original springs were partially restored after installation of a clay and cement seal in the construction area. However, a 5.8-magnitude earthquake on September 2, 1992 apparently ruptured areas in the pipeline trench that had been "repaired," again resulting in the loss of water flow in the grottos. Anderson has said that flows were easily 5,000 gallons per minute (about 19,000 liters/minute) when he first purchased the hot springs property, but more recently the flow has been reduced to 90 gallons (340 liters) per minute (The Spectrum, February 14, 2002; Figure 6).

Blackett (1994) obtained a post-earthquake spring sample collected from one of the new spring orifices where the Quail Creek pipeline crosses the Virgin River. The chemistry of the post-earthquake sample was similar to previous analyses. For 1994, Blackett and Wakefield (2002) list total dissolved solid (TDS) contents of 8907 mg/liter for the Dixie (Pah Tempe) hot spring, with 2130 mg/l Na, 760 mg/l Ca, 1238 mg/l HCO_3, 1841 mg/l SO_4, and 3195 mg/l Cl. The water is a sodium calcium-chloride, sulfate and bicarbonate type. Geothermometers suggest equilibration temperatures between 167EF and 176EF (75EC and 80EC) (Blackett and Wakefield, 2002).

SUMMARY

This is the story of three hot spring resorts in Utah. There is not a unifying theme to their demise. The Wasatch-Beck's and Pah Tempe springs are perhaps just located in the wrong place. The Wasatch Warm Springs fault geothermal area is unfortunately sandwiched in a narrow transportation corridor between the Great Salt Lake to the west and the Wasatch Mountains to the east. Two major interstates, gas pipelines, and an extensive rail system now directly overlie the original springs. Sometimes you can get a whiff of sulfur as you drive by. Castilla simply appears to have died of neglect. The closure of the Pah Tempe resort is a sad story, but hopefully not over. Although the springs are located directly next to the only perennial river and exploitable source of surface water in Washington County, the hot water is still there (as it is for the other two geothermal areas). In all three areas, the beauty of the natural hot spring environment is gone, but the resource remains.

ACKNOWLEDGMENTS

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ELECTRIC POWER GENERATION IN THE ROOSEVELT HOT SPRINGS AREA - THE BLUNDELL GEOTHERMAL POWER PLANT -

Andrew Chiasson
Geo-Heat Center

INTRODUCTION

The Blundell Geothermal Power Plant is a single-flash plant with a net capacity of 23 MW_e (26 MW_e gross). The geothermal brine is produced from four wells that tap highly fractured crystalline rock of the Roosevelt Hot Springs geothermal resource. This geothermal resource is a hydrothermal field where groundwater is heated by underlying magma. Production depths generally range from between 1,253 to 7,321 ft (382-2,231 m) at reservoir temperatures of 464ºF to 514ºF (240-268ºC)(Blackett, et al., 2004).

The Blundell Plant, named after a former president of Utah Power, is located in Beaver County, UT, approximately 15 miles northeast of the town of Milford and about 165 miles south of Salt Lake City. The plant itself is currently owned by PacifiCorp (who merged with Scottish Power in 1999), but the geothermal field is owned by Intermountain Geothermal Company, a subsidiary of California Energy Company. The Blundell project was completed in June 1984, at which time the geothermal field was developed by Phillips Petroleum and the power generation plant was built by Utah Power & Light (UP&L). The plant's "claim to fame" was that it was the first commercially-produced geothermal power in the United States outside of California. The project earned the U.S. Department of Energy's innovation award in 1984.

THE GEOTHERMAL RESERVOIR

The Blundell Power Plant is located in the Roosevelt Hot Springs Known Geothermal Area (KGRA) (see Figure 2, page 3), on the eastern margin of the Basin and Range Province near the Colorado Plateau. The area, intensely studied since the early 1970s, has been used as a natural laboratory for the development and testing of geothermal exploration and evaluation methods. Hundreds of geoscience papers and articles appear in the literature regarding the Roosevelt Hot Springs area. Conceptual models of the area are provided by Faulder (1991), Becker and Blackwell (1993), and Moore and Nielson (1994) to name a few.

Geology and Structure

The commercial geothermal reservoir is associated with the Negro Mag and Opal Dome faults. Production from the geothermal system is primarily from highly fractured Tertiary granite and Precambrian metamorphic rocks bounded to the west by the Opal Dome fault, to the north by the Negro Mag fault, and to the east by the Mineral Mountains (Figure 1).

The Mineral Mountains, the first range west of the Wasatch front, are a north-south trending granitic intrusive complex intruded into Precambrian rocks beginning about 25

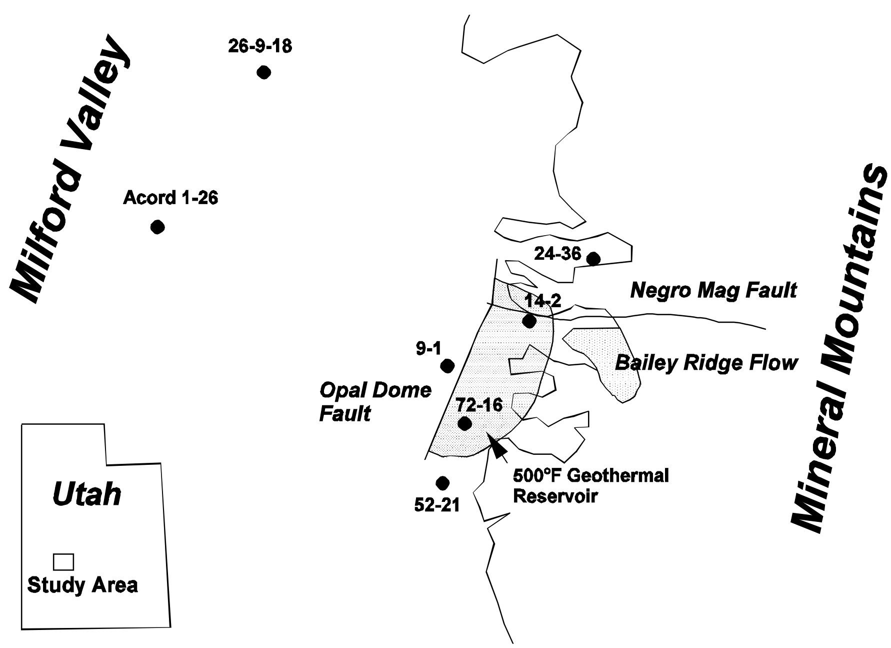

Figure 1. Roosevelt Hot Springs location map.

million years ago. Subsequent rhyolitic volcanism occurred beginning about eight million years ago and ended about 500,000 years ago, resulting in the formation of rhyolite domes in the central Mineral Mountains.

Geochemistry

Chemical analyses of waters from wells intersecting the geothermal reservoir are shown in Table 1 from Capuano and Cole (1982) and Moore and Nielson (1994). The waters are described as a dilute sodium brine, and analyses of the samples from wells and springs suggest that they are from a common reservoir source. The isotopic composition indicates they are of meteoric origin.

Table 1. Chemical Analyses of Waters from the Roosevelt Hot Springs Geothermal System

Parameter	Units	Well 14-2	Well 72-16
Total Depth	m	1,862	382
	ft	6,109	1,253
Na	ppm	2,150	2,000
K	ppm	390	400
Ca	ppm	9.2	12.2
Mg	ppm	0.6	0.29
Si	ppm	229	244
Sr	ppm	-	1.2
As	ppm	3.0	-
Li	ppm	-	16
B	ppm	29	27.2
F	ppm	5.2	5.3
Cl	ppm	3,650	3,860
HCO_3	ppm	-	181
SO_4	ppm	78	32
TDS	ppm	>6,614	6,444
pH		5.9	7.5
Temp.(bottom hole)	°C	268	243
	°F	514	469

Reservoir Model

Faulder (1991) describes a conceptual model that summarizes the hydrothermal system (Figure 2). The model describes fluid recharge, fluid circulation paths, a heat source, and an outflow plume.

The primary geothermal reservoir dimensions were estimated by Faulder (1991) at 10,000 by 23,000 ft (3,050-7,010 m) with a depth of about 10,000 ft (3,050 m). Initial well test information reported by Butz (1980) on well 14-2 showed total well flow rates of 500,000 lb_m/hr (226,800 kg/hr), and under flowing conditions, the maximum temperature recorded was 503°F (262°C) at a maximum pressure of 954 psi (6.57 MPa). Kerna and Allen (1984) reported that subsequent well tests showed that each production well was capable of producing 1 million lb_m/hr (454,000 kg/hr) of geothermal fluid at wellhead conditions approaching pressures and temperatures of 380 psi and 440°F (227°C).

Groundwater recharge to the geothermal reservoir is mainly from runoff and snow-melt (meteoric water) from the west flank of the Mineral Mountains. Some groundwater contribution from inter-basin transfer from Beaver Valley (to the east) to Milford Valley through the Negro Mag graben structure is also possible. Downward circulation of water occurs through the system of extensive joints and fractures associated with the Negro Mag graben. Microseismicity suggests that the presence of open fractures may exist at depths of 10,000 to 26,000 ft (3,050 to 7,925 m)(Faulder, 1991). Groundwater then heats up and flows until it encounters the deep-seated Opal Dome and Negro Mag Faults. Up-flow occurs through these faults into the intensely fractured intersection of the Opal Dome and Negro Mag grabens and other low-angle faults, providing a geothermal reservoir for the fluids. Circulation in the reservoir occurs in the complex, well-developed, three-dimensional permeability structure.

The favored theory explaining the heat source is the presence of a magma chamber under the western central Mineral Mountains. This magma plume is believed to extend from a depth of 16,000 ft (4,875 m) to the upper mantle.

HISTORY OF POWER GENERATION

The Early Days

Utah Power and Light (UP&L) reported that the hot springs in the area was used around the early 1900s by settlers, miners, and cattlemen for bathing, laundry and swimming. Figure 3 is a photograph showing remnants of one building. The springs are reported to have been dry since 1966, but steam still seeps from the ground near a swimming pool once filled with geothermal water (Figure 4).

Phillips Petroleum obtained a lease at Roosevelt Hot Springs in 1974. Through exploratory drilling in 1975, the 500°F (260°C) liquid-dominated reservoir was discovered and in April 1976, the Roosevelt Hot Springs Unit (RHSU) was formed and was the first geothermal unit approved by the U.S. Department of the Interior. The RHSU is eight miles long and six miles wide. Extensive resource and reservoir evaluation then took place and Phillips Petroleum and UP&L signed a contract in 1980, with Phillips agreeing to develop the geothermal resource and UP&L agreeing to provide the generating plant and steam transportation facilities.

Biphase Turbine Testing

UP&L first generated commercial electricity in 1981 using a 1.6-MW_e-biphase turbine research unit installed on one of the wells. The unit was designed by Biphase Energy Systems of Santa Monica, CA (now Douglas Energy Company,) with additional funding and effort from Electric Power Research Institute (EPRI) and UP&L.

At that time, biphase turbines were considered somewhat pioneering technology. Also referred to as "total flow" turbines, biphase turbines are wellhead units that accept brine and steam and improve energy conversion. One field test by Cerini and Hughes (1981) reported a 25% greater power output with a biphase unit as compared to a single-flash operation.

In principle, the biphase stage does the same job as a single-flash stage, but extracts extra power from the fluid stream by converting kinetic energy in the brine to shaft power

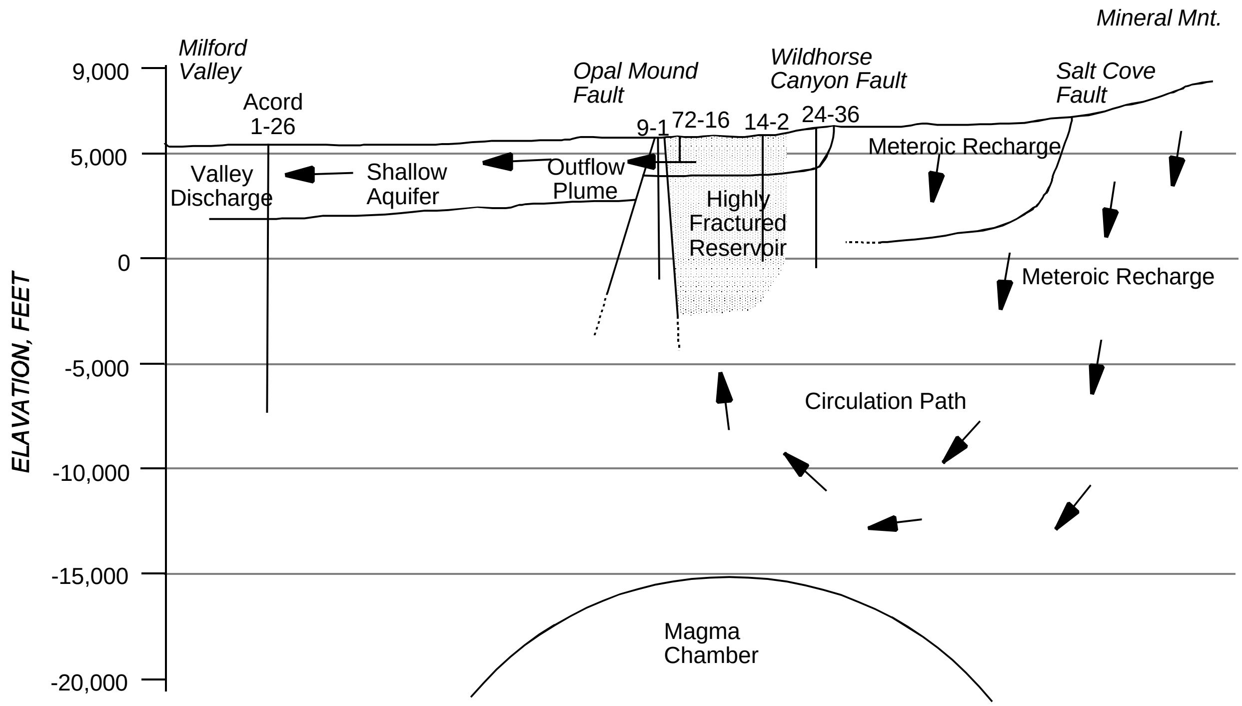

Figure 2. *Conceptual geologic model of the Roosevelt Hot Springs hydrothermal system after Faulder (1991).*

Figure 3. *Building remnants from old hot springs days.*

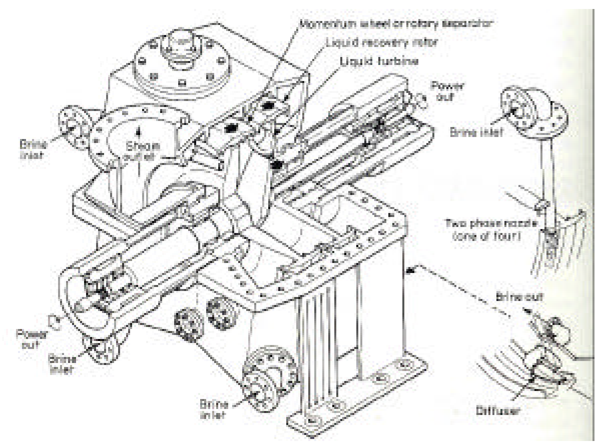

Figure 5. *The biphase turbine. (By courtsey of Biphase Energy Systems of Santa Monica, CA).*

Figure 4. *Steam seeps at Roosevelt Hot Springs.*

(Figure 5). First, the pressurized water/steam mixture flows through a nozzle where it impinges tangentially on the inside rim of a rotary separator. Frictional drag forces causes the rotary separator to spin. Flashing occurs as the fluid passes through the impingement nozzle, and the faster moving steam further accelerates the rotor. The clean steam, separated by centrifugal force, then passes along the radial axis of the rotor to a conventional steam turbine which can be installed at the wellhead or in a central plant. The brine layer on the inner wall of the rotary separator passes through holes to an outer liquid turbine whose shaft is connected to a generator. The used brine is then repressurized for reinjection.

