Canby Cascaded Geothermal Development Project
Phase 1 Feasibility Study

Geothermal Technologies Program - Low-Temperature Resources

DE-EE0004431

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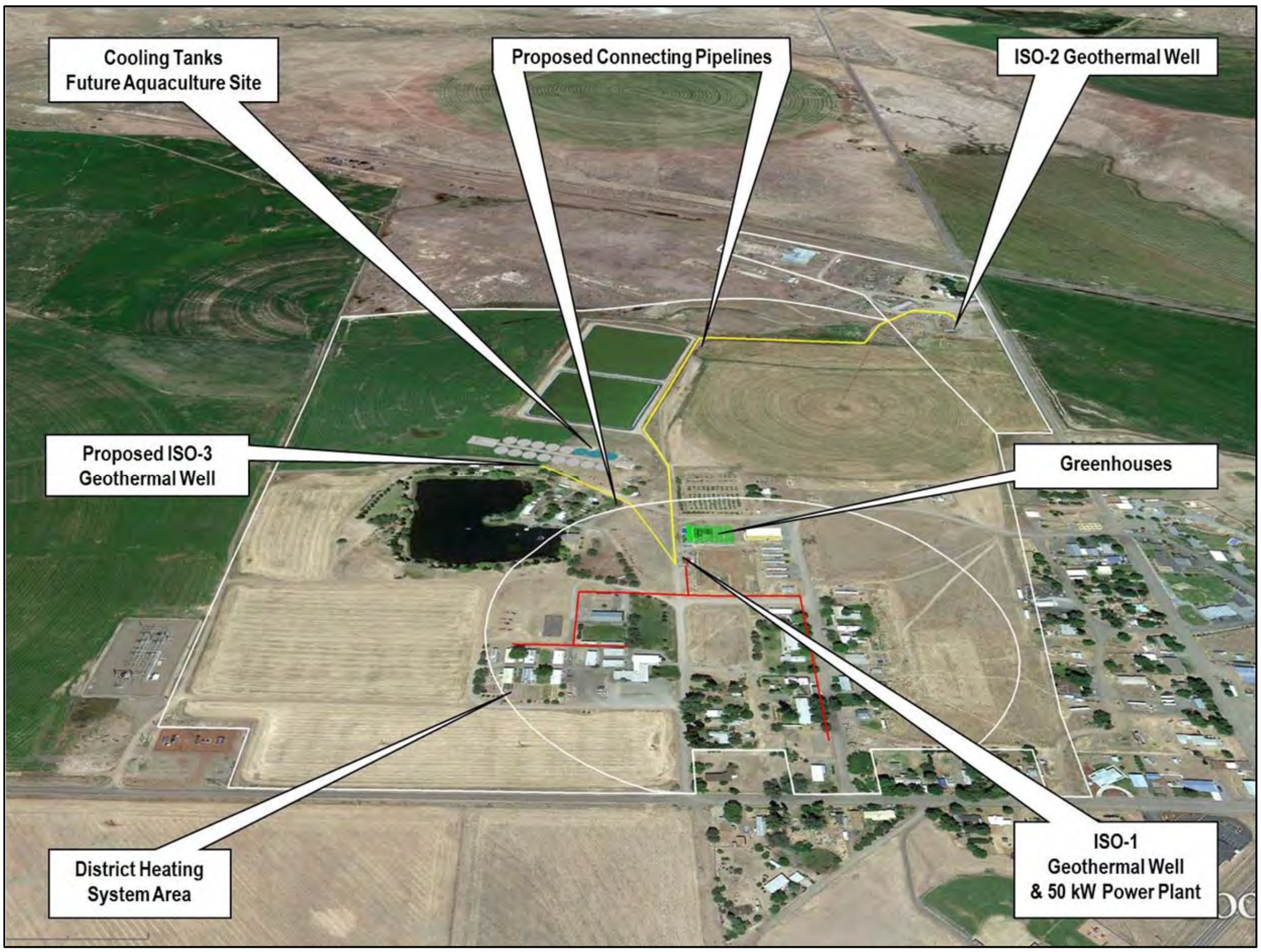

Final Report

April 1, 2013

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CANBY CASCADED GEOTHERMAL DEVELOPMENT PROJECT

Executive Summary

The objective of the Canby Cascaded Geothermal Development Project is to determine the economic feasibility of a cascaded geothermal system from small power generation (50 kW increments) through several direct-use applications that include an existing geothermal district heating system, greenhouse and aquaculture operations before re-injection of geothermal fluids back into the local aquifer.

This report summarizes the environmental assessment, engineering feasibility, injection site study, power sales and interconnection study. A financial analysis has been completed for the proposed cascaded project and can be found in the Appendix.

BACKGROUND
The Canby Project has been developing local geothermal resources since 1998. The ISO-1 geothermal well was drilled with the resources and determination of a small community and USDOE assistance in 2000. The I'SOT Geothermal District Heating Demonstration Project was completed in 2003 with the help of grants from the CEC GRDA Program and NREL and uses an annual average of 16.7 gpm of $\approx$ 195°F geothermal water to district heat 70,000 ft^2 of residential, agricultural, and commercial buildings. The district heating system supports California's first geothermal Laundromat that uses geothermal energy to both wash and dry domestic laundry in a cooperative setting.

In 2008, the Canby Project was again selected for funding by the GRDA Program to drill a second geothermal well (ISO-2) to generate 280 kW of renewable power and cascade the spent fluids, however the well was not able to produce sufficient flow and temperature to reach that benchmark.

In 2011, under this contract, the DOE helped fund a $200,000 Phase 1 feasibility study to design a scalable cascaded geothermal system in anticipation of successful CEC assisted drilling of the ISO-2 geothermal well. Based on increments of 280-50kW power modules, the engineering design was to determine the most cost effective path to:

- Supply geothermal power to market or to a local community via micro-grid.
- Cascade remaining heat and domestic hot water to the existing district heating system.
- Supply thermal heat for greenhouses for an expanding aquaponic system .
- Use rejected heat from the power plant to heat cooling tanks for fish farm.
- Facilitate injection back into the geothermal aquifer.

Beginning in March 2011, Evergreen Energy and the project principal investigator met with a number of local utilities for possible power purchase agreements and interconnect options. This was at a time before the California RPS was satisfied, inexpensive natural gas was not available, and ISO-2 expectations were to provide over 1 MW of power to market. The utilities approached were as follows:

- PacifiCorp
- Lassen Municipal Utility District
- Plumas-Sierra Rural Electric Coop.
- Pacific Gas and Electric Company

- Surprise Valley Electrification Corporation

These were the best of times to sell renewable power in California, and while there were some obstacles for interconnection and PPA's, it was still favorable to sell 1-2 MW at $.08-$.10/kWh.

After the disappointing drilling results of ISO-2 in September 2011, it was clear that energy provided by the project resource would be used onsite for the local community and direct-use applications.

During the last two years, MT surveys were conducted in the project area, in addition to the greater area around Canby, to further understand the local resource and provide additional data used to site the proposed ISO-3 geothermal well. Limited resources were used to improve the performance of ISO-2, and combined with the resource availability of ISO-1, demonstrate adequate energy to complete stated project tasks.

The project goal is to take a holistic approach in determining the value of the entire cascaded geothermal system from power production through all downstream direct-use applications; not power production only. The value will be determined by:

1. Annual power savings from local community.
2. Annual savings from the existing geothermal district heating system.
3. Annual revenue potential from greenhouse crops.
4. Annual revenue potential from fish production.

After project implementation, energy flows, temperatures, savings, and potential revenue from all applications will be posted on canbycascadedgeothermal.com in real-time as an education website and as a portal for anyone to check project development. Community renewable energy projects should share their experience with other communities and a website is a perfect place to do it.

The Canby Project will be scalable, currently based on 50 kW increments of power production from ElectraTherm's Green Machine. The vision of the Canby Project is to create a sustainable, renewable energy model that would be applicable, not only to small communities in the United States but to rural communities around the world. Supporting this model would bring benefits to American companies, like ElectraTherm, by demonstrating that even modest low-temperature geothermal resources can have a huge impact on a small community scale, giving reliable energy production, jobs and food supplies to the local public, while reducing the overall carbon footprint.

Financial Projection

A financial projection for a 50 kW scale cascaded project was completed for this report, aggregating the value of power and downstream direct-use applications. Efforts were made to use conservative estimates with respect to greenhouse and aquaculture operations, while capturing present, well documented savings from the district heating system. The aquaponic system has been in successful operation for two years and the Kelley Hot Springs Fish Farm will be intimately involved with the success with the aquaculture operation. This operation sells 2,000,000 lbs. of tilapia, bass and catfish per year to the live fish market in San Francisco. This is a unique intersection of opportunities that makes the Canby Project feasible and profitable.