A photo of the skid-mounted unit installed at the Blundell location is shown in Figure 6. This 1600-kWe unit

Figure 6. ***Skid-mounted biphase turbine system operated at Roosevelt Hot Springs (photo from www.douglasenergy.com).***

generated power to the UP&L grid for approximately 4,000 hours beginning in October 1981. Inspection after the service time revealed no corrosion or scale deposits on the high velocity surfaces. Options were weighed regarding use of conventional flash technology vs. biphase technology, and for various reasons, conventional flash technology was chosen (Hays, 2004).

The Present and Future

UP&L began construction on the present plant in 1982 and commercial power generation began in 1984. The plant uses a single-flash process. According to Kerna and Allen (1984), electricity was produced from 2.25 million lb_m/hr (1.00 million kg/hr) of geothermal fluids from four production wells. Wellhead separators at each well produces clean steam that is piped to the power plant's turbine to turn the generator. The generator uses about 400,000 lb_m/hr (180,000 kg/hr) of steam. Unused wellhead brine, as well as steam condensate from the turbine, are fed to a surge tank and then returned to the reservoir through three gravity-fed injection wells. The piping network consists of about 4.5 miles (7.2 km) of brine piping and one mile of steam piping as shown in Figure 7. Photographs of the plant are shown in Figure 8.

In 1991, PacifiCorp, which operates as Utah Power in Utah and Idaho, began a 30-year steam purchase contract. Since that time, the plant's average annual power generation has been about 167,000 MWh (Figure 9). PacifiCorp merged with Scottish Power in 1999. A new turbine rotor was installed in May 2001 to increase plant efficiency.

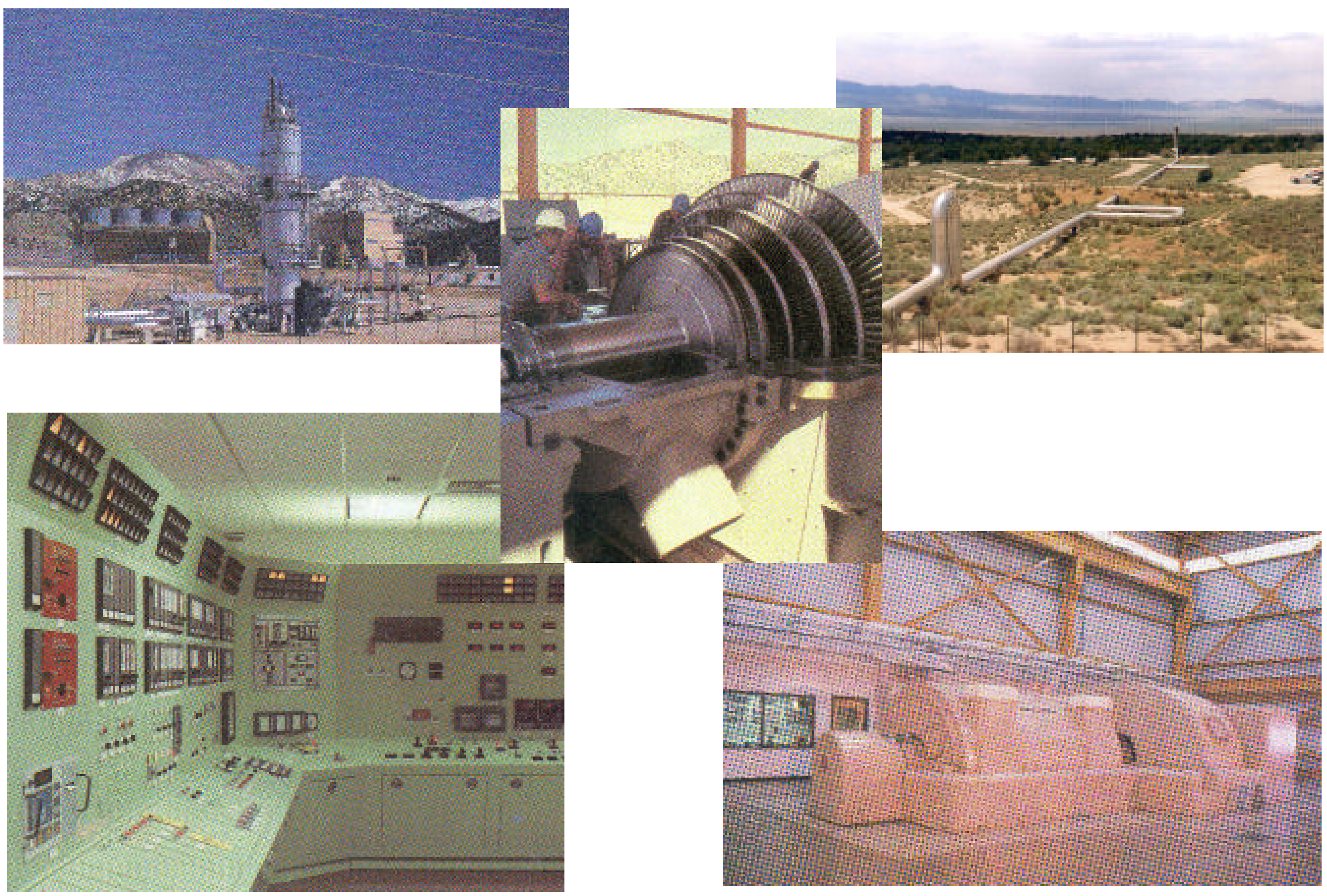

Figure 8. ***Photographs of the Blundell Geothermal Power Plant (clockwise from upper left: seperator, cooling tower and plant building; turbine exposed; transfer piping showing expansion in loops; turbine and generator; control room).***

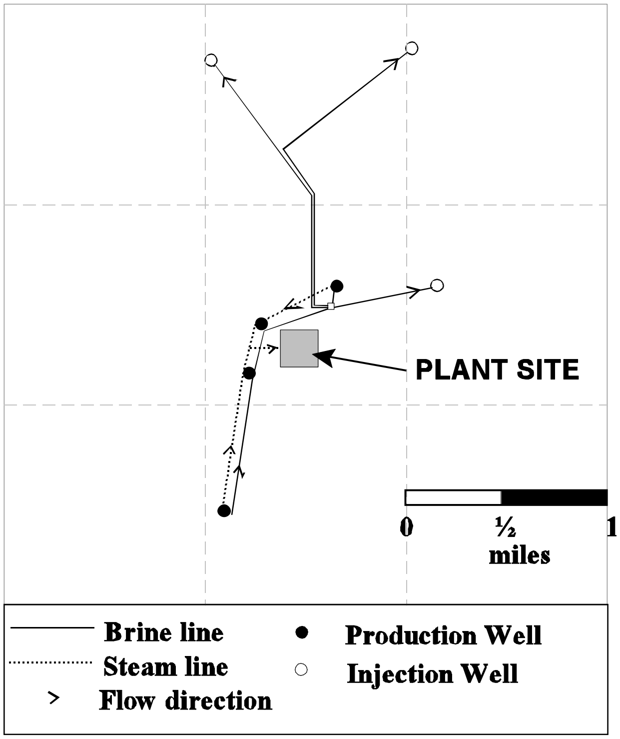

Figure 7. ***Piping layout at the Blundell Geothermal Power Plant.***

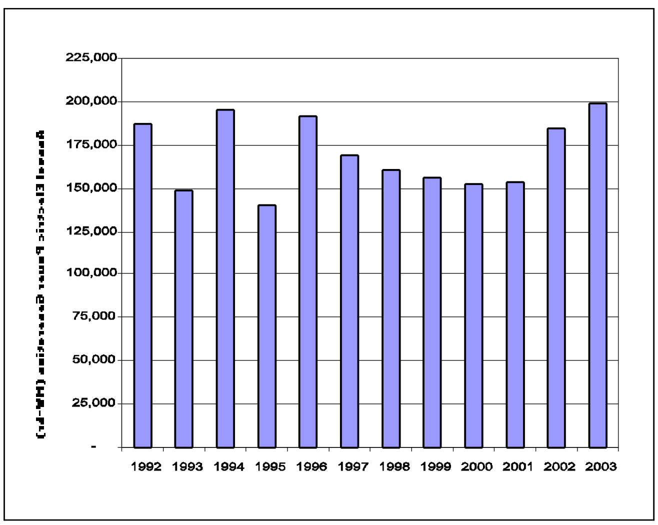

Figure 9. ***Electric power generation from Blundell Geothermal Power Plant, 1992-2003 (Blackett, et al., 2004).***

According to PacifiCorp's 2003 Integrated Resource Plan (IRP) (www.PacifiCorp.com), a 10-12 MW_e expansion is being evaluated and will be implemented if deemed "appropriate and cost effective." The expansion is reportedly from a "bottoming cycle" using binary power technology (Blackett, et al., 2004). Based on PacifiCorp's steam-purchase contract, the plant is scheduled for retirement in 2021.

ACKNOWLEDGMENTS

We would like to thank PacifiCorp for allowing us to use material from their brochures, and Loretta K. Firman, Plant Supervisor, for giving a tour of the plant in June 2004.

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THE COVE FORT-SULPHURDALE, UTAH GEOTHERMAL FIELD

INTRODUCTION

The Cove Fort-Sulphurdale (CFS) Known Geothermal Resource Area (KGRA) is located in Millard and Beaver Counties in south-central Utah, near the intersection of Interstate Highways 15 and 70 (Figures 1 and 2).

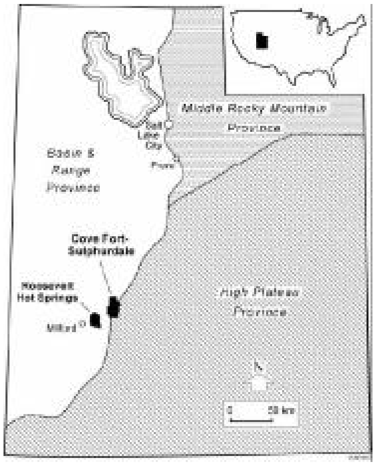

Figure 1. Location map of the Cove Fort-Sulphurdale resource area.

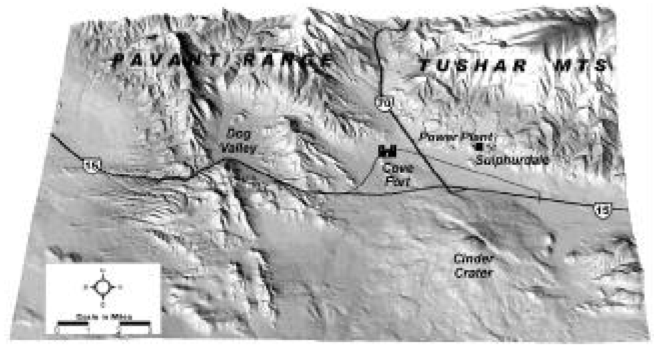

Figure 2. 3-Dimensional map of the Cove Fort-Sulphurdale area.

Cove Fort is an old stone fort built by Mormon settlers in 1867 as a way station for travelers. The presence of sulfur mines, gas seeps that emit hydrogen sulfide and altered ground initially suggested the existence of an extensive and exploitable geothermal resource. The site of the old mine at Sulphurdale is the largest of these sulfur deposits (Figure 3).

Figure 3. Photomontage of the sulfur mine and buildings.

In 1893, all of the nation's native sulfur, about 1200 tons, came from Sulphurdale. The mines produced a total of 30,000 long tons between 1885 and 1952, when competition from other sources forced it to close. (Callaghan, 1973).

GEOLOGY

The CFS KGRA lies near the junction of the Pavant Range and Tushar Mountains on the eastern margin of the Basin and Range province (refer to Figures 1 and 2). These mountains mark the transition between the Colorado Plateau and the Basin and Range provinces. They are composed primarily of Paleozoic to Mesozoic sedimentary rocks that are covered to the south and east of Cove Fort by Tertiary volcanic rocks (Steven and Morris, 1981; Figure 4). Intrusive rocks related to the volcanic activity are exposed at several places within the area.

Numerous reports and maps have been published on the geology of the CFS area. Ross and Moore (1985) provide an excellent summary. The sedimentary rocks of the CFS area are part of a broad, north-trending thrust belt deformed during the Late Cretaceous Sevier Orogeny. Rocks penetrated to depths of up to 7,700 feet in Union Oil Company's deep geothermal wells consist largely of limestone and dolomite that were variably metamorphosed by Tertiary intrusions (Figure 5). Sandstone occurs near the top of the sedimentary sequence

The Tertiary volcanic rocks erupted between about 30 and 19 m.y. ago from widely scattered centers in two distinct volcanic terranes – the Marysvale volcanic field of the southwestern High Plateaus to the east of Cove Fort and the Basin and Range to the west. They include lava flows, volcanic breccias and thick sequences of ash flow tuffs

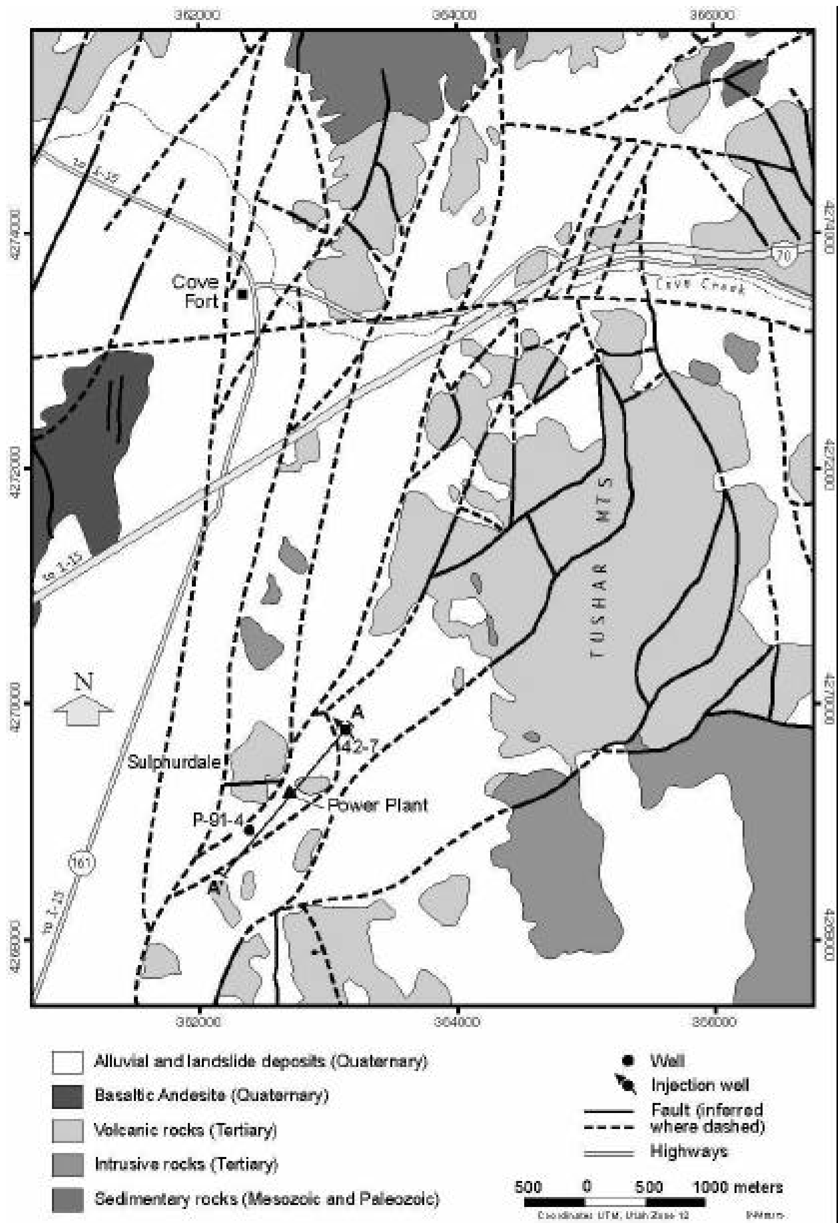

Figure 4. ***Simplified geologic map of the Cove-Fort–Sulphurdale area (modified from Steven and Morris (1981) and Ross and Moore (1985)).***

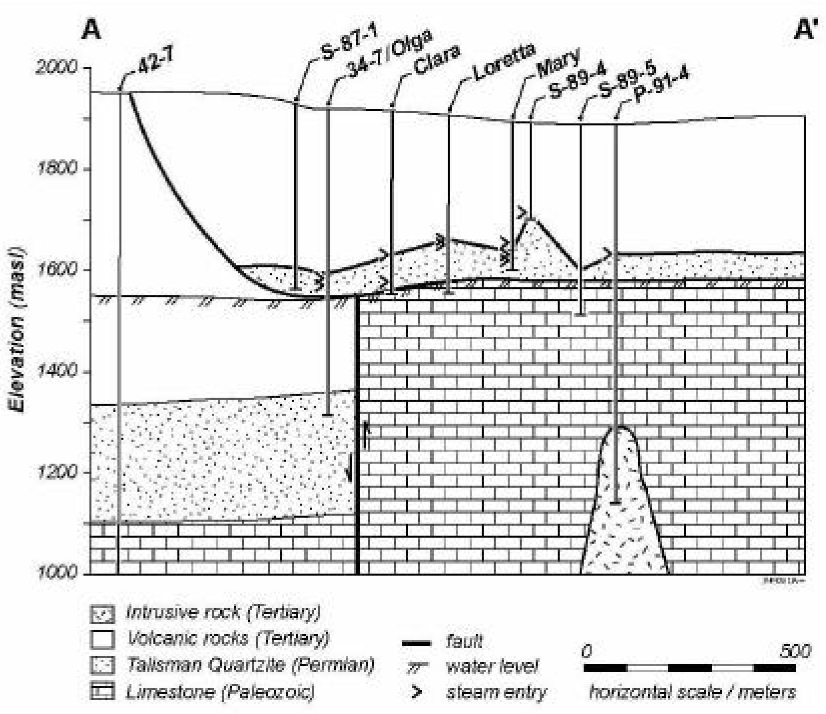

Figure 5. ***Northeast-southwest cross section showing the distribution of rocks encountered in the wells. See Figure 4 for the location of the cross section.***

derived from local and distant sources. The base of the volcanic sequence near Cove Fort consists mainly of locally derived lava flows and breccias of intermediate composition (Steven and others, 1979). The upper parts of the Tertiary volcanic sequence consist predominately of ash-flow tuffs. Some of the units reach thicknesses of several thousand feet. Many of the ash flow tuffs are distinctive and widely distributed, and they are important marker horizons that have allowed detailed mapping of structures within the geothermal field (Moore and Samberg, 1979; Steven and Morris, 1981).

Renewed volcanic activity between 1 m.y. and 0.3 m.y. ago produced a shield volcano in the Cove Fort basalt field (Steven and Morris, 1981). Callaghan (1973) and Steven and others (1979) have suggested that the heat source of the Cove Fort-Sulphurdale geothermal system may be related to this basaltic volcanism, but there is no direct geochemical or thermal evidence to support this hypothesis.

In their review of the CFS area, Ross and Moore (1985) concluded that geologic and geophysical data indicate that the geothermal system is controlled by faults and fractures. The oldest structures are thrust faults that disrupted the sedimentary rocks during the Sevier Orogeny. Thrust faults may be widely distributed at depth in the reservoir rocks of the thermal area. Since Basin and Range tectonism began in the mid-Miocene (Steven and others, 1979), rocks of the CFS area have been disrupted by both high- and low-angle northerly and easterly trending normal faults. Continued activity is indicated by fault scarps in the alluvium and lava flows of the Cove Fort basalt field (Steven and Morris, 1981) and by a high level of microearthquakes in the vicinity of Cove Fort (Smith and Sbar, 1974). Here, at Sulphurdale, and along the western margin of the Pavant Range, the trends of the faults are marked locally by the alignment of sulfur deposits, acid-altered alluvium, and gas seeps.

Low-angle faults bound extensive gravitational glide blocks between Sulphurdale and the steeply dipping Cove Creek fault, which parallels Interstate 70. These westerly dipping low angle faults display pronounced arcuate trends in plan view (refer to Figure 4). The gravitational glide blocks form a nearly impermeable cover over the geothermal system that has profoundly influenced the distribution of the surficial alteration and shallow temperatures and thermal gradients along the northwestern flank of the Tushar Mountains (Ross and Moore, 1985).

EARLY EXPLORATION

The Thermex Company took the first fee geothermal leases in the CFS area in 1972 (Huttrer, 1994). In 1974, when the Federal geothermal regulations went into effect, a "land rush" began and fee, federal, and state leases were acquired by numerous companies, including AMAX (later Steam Reserve), Phillips Petroleum Company, Chevron Resources Company, Hunt Energy Corporation, and Union Geothermal Division. Also holding federal leases in the CFS area were Earth Power Corporation and the Grace-owned companies of Thermal Resources, Inc. and U.S. Geothermal Corporation. Federal leases held by Earth Power and the Grace companies were subsequently farmed out to Hunt Energy.

The companies started a massive exploration effort in 1974. During 1975 and the following three years, numerous rigs were operating throughout the CFS area drilling temperature-gradient holes. Competition was strong and secretive, to the point that gradient holes were being locked to prevent others from logging them. The attempts at locking holes were not always successful and numerous cases of hole "break-in's" were reported to government agencies.

More than 200 temperature-gradient holes were drilled in an area of more than 100 square miles (260 km^2) . Ultimately, most of the companies agreed to trade data. The results showed that the drilling efforts had defined a shallow thermal anomaly that covered more than 70 square miles (181 km^2) . It was also discovered that, despite the immense size of the shallow anomaly and all of the surface geothermal manifestations, the deeper and hotter source of the anomaly was still an elusive target.

Between 1975 and 1979, Union Geothermal Division drilled four deep exploration wells to test the geothermal system. The first well, CFSU 42-7, recorded temperatures of nearly 350°F (177ºC) below depths of 5,000 ft (1,524 m) (Figure 6). However, the high cost of drilling, high corrosion rates, low reservoir pressures, and the apparent limited extent of the high-temperature reservoir led to a premature conclusion by Union Geothermal Division in 1980 that the field was not economic for large-scale electric power production (Ross and Moore, 1985).

Figure 6. Photo of the CFSU 42-7 wellhead.

RESOURCE DEVELOPMENT

In 1983, Mother Earth Industries, Inc. (MEI) obtained fee leases from Steam Reserve, geothermal leases on the patented mining claims from Forminco and the Union Geothermal Division federal geothermal leases. In October 1983, while drilling their first well, 34-7, MEI penetrated a 100-psi (690-kPa) , 350°F- (177ºC-) dry steam resource at 1,165 feet in fractured sandstone (Talisman Quartzite) below the volcanic rocks (Huttrer, 1994; refer to Figure 5). The drillers were unable to contain the steam, and the well discharged uncontrollably for 24 days. Oil field techniques had to be used to cap the well. Although the well was lost, this blow out demonstrated the existence of a shallow steam reservoir. In January and May 1984, MEI completed wells 34A-7 and 34B-7, within 200 ft (60 m) of the original well, as dry steam producers. They too penetrated the steam at about 1,160 ft (354 m) (Huttrer, 1994).

In 1987, MEI began a broad scale exploration program that included a soil mercury survey and several geophysical studies, together with the drilling of slim diameter wells offsetting the existing steam production wells. The geophysical work included self potential (SP), ground magnetic, and controlled-source audio magnetotelluric (CSAMT) surveys. Based on the results of these surveys, ten new temperature gradient holes were drilled to an average depth of 100 ft (30 m) at sites around the Sulphurdale fee lands (Huttrer, 1994).

Following the encouraging results of the 1987 exploration studies and drilling, MEI drilled six slim holes and twinned three of them with production-scale wells in 1988 and 1989. All of the production wells and all but one of the slim holes produced steam from the Talisman Quartzite. Flow tests of these wells showed that permeability within the steam cap was very high and that all of the wells were hydraulically connected. No wells were drilled in 1990, but in 1991, steam pressure losses due to increased power plant demands dictated the need to explore for the hot-water reservoir long thought to underlie the steam cap. Well P91-4 was drilled at the northwest corner of the Sulphurdale pit (Figure 7). It encountered a 315°F- (157ºC-) liquid-dominated geothermal reservoir in Paleozoic carbonate rocks at a depth of about 1,800 ft (550 m) (Huttrer, 1994). Small amounts of steam were produced before the well hit the water table at 1,050 ft (320 m), but these zones were cased off.

Figure 7. Photograph of well P91-4. The well is equipped with a pump.

UTILIZATION

The CFS geothermal resource was developed in three phases. Construction of the first phase began in 1984 and came online in 1985. It consisted of four ORMAT binary units that used isopentane as a working fluid. These units had a combined generating capacity of approximately 1.5 MW_e . Figure 8 shows an overview of the plant and Figure 9 shows one of the four ORMAT binary units.

The second phase of development started in March 1988 with a non-condensing topping turbine capable of producing 1.8 MW_e . Both of these phases utilized steam from two wells on the federal lease. A third phase, consisting of a condensing turbine with a 7.5 MW_e capacity, was constructed in 1990 and utilized steam from three wells located on the fee land (Figure 10).

Figure 8. ***Overview of the power plant. The sulfur deposit and Cove Fort volcano are in the background.***

Figure 9. ***One of the ORMAT binary units.***

Figure 10. ***The condensing turbine.***

From mid-1992 to April 1994, steam production from the federal wells was stopped, but wells on the fee land continued to produce steam for the 7.5-MW_e condensing turbine. Normal operations resumed in April 1994. In May 1996, the water well, P91-4, was put into production and the non-condensing topping turbine was removed from the system. Subsequently, all five steam wells and the water well supplied steam to the condensing turbine. A dual flash system was used to separate steam from water produced by well P91-4. The steam produced in a high-pressure separator supplied steam to the condensing turbine. The separated water from the high-pressure separator was flashed again in the low-pressure separator. This low-pressure steam was used in the ORMAT binary units to produce additional electricity. The separated water from the low-pressure separator was injected back into the reservoir through well CFSU 42-7.

About 1992, MEI sold the resource and property to the city of Provo, Utah and the Utah Municipal Power Authority (UMPA). Electricity was provided to five Utah cities. In June 2003, Provo and UMPA sold the plant and resource to Recurrent Resources. The plant has been shut down since the sale. No plans have been released by Recurrent Resources to restart the plant or for further development of the resource.

ACKNOWLEDGMENT

Photographs by Roger Bowers, Ely, NV and geologic maps by Joe Moore, EGI, Salt Lake City, UT.

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CRYSTAL HOT SPRINGS - SALT LAKE COUNTY

Jon Allred
Utah Energy Office
Salt Lake City, UT

INTRODUCTION

For more than 100 years, Crystal Hot Springs has provided geothermal water to a wide variety of community uses. At present, these uses include building heat for dormitories at the Utah State Correctional Facility, a commercial greenhouse next door to the prison and a fish farm nearby. Well known from pioneer times, this collection of geothermal springs and ponds are located 15 miles (24 km) south of Salt Lake City and should not be confused with Madsen's Crystal Hot Springs, another geothermal resource located about 70 miles north in Box Elder County. Unlike Madsen, which is highly saline, the Draper resource produces salts and sulfur mild enough for watering cattle, and meets state standard as a secondary drinking water source. However, dissolved oxygen and other water chemistry still require careful management to prevent pipe corrosion and mineralization. Current regional drought conditions have reduced geothermal flow. Still, with careful management, Crystal Hot Springs can support new commercial uses in addition to those in place.

GEOTHERMAL RESOURCES

Located adjacent to Interstate 15, Crystal Hot Springs is an artesian geothermal flow that fills a number of ponds and a small lake that scuba divers have measured at more than 50 ft (15 m) deep. In 2003, temperatures were reported at 195EF (91ºC) in a 400-ft (122 m-) deep production well, consistent with other reports and investigations done over the years. Occasional well pump testing over the last 30 years consistently reports artesian flow at 600 to 1,000 gallons per minute (38 - 63 L/s). Pumping of geothermal well water causes a corresponding immediate decline in artesian flow. Elsewhere in Salt Lake Valley, groundwater measurements since about 1930 show a steady decline in water table of 15 to 40 ft (5 - 12 m)(Haradan, 2003). The primary cause of this decline is believed to be well pumping, although periods of apparent recharge coincide with high levels of annual precipitation.

Northern Utah is characterized as cold desert, with total annual precipitation seldom exceeding 15 inches (38 cm). Crystal Hot Springs is located at the south end of the Salt Lake Valley at about 4,550 ft (1,387 m) elevation above sea level. As such, winter low temperatures may reach 0ºF (-18ºC); while, summer high temperatures commonly reach 100ºF (38ºC) . Windy conditions are frequent, because mountains to the east and west form a funnel in whose path the springs lie, and there is little micro terrain or vegetation to block air flow. The area experiences about 270 sunny days per year, although conditions around nearby Traverse Ridge are known for storminess. Atmospheric humidity can descend to as little as 20 percent, relative. Soils are typically alkaline.

Crystal Hot Springs is within the municipal boundary of Draper City, a 400-square mile (1,037-km^2) geographic basin underlain by groundwater in unconsolidated deposits. Salt Lake Valley is bounded by the Wasatch Mountains on the east and the Oquirrh Mountains on the west. The Crystal Hot Springs geothermal system rises from the northern base of an east-west ridge known as the Traverse Range (Murphy and Gwynn, 1979). This feature is intermediate in elevation between the Wasatch Range to the east and the valley grabens to the north and south. A series of northeast striking normal faults, with a combined displacement of at least 3,000 feet (914 m) separate the Traverse Range from the Jordan Valley graben to the north. The spring system is located between two closely spaced range-front faults that are intersected by a north-northeast striking fault.

The Wasatch Mountain fault system exhibits predominately vertical movement, and represents the longest and most tectonically active geologic structure in Utah, with abundant evidence of surface rupturing events. The Wasatch fault is crosscut by numerous underlying, older faults and folds that complicate understanding of geothermal resources found on both slopes of the range. The entire region is also part of the Intermountain Seismic Belt and, as such, produces terrestrial heat flow averaging about 107 milliwatts per square meter (mW/m^2). In contrast, the adjacent Colorado Plateau region to the east exhibits average terrestrial heat flow of about 57mW/m^2.

The geothermal system is fed by mountain rain and snowfall that descend through fractured bedrock before returning to the surface by convection and artesian flow into overlying unconsolidated alluvium (Blackett and Wakefield, 2003). The Crystal Hot Springs resource is considered to be fault-controlled, with geothermal energy rising from normal heat flow of the Basin and Range province, rather than by cooling of igneous rock at depth (Murphy and Gwynn, 1979).

The surface expression of Crystal Hot Springs consists of several springs found within a 70-acre (28-ha) area that lies mostly within state prison property (Murphy and Gwynn, 1979). Some of the springs feed small ponds located at the eastern edge of the geothermal zone, while others are present at the bottom of Crystal Pond, a small lake at the western edge of the geothermal resource.

Chemistry tests in 1979 reveal silica, calcium, magnesium, sodium, and related minerals in concentrations below 230 parts per million (ppm). Chlorine was found to be higher, at 590 ppm. Total dissolved solids (TDS) registered 1,462 ppm in 1979, which is slightly lower than tests done more recently that found TDS at about 1,750 ppm. In contrast, pH was measured at 5.9 in 1979, somewhat more acidic than recent test results that ranged from 6.0 to 6.5. One test indicated pH at 7.6, total suspended solids (TSS) at 14 mg/L and TDS at 1,810 mg/L (Murphy and Gwynn, 1979). Well pumping tests in 1979 proved steady flow at 650 to 1,000 gpm (41-63 L/s) (Murphy and Gwynn, 1979). Water quality testing done for discharge permit approval indicated levels of arsenic, managanese, radium, potassium, various chlorides and radium slightly higher than found in Jordan River receiving waters. In 2003, a nearby well tested to a maximum flow of 1,100 gpm (69 L/s). However, neither of these tests examined the cone of depression, nor projected rates of recovery. Temperature gradient testing found an elliptical area 200 hundred yards (183 m) wide in which soil temperatures exceeded 190ºF. A roughly concentric area 600 yards (550 m) wide tested to at least 90ºF (32ºC) at a depth of 200 ft (61 m). It is believed, but not verified, that the Crystal Hot Springs resource is a limestone reservoir, resulting in production of CO_2 that may supply some corrosive effect in spite of best efforts to keep oxygen and other gases from entering at points in the mechanical system above ground.

GEOTHERMAL USES

Crystal Hot Springs has been commercially exploited since the late 1800s, supporting a brewery, stock watering, log floating, a recreational resort that burned down in the 1920s, beaver raising and a country inn. At present, geothermal water is used for production of fish for commercial sale, greenhouse production of cut flowers, and building heat at the prison. As such, Crystal Hot Springs may be one of the better examples of multiple-use development of geothermal energy in the region.

Prison Building Heat

In 1983, the Utah Department of Corrections installed a geothermal well and heat exchange equipment to supply space heat to Oquirrh 4, a minimum-security dormitory facility that also included a gymnasium, offices and a cafeteria. That equipment met winter season building heat requirements and year-round hot water needs for Oquirrh 4 until sometime during 1985, when corrosion resulted in severe pitting of stainless steel pipes. Mineral build-up also caused pump shaft failure. Both wells were abandoned in place, along with the original heat exchanger and related equipment. Since then, the discharge permit for one well has expired and its location has been lost to memory. Prison officials and Johnson Controls plan to eventually search for the missing well, determine if it can be rehabilitated, and verify whether or not lapsed water rights and state permits for pumping and discharge can be renewed.

In 2003, the State of Utah Department of Corrections contracted with Johnson Controls, a world-wide energy service company (ESCO) to re-establish a geothermal building heat and culinary water system in two phases. This new geothermal facility is part of a larger contract awarded to Johnson Controls for improved facilities management at the Draper prison, the largest correctional facility in the region. The overall contract improvements for energy, water and waste management services is worth $5.7 million. Energy control measures (ECMs) include the installation of more efficient lighting and motors, use of digital building climate controls and the two-phase geothermal system.

The Johnson Controls performance guarantee calls for annual savings of about $228,000 on energy improvements, and $175,000 in annual savings for improvements in water, sewer and solid waste handling. For performance comparison purposes, base year energy consumption at the prison complex totals 19.5 million kWh and 1.85 million therms (195 kJ) of natural gas for about 1.1 million square feet (102,000 m^2) of buildings (Johnson Controls, 2003).

Phase I of the geothermal portion of the project calls for supplying culinary hot water and building heat for the Oquirrh 4 complex. Built in 1987, each of the four units at Oquirrh 4 contains 9,714 square feet (902 m^2) of floor area. All units are constructed of hollow concrete masonry, built-up roof and single pane windows. These units were originally heated by ducted forced air coils supplied with steam from a campus distribution system fired by natural gas. That mechanical system is still in place, and can be supplied interchangeably by either campus steam or hot water from the geothermal-plate-and frame heat exchanger (Figure 1).

Figure 1. ***Plate-and-frame heat exchanger (Bruce Munson, Johnson Controls).***

Phase I geothermal improvements refurbished one of the old geothermal wells, installed a line-shaft constant speed pump on the geothermal side, new heat exchange equipment, and variable speed drive for heat control on the building side (Figure 2). Among other things, the holding tank from the 1983 system was removed as part of effort to prevent air intrusion that is believed to contribute to corrosion and mineral deposition. The constant speed pump installed in Phase I is set at 240 gpm (15 L/s) on maximum capacity of 300 gpm (19 L/s). Entering water temperature is about 185EF (85ºC) . The system uses the existing coil and fan equipment from the original steam system. A variable-speed drive on the clean side governs the rate of heat exchange, with a 40EF (22ºC) drop in geothermal temperature being an efficiency goal. Actual discharge water temperature is about 160EF (71ºC) . Constant-speed pump pressure is applied to the geothermal side in order to prevent precipitation of minerals that might otherwise occur during periods of slack demand.

Figure 2. Heat exchange building with wellhead and pump in foreground.

Johnson Controls avoided installing probes for flow measurement piping in order to reduce the number of potential places where air intrusion could occur. Instead, a sensor to measure geothermal heat is in place to calculate energy passing through the heat exchanger. Strainers that would normally be in place have also been omitted in order to reduce points of potential corrosion. Piping on the geothermal side is made of fiberglass-reinforced plastic, considered a good general alternative to stainless steel for chemical and temperature conditions at Crystal Hot Springs. The vertical turbine pump is located seven feet (2 m) down a 1,000-ft (305-m) deep well, and is a Bell and Gossett enclosed lineshaft, 12-in. (30-cm) conductor casing to 40 ft (12 m), 4-in. (10-cm) pump column, 6-in. (15-cm) Schedule 40 liner to 1,000 ft (305 m), slotted bull nose entry below pump bowls and impellers.

At the time Johnson evaluated the existing heating system at Oquirrh 4 (Figure 3), the heat recovery system was in poor condition, and variable air volume vanes were fixed in place and inoperable. Meanwhile, to meet air quality needs, 100 percent outside air is still used for both ventilation and winter heating. As such, there is no return air circuit, resulting in substantial heating system inefficiency. Thus, Johnson Controls estimates that use of geothermal heat probably saves more in natural gas for the Oquirrh 4 facility than its proportionate share of square footage served by the overall prison gas-fired steam facility. As is common with large institutional uses, general lack of sub-metering at the correctional facility prevents the accumulation of itemized data on cost savings.

Figure 3. Oquirrh 4 Complex.

Thermostatic controls are set higher on the campus steam side to prevent heat from that system entering the Oquirrh 4 loop unless geothermal flow fails. During the first six months of geothermal system operation, natural gas-fired steam has been needed only once, when the geothermal pump failed due to ingestion of well debris left from the 1983 geothermal system. As expected, system controls made a smooth switch to campus steam heat when the geothermal pump failed.

Phase II geothermal development, planned for late 2004, calls for replacement of the fixed speed 10-horsepower (hp) (7 kW) geothermal well pump by a 25-hp (19-kW) variable-speed drive that can potentially deliver up to the full water right of 750 gpm (47 L/s). The practical expectation is for a base load of about 600 gpm (25 L/s). A second heat exchanger will also be added. This larger geothermal flow will continue to supply space heat for the Oquirrh 4 cell block, and will also supply the prison furniture shop, sewing shop, and Special Service Dormitory (SSD). Altogether, geothermal heat will eventually supply space heat and culinary hot water for a total of 252,350 square feet (23,440 m^2) of building area.

Under Phase II, geothermal input temperature is expected to reach 185ºF (85ºC) or higher, dropping to 165ºF (74ºC) at discharge during warm weather and 135ºF (57ºC) in winter. A variety of other improvements will be needed to ensure system performance, including fan/coil unit heaters in the prison industry buildings, upgraded insulation and thermostats in individual sections. Phase II improvements will continue to send the usual 200 gpm (13 L/s) discharge flow to prison fish ponds. However, discharge by buried pipe to the cooling pond will rise from about 40 to 400 gpm (2.5 to 25 L/s) or more. After Phase II geothermal improvements are operational, the existing back-up boiler will be considered for retrofit to better fit with the geothermal system.

Phase I of the geothermal performance contract calls for capital expenditures of $519,000 intended to produce guaranteed annual energy savings of $68,944 in deferred natural gas cost. Those savings are tempered by an expected base increase of $1,068 in additional annual electricity charges for pumping geothermal fluid and electronic controls. Geothermal improvements are projected to have a payback period of 7.6 years, and a predicted equipment life of 17 years. In contrast, the overall performance contract has a combined estimated payback period of 15 years. Phase II geothermal improvements are expected to cost a total $1,523,611, and should produce annual natural gas savings of $123,813, offset by an increase in electricity cost of $69,145 for pumping geothermal water. Phase I became operational in January of 2004, providing initial monthly savings of $17,000 in deferred natural gas costs.

Bluffdale Flowers

In 1981, Utah Roses established a commercial greenhouse using 450 gpm (28 L/s) of geothermal water pumped from a 1,000-ft (305-m) deep well on property located immediately adjacent to the prison. That facility was sold and renamed Bluffdale Flowers in 1998. In the interim, some 250,000 sq ft (2.3 ha) of greenhouse space was constructed for raising roses and other ornamental flowers (Figure 4).

Figure 4. ***Interior of Bluffdale Flowers greenhouse with finned-tube heating system.***

In 1983, at about the same time the prison was developing its first attempt at geothermal building heat in 1983, Utah Roses used U.S. Department of Energy funding to install a geothermal production well at a commercial greenhouse located in Sandy City, about five miles north of Crystal Hot Springs. Well depth eventually reached 5,000 ft (1,524 m), but produced only about 200 gpm (13 L/s) of water at 120ºF (49ºC) and was therefore abandoned. Eventually, the entire greenhouse operation in Sandy was also abandoned and operations were consolidated at the Crystal Hot Springs site.

At present, Bluffdale Flowers uses a 40-hp (30-kW) lineshaft pump running at constant speed to supply geothermal water from a well depth of about 200 ft (61 m) (Figure 5). Space heat is provided through plate-and-frame heat exchangers showing an intake temperature of about 190EF (88ºC) and discharge temperature of 140EF (60ºC) (Figure 6). There is no back-up heat system, and indoor greenhouse temperatures on winter nights may descend to near freezing. A brief experiment with by-passing the heat exchanger caused rapid mineral fouling of capillary piping. Discharge water travels by 8-in. (20-cm) pipe to Crystal pond where it cools to about 80EF (27ºC) before traveling about 1,000 ft (305 m) by open ditch to a Hi-Tech Fisheries, a downstream user of geothermal water (described below).

For several years, attempts were made to re-inject spent geothermal water for aquifer recharge. However, artesian effect and slow permeability resulted in surface leakage and pump failure. After deliberation, the State of Utah Division of Water Rights was persuaded to grant a permit for surface discharge of spent fluid. As such, even though greenhouse use of heat-exchanged water is a “non-contact” use of the geothermal resource, surface disposal exposes the fluid to chemical alteration. Geothermal pumping is limited to the cool months of September to May each year during the hours of 4:00 p.m. to 8:00 a.m.

Figure 5. ***Lineshaft pump at Bluffdale Flowers (Jack Kaleel).***

Figure 6. ***Plate-and-frame heat exchanger (Stan Goldberg).***

The state-issued discharge permit requires semi-annual water tests for metals, including cadmium, copper, lead, mercury, radium and others. Some concern has been raised regarding tests of discharge water that show TDS at 1,700 ppm, close to the state maximum limit of 2,000 ppm, and pH readings as low as 5.9.

Bluffdale Flowers is in the process of expanding greenhouse space from 250,000 to 500,000 sq ft (2.3-4.6 ha). To provide winter space heat, discharge water at about 140EF(60ºC) will be re-heated using natural gas boilers to about 180EF (82ºC) and circulated through that additional space before discharging en-route to Hi-Tech Fisheries further downstream.

Water rights total about 1.95 cubic feet per second (55 L/s), which would allow Bluffdale Flowers to augment geothermal flow by running the idled re-injection pump in reverse, resulting in a potential doubling of geothermal flow to about 900 gpm (57 L/s)

Bluffdale Flowers managers note that artesian flow is substantially lower in 2004, compared to recent years, as evidenced by the fact that natural ponds are nearly empty during early summer. Ordinarily, these ponds would actually deepen as summer progresses, due to cessation of greenhouse and prison use of geothermal water during previous cool months. Informal discussion among various parties in the area suggest that persistent regional drought conditions account for a large fraction of diminished geothermal spring flow. More recently, discussion has focused on the possible role of prison geothermal pumping as a cause of spring flow reduction for other geothermal users. These concerns add interest to the widespread belief that water rights have been over-appropriated by the State Engineer. As noted above, regular groundwater monitoring in Salt Lake indicates that wells have caused a steady decline in water table across several decades (Haradan, 2003).

Other Commercial Geothermal Uses

In the past, a number of aquaculture operations have used discharge water from either the prison, Bluffdale Flowers or directly from Crystal Pond, the largest of several ponds fed by Crystal Hot Springs. The most successful of these downstream geothermal users is Hi-Tech Fisheries, a 25-year old commercial producer of tropical fish based around Crystal Pond. Hi-Tech is a contract operator on behalf of Utah Corrections Industries, an enterprise of the state prison system. As such, the land, water rights and facilities are largely state-owned. Labor is provided by prison inmates.

Crystal Pond varies widely in size, up to about 3.0 acres (12 ha), but currently covers only about 1.0 acre (0.4 ha) in surface area due to persistent regional drought conditions. The pond was once host to a large variety of fish but is presently occupied only by a few hardy species of low-value fish that help control mosquitoes. Hi-Tech Fisheries uses discharge water from Bluffdale Flowers and from the prison geothermal facility to feed Crystal Pond, which is also supplied by artesian springs. Discharge water from Bluffdale Flowers leaves that facility at about 140EF (60ºC) , and travels through a succession of 8-in. (20-cm) piping, open ditches and intermittent ponds before arriving at Hi-Tech at an acceptable temperature of about 80EF (27ºC) . Discharge water from the prison geothermal facility travels entirely by pipe to Hi-Tech. Together, this flow moves successively through covered greenhouse space totaling about 4,500 sq ft (418 m^2), occupied by some 80 fish propagation tanks that vary in size from 200 to 1,000 gallons (760-3,786 liters) (Figure 7). Many of the fish originate from Africa's Lake Malawi, where water conditions are similar to those produced at Crystal Hot Springs. At times, this facility has also produced a variety of vegetables for commercial sale, including corn, tomatoes, squash and peppers. Propagation of aquarium plants for retail sale was also tried for a time, but proved unsuccessful.

During cold weather, geothermal water may arrive at fish tanks at temperatures as low as 60EF (16ºC), only marginally viable for fish propagation. In the past year, Hi-Tech also reports that combined inflow to Crystal Pond is down by about 50 percent from average years, resulting in the pond's lowest water level in 30 years. As a result, Hi-Tech currently re-circulates its own outfall water back into Crystal Pond in order to maintain adequate supply to the fish tanks. Concern has been raised by Hi-Tech that declining water supply may also be due, in part, to recent re-establishment of prison geothermal use, and recommends that consideration be given to circulating additional prison geothermal discharge water through Hi-Tech before final outfall to wetlands or the Jordan River.

Figure 7. ***Fish propagation tanks (Hi-Tech Fisheries).***

At present, about 200 gpm (13 L/s) of geothermal outflow from the prison goes directly to Hi-Tech. The remaining 40 gpm (2.5 L/s) is sent to a cooling pond that is planned for eventually serving new wetland development. About 450 gpm (28 L/s) of geothermal discharge flows toward Hi-Tech from Bluffdale Flowers, although an unknown amount is lost to evaporation and seepage along that path. Hi-Tech does not directly measure the combined total of inflow to Crystal Pond from these various sources. Discharge water from Hi-Tech Fisheries ordinarily travels about 800 ft (244 m) in a ditch to a collector canal running through farm fields before either percolating fully into soil or reaching the Jordan River.

Original plans called for discharge of geothermal water from the prison to percolate into the soil through open ditches, with no significant surface flow off-site. However, the need for mosquito abatement resulted in re-direction of geothermal water through a buried 14-in. (36-cm) concrete pipe running about 1.5 miles (2.4 km) before entering a cooling pond. The pond is designed to overflow into the Jordan River through a culvert running under the Bangerter Highway, reaching the river at a temperature close to ambient.

UDOT Wetland Development

The Utah Department of Transportation (UDOT) plans to take geothermal discharge water, in combination with other surface flow, to create a new wetland in the area below the lowest pond at Crystal Hot Springs. This end-use of geothermal water helps fulfill UDOT need for wetland creation to offset loss of wetland caused by highway development elsewhere. As such, geothermal water is expected to reach ambient temperature before entering the river, having dissipated heat through a combination of at least three different beneficial uses and passing through thousands of feet of ditches and piping before disposal.

Crystal Springs Fisheries

A second aquaculture facility is also using geothermal waters in the area–Crystal Springs Fisheries, located just outside the Correctional Facility. Spring water at 80°F (27°C) feed 12,000 ft^2 (1,115 m^2) of indoor fiberglass tanks and raceways under three greenhouses covering a little less than an acre (0.4 ha). These consist of 200 tanks at 150 gal (568 liters), 350 at 250 gal (946 liters) and 14 raceways. Between 667 and 833 gpm (42 and 53 L/s) are used on the average with approximately double this during peak periods. Approximately half a million cichlids (tropical fish from Africa) are raise annually.

SUMMARY

Crystal Hot Springs will continue to provide water and energy for community uses into the foreseeable future. Further study of resource hydrogeology could assist with long term planning for further economic development and help prevent conflicts between users and their respective water rights. There is ample supply of geothermal water for development of additional uses of Crystal Hot Springs, particularly with more careful delivery of outfall water from one use to the next.

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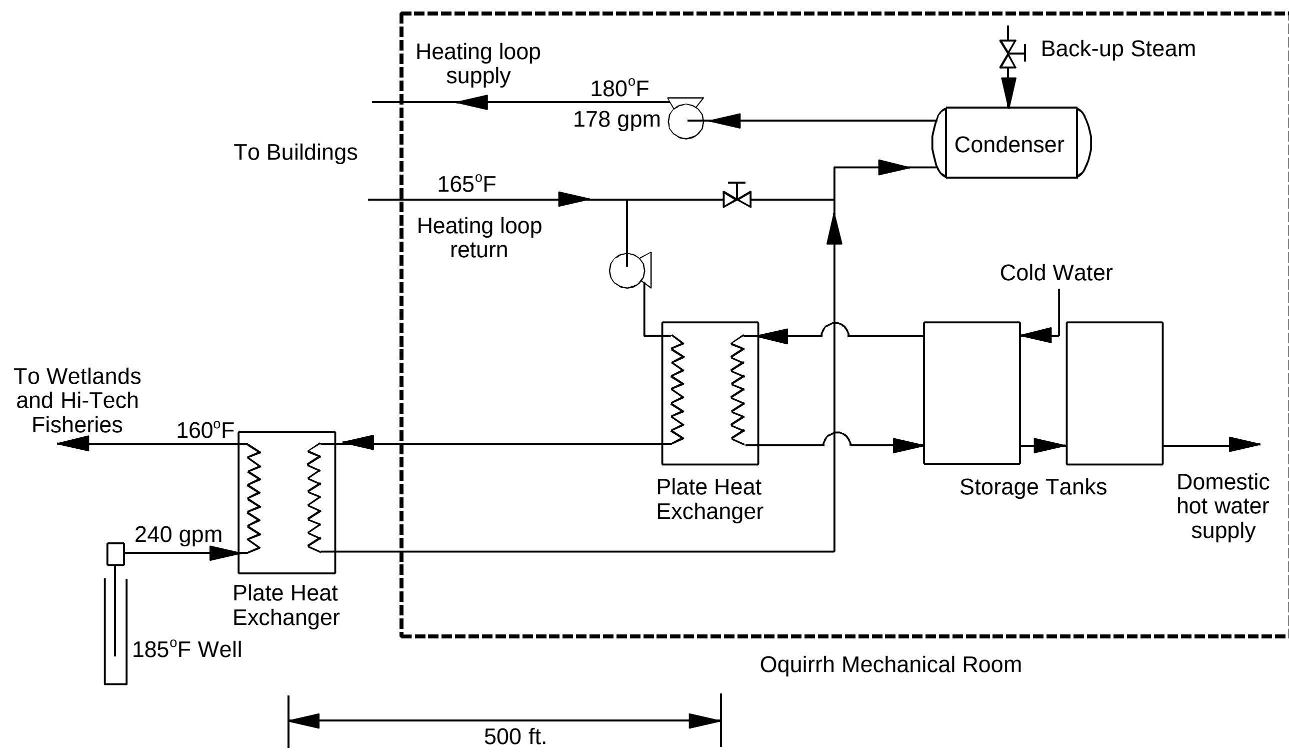

Schematic of the Utah Department of Corrections heat supply system to the Oquirrh building complex.

MILGRO GREENHOUSES NEWCASTLE, UTAH

Jon Allred
Utah Energy Office
Salt Lake City, UT

Figure 1. Milgro greenhouses.

INTRODUCTION

Milgro greenhouses in Newcastle, Utah may be among the most successful commercial application of geothermal water for space heating in the United States. This report describes a variety of factors that affect direct use of geothermal water for agriculture in arid regions such as Utah.

THE MILGRO COMPANY

The Milgro commercial nursery operation is located in Utah's Escalante Valley, 35 miles (56 km) west of Cedar City. Operations began in 1993 with 527,400 sq ft (4.9 ha) of greenhouse space for production of cut flowers for retail sale. Facility expansion occurred in large increments in subsequent years, resulting in a current total of more than 1.1 million sq ft (10 ha) of enclosed space as of 2004. The Newcastle facility is part of more than 3.3 million sq ft (30.6 ha) of greenhouse space currently owned by Milgro. The Newcastle site is now the nation's largest producer of chrysanthemums, and Milgro recently acquired Royal Van Zanten, a Dutch company that was one of three major sources of chrysanthemum cuttings in the United States. Milgro now ships 30 million cuttings to other growers each year. In fact, thanks to the Newcastle site, the Milgro family of greenhouse operations is now one of the nation's largest growers of flower bulbs, after having produced no bulbs prior to Newcastle development.

Milgro's total covered area at Newcastle currently amounts to about 26 acres (10.5 ha), along with more than 200 acres (81 ha) in bare land overlying the geothermal zone. An existing total of wells on the property enable further expansion and perhaps further diversification of product lines. The combined production of Milgro's greenhouses ranks as the 11th largest in the United States. Currently, Milgro produces a total of more than 13 million potted plants and cut flower per year.

GEOTHERMAL RESOURCE

Location

The Newcastle geothermal resource is located at the southeastern margin of the Escalante Valley, in the transition zone between the Basin and Range and Colorado Plateau physiographic provinces (Blackett, et al., 1997). The geothermal upwelling is associated with the Escalante aquifer, and may be connected to the Cedar Valley aquifer at the northern edge of the northeast-running Antelope Range fault.

Geothermal energy in this area was accidentally discovered by the Christensen brothers in 1975 while drilling for irrigation water. Well temperatures reached 226ºF (108ºC) at a depth of about 300 ft (91 m). The outfall plume runs northwesterly, producing 197ºF (92ºC) water at the Milgro facility.

Milgro operations are located at the base of an alluvial fan on the north slope of the Bull Valley Mountains at an elevation of about 5,310 ft (1,620 m) above sea level. Surrounding slopes are composed of Tertiary ash flow, with the Antelope Range fault delineating the south and eastern boundaries of the valley. Geothermal production wells at Milgro run from 600 to 1,000 ft (180 - 305 m) deep, with the primary production zone at 300 to 600 ft (90 - 180 m,). At present, wells on Christensen property produce the hottest fluid, at about 250EF (121ºC). Exploratory drilling 20 years after original resource discovery yielded slightly lower temperatures and deeper water table. Those observations are consistent with the operational history at Milgro that indicates declining water level, and the predictable effect of drought conditions over the past five years. Geothermal fluid reaches 125EF (52ºC) at a church building in Newcastle, located at the eastern edge of the geothermal resource, which circulates geothermal water for space heating.

Investigations

The Newcastle geothermal resource is located at the southern end of Escalante Valley, an area of about 800 square miles (2,070 km^2). Groundwater levels in the area have declined steadily since 1950, showing no recovery during periods of above average precipitation (Christiansen, 2003). The declines are believed to be a result of continued large withdrawals for farm irrigation. Studies have defined a shallow, unconfined aquifer that channels the outflow of geothermal fluids into the subsurface of the Escalante Valley. The fluid cools by conduction and probably mixes with shallow groundwater at system margins. A maximum temperature of 266EF (130ºC) was measured in a 1981 geothermal exploration well that penetrated the upper edge of the geothermal aquifer outflow plume. Well water sometimes flashes to steam at the surface.

The Newcastle area was at one time listed within one of 13 designated KGRAs (known geothermal resource areas) in Utah, a designation that allowed competitive leasing for energy development on federal land, some of which overlies the higher elevations of the Newcastle resource (Blackett and Wakefield, 2001). As of 2004, only three KGRAs areas remain, two of which now host geothermal power generation facilities. As demonstrated by the accidental discovery at the Christensen farm, the Newcastle geothermal anomaly is considered a cryptic, or blind resource, with no natural surface manifestation. Geothermal fluid rises into apparent Quaternary alluvial fill, and then runs northwesterly at a shallow depth. Peak heat flow reaches nearly 9,800 milliwatts per square meter (mW/m^2), declining to about 500 mW/m^2 within a mile in any direction. Geothermal fluid contains approximately 1,100 parts per million total dissolved solids, with a pH of about 8.0, which is tolerably alkaline for most pipe types.

Chemical signatures of geo-thermometers placed intermittently since then also suggest a maximum resource temperature of about 266EF (130ºC). Exploratory drilling in the same location during the summer of 2001 yielded 243EF (117ºC). Two fresh-water, non-geothermal wells are located within 300 yards (275 m) of Milgro's geothermal production wells. That cold-water resource exhibits a pH of about 7.0 and very low conductivity. It is widely believed that farming operations in the region have been over-producing this ground water for more than 40 years. Long-term decline of the water table may have accelerated during drought conditions that are now in their sixth year. Groundwater moves northward from the slopes of the Dixie National Forest across the Escalante valley en route to a terminus underneath Sevier Lake. Much of that migration is intercepted by agricultural pumps in the Beryl area.

Indications are that the Newcastle geothermal reservoir is primarily meteoric, so it should recharge by atmospheric precipitation. If so, then regional drought conditions could indeed account for a large portion of the 90 ft (27m) of total head lost since 1990. Otherwise, a continuing steady loss of water table could indicate that the resource is either all, or part Pleistocene water, which originated from glacial flow. As such, the resource would be considered a relatively closed system, and less likely to recharge after drawdown.

Bore hole temperature gradient profiles from 1976 to the present exhibit a mixed picture of changes in temperature and water table level, from which conclusions regarding well production cannot be deduced (Blackett, et al., 1997). Persistent regional drought conditions complicate the picture by apparently accelerating water table declines and possibly causing some loss of production well temperature. However, in the absence of definitive flow testing, there is some indication from Milgro that an increase in pump withdrawal results in an increase, rather than a decrease, in resource temperature

Major declines in ground water in the region are accepted as fact, but seldom precisely measured. The Utah Geological Survey (UGS) has not been able to install monitoring equipment in any of the existing Milgro wells wells due to potential entanglement of cables and probes. However, several years ago, about 30 thermal gradient bores were made by the Utah Geological Survey to create a log of the vapor zone, or unsaturated area above the water table. Many bore holes have since collapsed, leaving perhaps five to eight holes in usable condition.

Tests of remaining holes in April, 2004 confirm that geothermal water levels have declined by an additional 15 to 30 ft (5 to 10 m) over levels measured in 1999 and 2001. As an alternative to using existing commercial wells and additional bore holes, UGS has suggested placing a separate monitoring well at the same 16-in. (41-cm) size as Milgro's two production wells, at a cost of up to $100,000. A 4-in. (10-cm) slim hole design is an alternative, at about $50,000.

In any case, isotopic shifts can be subtle, and finding a deuterium signature could require sophisticated evaluation. Results could indicate that the Newcastle resource is binary, a Pleistocene aquifer that is also permeated by meteoric flow. Additional study would be needed to determine the size of the reservoir and the permeability of its structure. Shutting down all geothermal pumps for several days could provide an opportunity to measure the rate of recovery in the immediate drawdown area, or cone of depression.

Milgro Company Issues

Milgro operations in California have not grown in recent years. Indeed, a number of independent greenhouse companies in California have closed, due to high cost of business in that state. That trend is consistent with strong business cycles in California that account for a large portion of overall economic growth in Iron County and other parts of southern Utah and Nevada. At the Newcastle site, land acquisition since 1998 totals more than 100 acres (40 ha), and greenhouse space expanded by about 500,000 sq ft (4.6 ha). Recent acquisition of Royal Van Zanten added sales along with some vertical integration of the market for plant cuttings. The opening of a Milgro-related trucking facility in St. George, 50 miles (80 km) south of Newcastle, assures adequate tractor-trailer capacity to meet required shipping requirements for volume and flexibility. In the past year, Milgro has expanded its refrigerated space by 20,000 sq ft (0.18 ha), for a current total of 80,000 sq ft (0.74 ha). Climate controls can be zoned to range from freezing to near ambient air temperature for forcing bulbs, hardening plant starts and storing product.

As is typical of western U.S. agriculture, Milgro relies upon a combination of migrant labor and highly skilled horticulturalists. Together, average Milgro employee income is well above minimum wage. Iron County business development incentives are intended to reward enterprises that help prevent social service burdens on hard-pressed public budgets.

In addition to its 1.1 million sq ft (10 ha) of enclosed space, Milgro leases a total of 140,000 sq ft (1.3 ha) of additional greenhouse space located 0.25 miles (400 m) east of Milgro's main operation. Due to persistent difficult business conditions, Milgro has no discretionary money for new plant investment, nor for geothermal investigative studies. The company has been soliciting potential business partners, particularly for cascade users of geothermal outfall. According to Milgro, the Utah tax structure is similar to, but more moderate than in California. Workman's compensation fund levies, in particular, are much lower in Utah. Fees and performance requirements for state, local and special district permits are both fewer and easier to meet than in California.

As noted for climate and transportation issues, the Newcastle location presents a mixed picture of advantages and disadvantages. On one hand, Iron County economic development strategy builds on the fact that Cedar City lies within one day's motor transport of 86 percent of the urban area of the mountain west and southern coast. Milgro ships to all 50 states, and substantial product deliveries reach as far east as Denver. However, the vast majority of deliveries are to southern California and San Francisco.

Newcastle is at a competitive disadvantage in being located almost 400 miles (644 km) from the wide variety of specialized services and supplies available in southern California. In recent years, business diversification in the Salt Lake City area has meet more of Milgro's needs, but is also relatively distant, at about 280 miles (450 km) from Newcastle. Milgro acknowledges that Cedar City has successfully developed a strong industrial economic base, but has little diversity in products and services of value to Milgro.

Regional transportation conditions may have influenced Milgro to acquire its own fleet of long-haul tractor-trailers as an independent, dedicated arm of the greenhouse business. At present, local industry makes heavy use of economical rail transportation for receiving large, homogeneous shipments of raw materials. However, most finished products are shipped out by tractor-trailer in smaller, more heterogeneous loads. The result is that the number of loaded outbound trucks outnumbers inbound traffic, requiring that additional empty trucks "dead head" into Cedar City to make up the difference. Premiums, or surcharges by trucking companies are considered by County officials to have a material effect on local manufacturing profitability. Meanwhile, Milgro recently expanded its own fleet from 15 to 18 tractor-trailers.

GREENHOUSE OPERATIONS

Introduction

The Milgro business commenced in 1980 with the Oxnard, California plant. The Newcastle facility is now the largest of their four greenhouse operations.. Land acquisition at Newcastle began in 1991, based on the region's desirable climate, low cost of land, relatively light regulatory burden and the presence of high quality geothermal water.

Acquisitions of additional land in 1998 and 1999 led to a 500,000 sq ft (4.6 ha) expansion of greenhouse space. Covered by arched, twin-shell plastic roof supported by fiberglass walls, Milgro's five greenhouse zones now total 1.2 million sq ft (11 ha), each zone capable of distinct climate control, including temperature, humidity and hours of sunlight. The "double poly" roof provides a dead air separation zone requiring fan-boosted pressurization and represents the industry's most cost-effective configuration for climate containment in this high-sunlight region.

Geothermal fluid is distributed through a series of pumps, actuated valves, forced air heaters, plastic tubing. Finned aluminum tubing was installed overhead in years past, when certain plant species required warm air, but cooler soil. That system is no longer in use.

Greenhouse zones are up to 1,400 ft (427 m) in length, with elevated rolling benches running crosswise above bare soil. Radiant heat is supplied by geothermal water running through 0.5-in. (1.3-cm) extruded polyethylene plastic pipe on 6.0 in. (15 cm) centers (Figure 2). In some zones, new cuttings are grown directly in bare soil, then transferred to pots for final growth in other zones (Figure 3).

Figure 2. Bench heating system.

Figure 3. *Bare soil heating system.*

Due to the mild nature of Newcastle geothermal water, heat exchangers have been by-passed and the fluid is run directly to greenhouse use. At any given time, any combination of four production wells may be in use. Well pump motors range in size from 30 to 100 hp (22 - 75 kW), with zone-level pumps of three to 15 hp (11 kW) supplying additional localized pressure. Production wells use "down-hole" or line shaft pumps that are less efficient than submersible pumps but are able to withstand the combination of temperature and pressure experienced at more than 300 ft (91 m) below ground. One production well motor is controlled by variable frequency drive (VFD) circuitry, which acts as an energy-efficient throttle.

Climate Automation

Quality control is vital to Milgro profitability. Uniformity in the number of leaves, buds and plant height are evidence of successful control of growing conditions. Newcastle's cold desert climate, characterized by low humidity and large seasonal and daily temperature swings, is hostile to outdoor plant growth, but helpful for controlling humidity and insect pests. A mild insect infestation can spread quickly, causing vast plant loss. Even in optimal conditions, plant loss averages 5.0 percent.

The geothermal system uses Q-Comm™ to control hundreds of valves for irrigation and heat control. This total includes main valves at geothermal pumps, 10 zone gates in each of three ranges, plus two other ranges with 40 controls each. Extensive controls are required in any greenhouse operation. At Newcastle, controls are relatively more extensive and precisely managed, resulting in somewhat higher cost for electricity and maintenance. Software also monitors outdoor conditions from a weather station installed on the roof, and can account for changes in wind as well, including potentially damaging high wind. Digital sensors can alter system settings in three minutes.

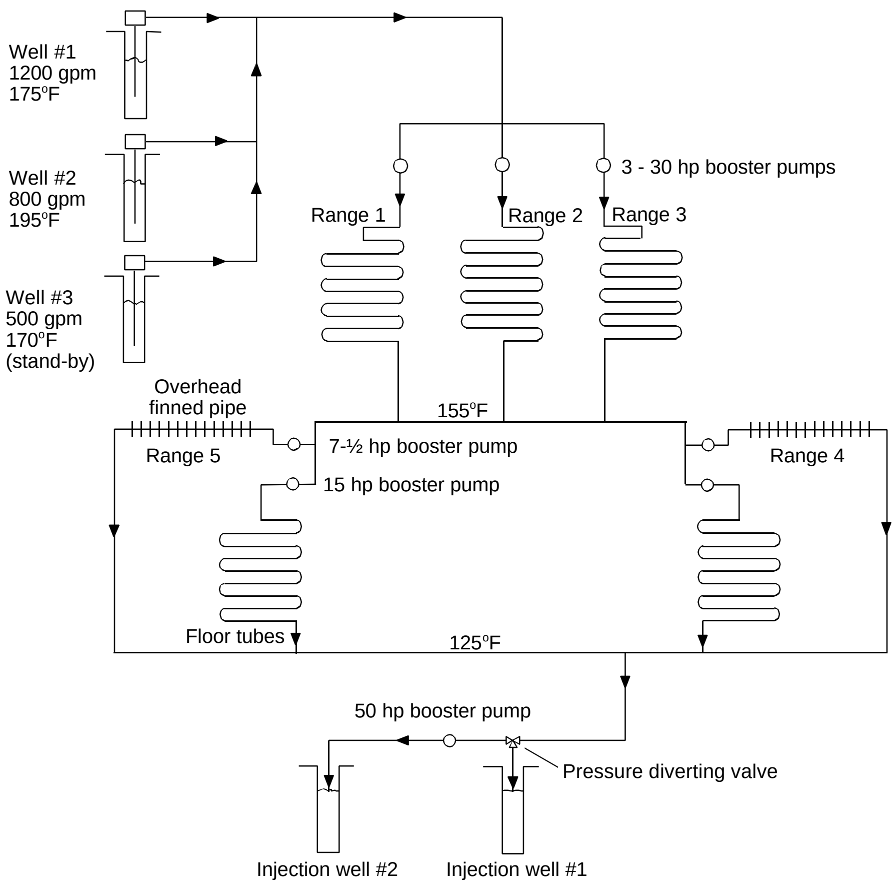

Figure 4. *Milgro greenhouse geothermal fluid flow. (Geo-Heat Center)*

Milgro has found that it is easier to screen out excessive sunlight in Newcastle than it is to add artificial light for plant growth when sunshine is lacking in climates with shorter days or more frequent cloud cover. Likewise, Milgro has found that it is far easier to induce necessary humidity in a dry climate than it is to remove excess atmospheric moisture during humid conditions often found in more temperature climates.

As noted, annual heating load is greater than cooling load because space heating is needed during cool evenings that prevail even in summer. Actual cooling load is also larger than indicated by average daily temperatures because strong day-night temperature swings are characteristic of Newcastle's climate. Milgro uses a variety of methods to cool the greenhouses and the energy implications are important.

First, automated vents, augmented by fans force unwanted air across the top of the shade cloth and out of buildings. The energy implications are important. Greenhouses in relatively humid climates may require natural gas heating to drive off humidity as a means of reducing pathogens. By contrast, excess humidity is not an issue at Newcastle. In fact, Milgro uses micro-mist equipment, running at water pressure up to 1,100 pounds per sq in, (7.6 MPa), and pad-and-fan evaporative coolers to simultaneously reduce greenhouse temperatures and increase humidity level. Air misting is designed to achieve full evaporation before leaf contact, thus achieving optimal air temperature reduction while avoiding leaf stains caused by minerals in irrigation water. Atomized moisture can achieve a 10EF (6ºC) temperature reduction at the leaf surface. Evaporative cooling can reduce indoor air temperatures by more than 20EF (11ºC). Both of these systems use water and electricity economically and can target individual greenhouse zones to closely match changing plant needs throughout different growth cycles.

Typically, Milgro's central digital processor seeks relative humidity at 75 percent on air temperature of 75EF (24ºC). Dead zones for digital response are 4EF (2ºC) and four percent humidity. Required humidity for forcing bulbs can be as high as 96 percent, and is economically provided by spraying water inside refrigeration units that total about 80,000 sq ft (0.74 ha) in floor area.

Milgro has nine available geothermal wells. Seven wells were developed for production, four of which were acquired as part of property purchases subsequent to initial development. Water temperatures coming out of the different wells vary from 170 to 240EF (77 to 116ºC). Wells are drilled to depths ranging from 500 to 1,000 ft (150 to 300 m), and completed with 16-in. (41-cm) slotted casing. The geothermal well production zone ranges in depth from 300 to 600 ft (90 to 180 m) underground. In 2004, Milgro plans to close and fill-in three production wells where sedimentation has reduced efficiency, and install three entirely new wells. Six other wells are in use or reserve, some of which can be used for either production or re-injection.

Milgro believes that, ideally, re-injection of geothermal water should occur 1.2 miles (1.9 km) up-gradient to ensure adequate access to the aquifer. Without formal analysis, they estimates a cost of $200,000 for the facility, which includes pipe, pump, land lease and other associated equipment. Milgro accepts the risk that re-injection of cooled water could have an effect on output temperature of production wells down-gradient. If that occurs, Milgro anticipates being able to regulate re-injection at an acceptable level.

The initial design of the greenhouse production system was based upon the use of plate heat exchangers to isolate radiant heating pipe from geothermal fluid. However, due to slow system response time, these heat exchangers were removed from the system in 1998. The benign chemical quality of Newcastle geothermal water causes little scaling or corrosion, also helping eliminate the need for heat exchangers. Milgro briefly used gas-fired boilers for supplying greenhouse heat, but found that response time was too slow to account for weather changes. Cycling boiler operation early only wasted energy.

Outdoor wind has not been a big problem for the greenhouse, even though high wind conditions are observed up to several times per year. A recent 70 mph (113 km/h) wind event caused no damage to the double-poly roof of greenhouse areas. An occasional micro burst is also observed, one of which pulled off a portion of fiberglass panel that was easily replaced. Automation software is also able to account for windy conditions, by closing wall vents as needed to protect equipment from damage.

Milgro's extensive use of automated mechanical means to control climate, adds somewhat to capital cost and operating expense. However, in relative terms, almost all greenhouses require extensive mechanical venting anyway, and digital control of motorized dampers results in slow, relatively inexpensive mechanical movements. Each of five climate zones is separated by vertical curtains. Retractable overhead shade cloth regulated solar insolation, and an additional overhead insulation curtains helps prevent heat loss during cold periods. These vertical separations are in additional to the two roof films that are themselves separated by a forced air current. The result is the ability to maintain temperature within 1-2EF (0.5 to 1ºC) of optimal, even as seasonal outdoor temperatures vary from –10EF to 105EF (-23 to 41ºC), and diurnal changes may swing by 40EF (22ºC). Without intervention, even a moderate outside temperature of 65EF (18ºC) can produce interior temperatures of 100EF (38ºC) or more.

In the past, Milgro burned natural gas for production of carbon dioxide (CO_2) to enhance plant growth in a portion of one greenhouse zone that totals 80,000 sq ft (0.74 ha). Gradual expansion of CO_2 use has been considered, but not decided, due to its potential value relative to cost of natural gas.

Water Quality

Ion control (pH) in Milgro irrigation water is considered the single most important chemical factor in successful control of production. Milgro tests irrigation water monthly, to account for seasonal fluctuations in salts. Newcastle irrigation water is moderate in sulfates, iron, and other precipitates. Boron is occasionally a problem. Geothermal water is not tested, as geothermal water is not in direct contact with plant materials. Observations of geothermal pipe interiors, and anecdotal reports by Milgro indicate that TDS, dissolved gases, including CO_2 and H_2S, are low to moderate in quantity. The result is a mild potential for precipitate deposition. Removal of plate heat exchangers some years earlier improved response time for overall geothermal heat transfer without incurring appreciable loss of wetted area for heat exchange at capillary ends of EPDM pipe. Tight bends, low velocity and potential air intrusion have apparently not caused appreciable mineral deposition, nor has Milgro reported persistent problems with heat transfer performance.

Maintenance

Maintenance is done on the geothermal heating system during summer, when geothermal load is low. Likewise, maintenance of the shade cloth system occurs during winter when shading requirements are low. Periodic change-out of geothermal production and re-injection pumps is required more frequently now than in the past, apparently due to increasing intrusion of sand into pump assemblies. The pump for the original well went six years without maintenance of any kind. More recently, overhaul of production pumps is expected to occur every three years, at a cost of about $10,000 if no problems are encountered. Overhaul of the re-injection well pump is similar. However, well maintenance is based on a sealed column of 200 ft (61 m) in depth, rather than 60 ft (18 m) to assure that re-injection waters go deep enough before dispersion. Re-injection pressures have caused well shaft erosion, resulting in the drilling of a second re-injection well further north, probably further from the aquifer recharge zone. Initial problems with corrosion at geothermal pipe valves was cured by use of Teflon parts.

Milgro #2 and #3 Greenhouses

As mentioned earlier, in addition to the main area of 25 acres (10 ha) of greenhouses owned by Milgro, they also lease two other complexes in the area. Milgro #2 consists of 60,000 ft^2 or 1.38 acres (0.56 ha), and Milgro #3 consists of 74,000 ft^2 or 1.70 acres (0.69 ha). Each has their own well, and both surface dispose of the wastewater into a pond. The wells, which vary from 170 to 220ºF (77 to 104ºC) use as much as 350 gpm (22 L/s). The estimated load factor is 0.44.

SUMMARY

Geothermal energy presents an opportunity to avoid fossil fuel expense. The added value of dry, sunny weather and the low cost of doing business in southern Utah are important coincident conditions. At present, geothermal savings by avoiding natural gas are offset by greater motor fuel expenses, so the qualitative advantages of the desert climate for greenhouse production stands-out as a factor in site location.

Milgro people emphasizes that geothermal should not be viewed as a basis for starting a business, but as an optional resource for an established, profitable activity. As such, even though geothermal energy and dry, sunny weather are phenomena of completely distinct origin their strong geographic coincidence in the United States suggests the value of considering them together, as Milgro has done. Milgro's relatively mild concern over the uncertainty of geothermal stability could be accounted for by the constancy of weather conditions that may be as much a factor in success as the geothermal resource.

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CASTLEVALLEY GREENHOUSES, NEWCASTLE

Robert Blackett
Utah Geological Survey
Cedar City, UT

John W. Lund
Geo-Heat Center

***Castlevalley greenhouses showing geothermal water supply lines*.**

BACKGROUND ON ESCALANTE VALLEY

Newcastle, Utah is a rural farming community located about 30 miles west of Cedar City, Utah along the southeastern edge of the Escalante Valley in Iron County. The Newcastle geothermal resource, low-to-moderate temperature hydrothermal system, was accidentally discovered in 1975 during an aquifer test of an irrigation well. Upon pump-testing of the well, Christensen Brothers--a local farming company (owners of Castlevalley Greenhouses)--discovered that the well had penetrated a geothermal aquifer. Termed a "blind" geothermal resource, there are no obvious surface manifestations such as hot springs or fumaroles to suggest that a geothermal system is present at depth. The water in the well was near the boiling point and reportedly flashed to steam when pumped to the surface. Subsequent studies by the University of Utah, Department of Geology and Geophysics (Chapman, et al., 1981), the Utah Geological Survey (UGS) (Blackett and Shubat, 1992) and the University of Utah Research Institute (Ross, et al., 1990; 1994) defined a buried zone of suspected geothermal upflow along the nearby Antelope Range fault that they postulate as the source of the hot water.

Studies also defined a shallow aquifer that channel the outflow of geothermal fluids into the subsurface of the Escalante Valley. Geothermal production wells, typically 500 ft (150 m) deep, tap the geothermal fluid in this unconfined aquifer. The fluids cool by conduction and probably mix with shallow groundwater at the system margins. A maximum temperature of 266°F (130°C) was measured in a 1981 geothermal exploration well (CHR-1), which penetrated the geothermal aquifer (outflow plume). Exploratory drilling in the summer of 2001 in the same location as CHR-1, however, yielded lower temperatures (~243°F, 117°C). Production wells at the greenhouses generally yield fluids in the range of 167 to 203°F (75 to 95°C). Chemical signatures or "geothermometers" suggest maximum resource temperatures of 266 to 302°F (130 to 150°C).

GEOTHERMAL STUDIES

Blackett and Shubat (1992) prepared a case study of the Newcastle geothermal system based on previous work and the results of detailed geologic mapping and various geophysical surveys. D. S. Chapman (Blackett, et al., 1990) developed a heat-flow map of the Newcastle area using data from about 30 exploratory, thermal-gradient drill holes. He reported an anomalous heat loss of 12.4 thermal megawatts (MW_t). A more recent calculation (Ross, et al, 1994), which accounted for corrected well positions and used the method of Chapman, yielded an anomalous heat loss of 13.8 MW_t. Ross and others (1990) completed electrical resistivity and self-potential (SP) studies which provided independent evidence for the location of the thermal fluid up-flow zone. A well-defined 108 millivolt (mV) SP minimum was mapped between temperature-gradient monitor wells with greatest heat flow and above the projected intersection of northwest-trending structures with the Antelope Range fault. Two lesser minima of -44 mV and -36 mV were also mapped to the southwest, above the buried Antelope Range fault. Numerical models of dipole-dipole resistivity profiles resolve near-vertical low-resistivity (4 ohm-m) bodies which are interpreted as up-flow zones. A low-resistivity (4 ohm-m) layer at a depth of about 150 ft (45 m) within the alluvium extending to the northwest is interpreted as the geothermal outflow plume.

UTILIZATION

Castlevalley Greenhouses consists of nine arched, double plastic covered building heated with 210ºF (99ºC) water. These greenhouses cover an area of about 33,750 ft^2 or 0.77 acres (0.31 ha) Water at around 350 gpm (22 L/s) is supplied to fan coil heaters at the end of each house. The main crop is tomatoes grown hydroponically. These are marketed by the owners through southern Utah. A few bedding plants are also grown.

Interior of a greenhouse showing the hydroponic growing system.

Fan coil heaters at the end of a greenhouse.

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BELMONT (UDY) HOT SPRINGS

Robert Blackett
Utah Geological Survey
Cedar City, UT

John W. Lund
Geo-Heat Center

Overview of the Camperworld Hot Spring.

GEOLOGY

Belmont Hot Springs (a.k.a Udy Hot Springs) is located 1 mile (1.6 km) southwest of Plymouth in northeastern Box Elder County on the flood plain of the Malad River. The springs consist of about 50 orifices that form a roughly semicircular pattern on the western flank of the river. The springs flow from fractured Paleozoic limestone at a small escarpment between the flood plain and the higher terraces of the Malad River Valley. Water temperatures range from 93° to 125°F (34° to 52°C). A large lake containing several spring orifices is the most conspicuous feature of the springs, but a series of smaller orifices given names such as "Indian Pool," Morning Glory Hole," and "Mud Pots" are present south of the large lake. Water from all orifices drain directly into the Malad River. Development at the former Belmont Hot Springs Resort has modified the original springs (Murphy and Gwynn, 1979). The facility is now operated by Camperworld.

The Belmont Hot Springs system is situated between the Wasatch Range on the east and the West Hills to the west. The two ranges, different in terms of geology and structure, are separated by Basin and Range structures beneath the Malad River Valley (Murphy and Gwynn, 1979).

Dissolved constituents, like many other Wasatch Front valley springs, are mainly sodium and chloride ions with TDS values approaching 8,400 mg/L.

UTILIZATION

The Camperworld facility, with an existing mature nine-hole gold course on the property, also serves as one of the few hot deep SCUBA certification sites in the Western United States. The dive pool is 28 to 30 feet (8.5 to 9.1 m) deep and is around 90ºF (32ºC) in the winter; however, at 115 to 120ºF (46 to 49ºC) in the summer, the pool is too hot for diving during that period. The dive pool is also used to heat four homes through black plastic pipes submerged in the pool. The office building floor is heated from a well, that is current being redrilled. On this property you will also find a large swimming pool heated at 90ºF (32ºC) with additional hot tubs. This resort has all the necessary water, sewer, and electrical hookups for RV's, or great areas for tenting and family reunions. The former owners operated a commercial aquaculture facility, raising lobsters and crayfish for distribution out of the local area. The gate in the raising channel broke, thus the facility is not longer operated. The current managers are considering raising bass and tropical fish.

Udy Hot Springs was also on the Salt Lake Cutoff, an emigrant road from California to Salt Lake City. Members of the U.S. Mormon Battalion, after being discharged from the U.S. Army, traveled this route to Salt Lake City. The first group over this trail arrived in the city on September 28, 1848.

The Camperworld swimming pool.

The SCUBA dive pool with the heated residences on the hill.

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One of the crayfish ponds.

UTAH HOT SPRING AND ALLAN PLANT COMPANY GREENHOUSES

Robert Blackett
Utah Geological Survey
Cedar City, UT

John W. Lund
Geo-Heat Center

Remain of one of the cisterns used for hot water collection for the resort (Bob Blackett).

BACKGROUND

Utah Hot Springs issue from several orifices in Pleistocene valley fill sediments at the western edge of the Pleasant View spur, or salient, about 300 ft (90 m) west of U.S. 89 on the Box Elder-Weber County line. Utah hot springs is within an urban-industrial setting adjacent to a utility corridor, highway, and Interstate 15. The springs were used for a time at a now-defunct resort, and are currently used to heat a small commercial greenhouse operation. The maximum temperature reported is 145°F (63°C); although, temperatures reported in most studies ranged between 135°F and 137°F (57°C and 58.5°C) (Murphy and Gwynn, 1979). Minor geothermal exploration was conducted in the early 1980s, but the resource is poorly defined. Although the area is industrial, large-scale development could be problematic due to the number of listed sensitive plant and animal species (10) possibly in the area. Small-scale geothermal power development, however, would likely blend well with other uses. Zoning restrictions in this "urban-fringe" area could impede some types of future development (Blackett, et al., 2004).

GEOLOGY

Utah Hot Springs are situated nearly due west of the boundary between the Weber and Brigham City segments of the Wasatch fault, where Personius (1990) describes surficial deposits and structural geology along these two fault segments. His work shows that at least three Holocene faults on the west flank of the Pleasant View spur postdate Bonneville Lake cycle (between 30 and 10 ka) deposits and trend roughly at right angles to the Brigham City segment of the Wasatch Fault. The three faults are marked by 10-16-ft (3-5-m) high scarps formed in Bonneville-Lake-cycle lacustrine gravels. The northernmost scarp also appears to cut Holocene fluvial and lacustrine deposits near the hot springs. He also notes that the springs appear localized at the intersection of this young fault and an older buried fault, described by Davis (1985), that flanks the west side of the spur.

Total dissolved solids content of Utah Hot Springs water ranges between 18,900 and 25,200 mg/L, consisting mainly of sodium chloride. In addition to the high salinity, the water contains 3 to 5 mg/L dissolved iron that oxidizes and precipitates when the water is aerated. The iron compounds have reportedly led to scale buildup in piping and heat exchangers within the greenhouses. Felmlee and Cadigan (1978) have reported that the water also contains measurable quantities of radium (66 µµg/L) and uranium (0.04 µg/L). Cole (1983) included Utah Hot Springs as part of a geothermal-geochemical research project, and suggested that the hot spring discharge fluids appear to have circulated to depths in excess of 3 mile (5 km), thermally equilibrating with reservoir rock at temperatures above 392ºF (200ºC).

UTILIZATION

The hot springs were on the Hensley/Salt Lake Cutoff emigrant trail used in the 1850s. At the turn of the century, a resort with a geothermally heat pool was built. Special trains were run from Salt Lake City and Ogden to the resort while it was in use. The resort was torn down about 1970; however two cisterns remain, that were used to collect the spring water. The springs presently flow under the railroad and across a gentle slope. They are deep red from the iron oxide that has precipitated from the water Water, at a rate of about 100 gpm (6.3 L/s) is collected at this point for the greenhouses run by Allan Plant Company. A total of 24 double plastic covered greenhouses are heated with the geothermal water. These greenhouses, covering about 52,000 ft^2 or 1.19 acres (0.48 ha) are used to raise bedding plants (mainly geraniums) and poinsettias, which are sold wholesale to garden centers throughout northern Utah. Approximately 300,000 flats of bedding plants and 8,000 poinsettias are sold annually.

Water enters the greenhouses at about 135°F (57°C) and supplies heat to the plants through PVC pipes under the tables, and then exits around 90°F (32°C). This radiant heat keeps the greenhouses at the desired 60 to 65°F (16 to 18°C), and heat is required year around, as in the summer, heat is needed for the seed propagation sand beds. Because of the high iron content in the water, special fittings are provided at intervals to the bottom of the heating pipes. These are flushed out with a hose three or four times a year.

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Interior of a greenhouse with the PVC heating pipes under the benches.

Spring water with iron precipitations -- greenhouses in background.

CRYSTAL (MADSEN) HOT SPRINGS

Robert Blackett
Utah Geological Survey
Cedar City, UT

John W. Lund
Geo-Heat Center

***Crystal Hot Springs Resort with cold stream in foreground and hot tubs in background*.**

GEOLOGY

Crystal (Madsen) Hot Springs, located about 1.3 mi (2 km) north of Honeyville in Box Elder County flows from the base of a small salient extending west from the Wellsville Mountains (northern extension of the Wasatch fault zone)(Blacket, et al., 204). The springs flow from fractured Paleozoic rocks at temperatures between 121 and 135°F (49.5 and 57°C). Although there are a number of warm springs and seeps in the area, the original main spring orifice is no longer visible. A nearby cold spring 52°F (11°C), along with water from the hot springs, is used to help fill a 300,000-gallon- (1.14-million-liter-) pool, while the hot springs alone are used to fill therapeutic hot tubs and mineral pools. Swimming pool temperatures range from 70 to 100°F (21 to 38°C). Roughly 2,000 ft (610 m) south of the main spring, a series of low-flowing warm springs and seeps are present in a small branch of Salt Creek, a tributary of the Bear River (Murphy and Gwynn, 1979).

Total flow from all springs and seeps at Crystal Hot Springs drains southwest along Salt Creek and has been estimated at about 4,000 gpm (250 L/s). Mundorff (1970) estimated discharge of about 1,680 gpm (106 L/s) for the main hot spring (Murphy and Gwynn, 1979). TDS content of the thermal waters at Crystal (Madsen) Hot Springs is the highest of any spring in Utah with TDS measured values above 46,000 mg/L. Over 90 percent of the ions in solution are sodium and chloride. In addition to high TDS values, the springs reportedly contain elevated levels of radium (220 µµg/L) and uranium (1.5 µg/L) (Felmlee and Cadigan, 1978).

UTILIZATION

The facility has several small pools, a soaking pool kept at 95 - 100°F (35 - 38°C), three hot tubs kept at around 97, 102 and 105°F (36, 39 and 40.5°C), and a small lap pool kept at around 82°F (28°C). A large pool, described above, is kept at 70°F (21°C). There is also a large water slide

Water slide, large pool and abandoned skating rink building.

emptying into a small pool at 70 to 80°F (21-27°C). A two-storey building houses the registration area, changing rooms and the "Blue" and "Green" rooms used for wedding and birthdays. There is also a RV park and picnic area adjacent to the pool area, managed by the resort. An abandoned roller skating building also sits on the property, used only for storage.

Hot tubs with water slide in background.

Pool heating system pipes.

The larger pool.

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MIDWAY AREA, WASATCH COUNTY

Robert Blackett
Utah Geological Survey
Cedar City, UT

John W. Lund
Geo-Heat Center

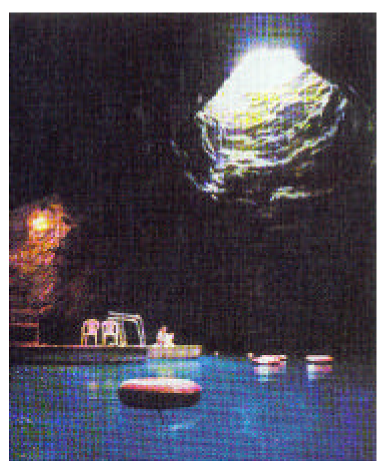
The travertine mound - the SCUBA dive "hot pot."

GEOLOGY

Midway is a small farming and resort town located about 5 miles (8 km) west of Heber City in Wasatch County. Thermal springs in and around the community issue from several widespread, coalescing travertine mounds covering an area of several square miles (kilometers) (Baker, 1968). Temperatures in these springs range from 100°F to 115°F (38°C to 46°C). Kohler (1979) suggested that thermal water at Midway originates from deep circulation of meteoric water from recharge zones located to the north near Park City. Thermal water is contained within fractured, Paleozoic quartzite in a broad antiform structure. Leakage to the surface is expressed as scattered thermal springs and widespread travertine deposits. Chemical geothermometry indicates that the maximum reservoir temperature is about 167°F (75°C). A Utah State University chemical analysis in 1995 showed that the water is mainly calcium (336 mg/L), sulfur (213 mg/L), sodium (123 mg/L), magnesium (70 mg/L), potassium (27 mg/L), and silica (11 mg/L), with traces of strontium, barium and manganese (Blackett and Wakefield, 2004).

UTILIZATION

Thermal water here has been used in pools and spas for several decades. Some new residences in this rapidly growing area reportedly use the geothermal water for space heating. A DOE-funded study (Kohler, 1979) showed that the geothermal system extends for several square miles (kilometers) around Midway. Midway's population was 1,554 during the 1990 Census, an increase of 30 percent over the 1980 Census. U.S. Highways 189 and 40 connect Midway with the larger, nearby communities of Provo, Heber, and Park City. The Heber Valley is an agricultural area producing alfalfa, corn, and cattle. At the Mountain Spa Resort, thermal water is used for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 95°F (35°C) thermal pool inside "the old hot pot," a large travertine mound.



Inside "The Crater."

HOMESTEAD CRATER

The large travertine mound is 55 feet high and 400 feet in diameter (17 m by 122 m) with a large hole in the top, which was the original access - much like a volcano. It was originally used for irrigation in 1890, and for hot tubs made of railroad ties by drilling an 8-inch (20-cm) drain tunnel through the 110-feet (33.5-m) thick walls. This drainage stopped the formation of the cone - which was originally called "Schneitter's Hot Pot' after the original Swiss family who settle there in 1864. Farming didn't pay off, so the owners built a two-story hotel in 1886. The ownership changed hands over the years, and in 1995 a large tunnel was constructed, so the 65-foot (20-m) deep pool at 95°F (35°C) could be used as a SCUBA dive certification site. Water draining from the pool through the 8-inch (20-cm) diameter pipe drains into a fish pond adjacent the to Homestead Resort, where Koi fish are raised. The resort also uses the water to heat their outside Jacuzzi.

MOUNTAIN SPA RESORT

This geothermal spring area started as a homestead in the Midway area, became a business in 1875 and a resort in 1890; thus, making it one of the oldest resorts in the state. The resort consists of a hot tub (94 to 104ºF - 34 to 40ºC), an outdoor pool (88 to 98ºF - 31 to 37ºC), and indoor pool (90 to 103ºF - 32 to 39ºC). Geothermal water is used directly in the pools, where the water is changed twice-a-week. The hot tub water is changed after each use. The water is also used to irrigate the lawns and to raise tomatoes. The resource, originating from 25 hot springs and two wells, flows at 110ºF (43ºC) at 933 gpm (59 L/s). The indoor pool is built over a "hot pot" with four vents feeding the pool. The resort also have guest rooms and cabins for rent, along with RV hookups. It is open from mid-April to mid-October. The facility is for sale and may be developed into a high-class health spa.

Detail of the travertine mound at Homestead Crater.

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MONROE-RED HILL HOT SPRINGS
- MYSTIC HOT SPRINGS RESORT -

Robert Blackett
Utah Geological Survey
Cedar City, UT

John W. Lund
Geo-Heat Center

***Mystic Hot Springs Resort*.**

GEOLOGY

Sanpete and Sevier Valleys

The Sanpete and Sevier Valleys form a long, narrow, northeast-southwest depression in central Utah. Although appearing geologically simple, surficial deposits mask a structurally complex area of subsidence caused by faulting, folding, and dissolution of salt from Jurassic formations. Warm springs and wells occur throughout both valleys, although, the hotter springs are located at the southern margin of the Sevier Valley.

Three hot spring areas extend over a distance of about 6 miles (10 km) at the southern end of the Sevier Valley. The springs -- Monroe, Red Hill, and Joseph -- were originally included in the Monroe-Joseph KGRA. Brook and others (1979) considered Monroe and Red Hill Hot Springs as one system, and considered Joseph Hot Springs a separate, but similar, system. The springs are associated with Quaternary normal faults which offset widespread mid-Tertiary, intermediate volcanic rocks erupted from the Monroe Peak and Mount Belknap calderas, and other sources farther westward (Mabey and Budding, 1994).

Monroe-Joseph Geothermal Area

Monroe Hot Springs and Red Hill Hot Springs are situated less than a 0.5 mile (0.8 km) east of the town of Monroe, a community of about 1,470 people (1990 census) located about 3 mile (5 km) east of Interstate Highway 70 in Sevier County. Monroe was the site of a number of geoscience and exploratory drilling studies sponsored by the U.S. Department of Energy in the late 1970's and early 1980's to assess the resource potential (Mabey and Budding, 1987). Although feasibility studies based upon fluid temperatures and flow-rates from a DOE-sponsored production well (600 gpm and 164°F) (38 L/s and 73°C) drilled around 1980 (Blair and Owens, 1982) showed that a district-heating system was not economical, the area could be attractive for process or agricultural direct-heat applications.

The Monroe and Red Hill Hot Springs issue at about 170°F (77°C) near the surface trace of the Sevier fault, adjacent to the Sevier Plateau. The Sevier fault is a 300-mile (480-km) long zone of rupture extending from the Grand Canyon northward into central Utah. Chemical geothermometers suggest maximum resource temperatures of about 230°F (110°C). Maximum measured temperature is 171°F (77°C) at Red Hill Hot Springs and 169°F (76°C) at Monroe Hot Springs. Combined flows for the Monroe-Red Hill system have been estimated at about 320 gpm (20 L/s).

Joseph Hot Spring discharges from a spring mound near the Dry Wash fault, which parallels the Sevier River along the northwest edge of a group of hills that are part of the

Antelope Range. The springs issue at 145°F (63°C) with flow rates approaching 32 gpm (2 L/s).

UTILIZATION

The Monroe-Red Hill Hot Spring area is 10 miles (16 km) south of Richfield in Sevier County. The proprietors have named the resort "Mystic Hot Springs" and offer a geothermal-heated swimming pool, therapeutic baths, camping facilities, and tropical fish ponds. The Monroe and Red Hill Hot Springs issue at about 170°F (77°C) near the surface trace of the Sevier fault adjacent to the Sevier Plateau.

Geothermal water flows from travertine mounds behind the Mystic Hot Springs resort at 168ºF (76°C) and 200 gpm (13 L/s). Visitors can soak in bathtubs set in the travertine deposits, or in a soaking pool (shown on page 1 of this issue). A swimming pool, next to the main building appears to be no longer used. The resort offers campsites, RV hook-ups, pioneer cabins and teepees and tropical fish ponds. Six tropical fish ponds are keep at 75ºF (24°C) year around, where Koi, Mollies, African cichlids, and fancy guppies are raised. The spring water has a total dissolved solids of 2905 mg/L, considing mainly of nitrate sulfate (813 mg/L), chloride (645 mg/L), sodium (599 mg/L), bicarbonate (425 mg/L), calcium (255 mg/L), potassium (69 mg/L), and silica (54 mg/L), with traces of other species. See their website at: www.mystichotsprings.com for more details.

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Travertine deposits with bath tubs behind the resort.

Red Hill travertine mound.

ST. GEORGE BASIN GEOTHERMAL AREA

Robert Blackett
Utah Geological Survey
Cedar City, UT

The St. George basin geothermal area covers roughly 250 mi^2 (650 km^2) in extreme southwestern Utah and includes the Santa Clara and Virgin River Valleys in Washington County. The area coincides with the St. George basin subprovince of Stokes (1988). The Pine Valley Mountains to the north, the Beaver Dam Mountains to the west, the Hurricane Cliffs to the east, and the Utah-Arizona state line to the south border of the basin. The basin lies along the western margin of the Colorado Plateau, just east and south of the Basin and Range - Colorado Plateau Transition Zone.

Sedimentary strata folded along northeast axes characterize the St. George Basin, although many consider the basin as part of the Colorado Plateau. Strata in the region generally dip gently northeastward, and the basin is bordered structurally on the east by the Hurricane fault, and on the west by the Grand Wash-Gunlock fault (Petersen, 1983).

The basin is underlain by a thick sequence of Paleozoic and Mesozoic strata, sandwiched between Precambrian metamorphic rocks, exposed in the Beaver Dam Range, and a series of Tertiary intrusive and volcanic rocks exposed in the Pine Valley and Bull Valley Mountains, respectively. Hamblin (1970) described four stages of Late Cenozoic basalt flows and cinder cones in the St. George Basin that form many elongate eroded ridges.

Two major structural trends include northeasterly aligned folds and faults of Laramide age, and post-Laramide north-south oriented extensional faults. The Virgin Anticline, a major Laramide feature, extends northeasterly across the center of the basin for about 17 miles (27 km). The Hurricane fault, a post-Laramide feature, is an active normal fault that extends for over 300 miles (480 km) from Cedar City through northwestern Arizona. The Grand Wash-Gunlock fault, which was active during Pleistocene time, can be traced from Gunlock, Utah southward for about 100 miles (160 km) into Arizona. The Washington fault, an active normal fault extending southward from the foothills of the Pine Valley Mountains across the Virgin Anticline and into Arizona, nearly bisects the St. George Basin (Sommer and Budding, 1994).

Veyo and Pah Tempe Hot Springs resorts in southwestern Utah offer swimming and therapeutic baths, through the latter is temporarily closed. At Veyo Hot Springs Resort, located southeast of the town of Veyo along the Santa Clara River canyon, spring flows are channeled to a swimming pool at a temperature of about 32°C (89°F). At the Pah Tempe Hot Springs Resort springs flow from a number of vents along the Virgin River at about 42°C (108°F) near where the river crosses the Hurricane fault between the towns of Hurricane and La Verkin. The thermal water is channeled into a swimming pool and therapeutic baths.

VEYO HOT SPRINGS RESORT

Veyo Hot Spring is located southeast of the town of Veyo along the Santa Clara River. Here the river has incised 1 and 2 million-year-old basalt flows to form a steep-walled canyon. Mundorff (1970) reported that spring temperatures ranged from 90° to 97°F (32° to 37°C), TDS values ranged from 389 to 402 mg/L, and the flow rate was constant at 120 gpm (8 L/s). Budding and Sommer (1986) reported a temperature measurement of 85°F (29.5°C).

PAH TEMPE HOT SPRINGS RESORT

Pah Tempe Hot Springs, also known as La Verkin or Dixie Hot Springs, are located along the Virgin River where the river cuts through Timpoweap Canyon along the Hurricane Cliffs. The north-trending Hurricane fault lies a short distance west of the springs. The springs issue from multiple vents in fractured Permian Toroweap Limestone. Widespread basalt flows ranging in age from 2 million years B.P. to 1,000 years B.P. lie in the vicinity of the springs, possibly relating to local heat sources for the thermal water.

In the mid-1980s, construction of a water pipeline for the Quail Creek (off-line storage) reservoir reportedly disrupted the discharge of existing hot springs and new springs emerged at lower bank-levels along the Virgin River (Ben Everitt, Utah Division of Water Resources, verbal communication, 1993). Flows to the original springs were partly restored after installation of a clay and cement seal in the construction area. In September 1992, a 5.8 magnitude earthquake evidently contributed to another disruption of spring flows as discharge decreased and again new springs emerged at lower bank- levels along the Virgin River (Ken Anderson, Pah Tempe Resort, verbal communication, 1993). Available analyses for the springs, done prior to the earthquake, are variable and possibly reflect differences in sample collection points. Blackett (1994) obtained a post-earthquake spring sample collected from one of the new spring orifices where the Quail Creek pipeline crosses the Virgin River. The post-earthquake sample results were similar to the previous analyses. The water is a sodium calcium-chloride, sulfate, and bicarbonate type. Geothermometers suggest equilibration temperatures between 167°F and 176°F (75°C and 80°C).

Flow rate, chemistry, and temperature have varied through time. Mundorff (1970), and Sommer and Budding (1994) reported that temperatures recorded at the springs have varied over the last 100 years from 100° to 133°F (38° to 56°C). It is not clear whether the spring temperatures have declined over the past century or if the earlier temperatures recorded were inaccurate. Recent measurements have shown the springs to issue at temperatures near 108°F (42°C). Flow rates measured by several workers suggest that the combined flows for all of the vents range between 4,500 and 5,000 gpm (280 and 315 L/s). Pah Tempe Springs are relatively high TDS content, ranging between 8,390 and 9,340 mg/L. See the article by S. Lutz, this issue, for more details.

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