Because the project is currently debt-free and has a substantial equity in the existing infrastructure, the projected financial performance is attractive. See Project Financial Projection in the Appendix.

Project Scope and Results

TASK 1.0 CONDUCT ENVIRONMENTAL REVIEW AND OBTAIN PERMITS
During the twists and turns of deciding how to proceed with developing the project, the EA effort followed as well, looking at all proposed options going forward and drafting several iterations to satisfy all environmental concerns. The final iteration of the draft EA will be submitted for public review after a DOE decision to go forward with the project is made. A joint EA/IS will allow further solicitation of California funding without delays due to CEQA concerns.

Historically, the Canby Project has a good track record with working with county, state, and federal agencies, such as the Modoc County Planning Department, Regional Water Quality Control Board, CA Fish and Game, and US Fish and Wildlife Service. The project has discharged geothermal water to a local river since 2003 (17 gpm annual average) and will now end discharge during this project. The project has also had good relations with local Tribes.

Since 1998, the project has been reviewed with multiple CEQA and NEPA efforts with successful outcomes and local support.

Currently, a joint EA/IS for the Canby Project is being prepared by Panorama Environmental, Inc. (formerly RMT). The EA/IS will meet the requirements of both NEPA and CEQA. Authorization of the DOEs action is subject to NEPA and Modoc County will need to issue a Use Permit and building permits for the project, requiring CEQA compliance. The EA/IS provides DOE and Modoc County the information needed to make an informed decision regarding the environmental effects of the construction and operation of the proposed project.

The proposed project evaluated in the EA/IS includes:

- Drilling and operating a new geothermal well known as ISO-3
- Constructing and operating pipelines and other infrastructure to support the cascaded geothermal system, which may include an aquaculture facility and greenhouses in the future.
- Building a power generation facility, cooling system, and transmission microgrid.

The EA/IS evaluates the potential individual and cumulative impacts of the proposed project as well as the impacts of the No-Action/No-Project Alternative, which assumes the project would not proceed.

Several administrative drafts of the EA/IS were prepared and reviewed by DOE and Modoc County. The EA/IS is currently being revised to address minor project changes. The next steps include finalization of the Draft EA/IS, circulation of the Draft EA/IS for a 30 day public review, and final approval by DOE and Modoc County. All environmental impacts would be less than significant and a Finding of No Significant Impact (FONSI) and Negative Declaration (ND) are anticipated.

The current working draft of the EA/IS is included in the Appendix.

TASK 2.0 ENGINEER CASCADED GEOTHERMAL POWER AND THERMAL SYSTEM

The energy infrastructure of our society is built on abundant, low-cost energy. Even in the geothermal energy sector, projects often make limited use of an abundant resource. A conventional organic rankine cycle (ORC) power plant operating on the 205°F water temperature available at Canby will utilize about 7.5% of the heat energy removed from the geothermal fluid for power production, with the remaining 92.5% rejected to a cooling tower. However, that power production amounts to only about 1.5% of the potential heat energy available with beneficial use of the power plant cooling energy and cascaded beneficial use of the geothermal fluid to a discharge temperature of 105°F.

The Canby geothermal resource is adequate for the community needs, but is not abundant. Power production for power only is not cost effective at Canby because of the modest temperature and flow, relatively high pumping energy required to access the geothermal water, and low value of wholesale power. We intend to demonstrate that power generation combined with maximum utilization of byproduct heat for other beneficial purposes can be cost effective and beneficial to a rural community such as Canby.

The primary engineering challenge of the Canby Project is to maximize the beneficial use of a modest geothermal resource, with power production fully integrated with the beneficial heat use.

DESIGN GEOTHERMAL RESOURCE AVAILABILITY

The design basis for the system utilizes the combined capacity of two existing production wells ISO-1 and ISO-2, with assumed injection of the geothermal fluid into a new well ISO-3.

	Flow	Temperature	Pumping Head
Summer, Average	160 gpm	205°F	266 ft
Winter, Maximum	220 gpm	205°F	370 ft

POWER PRODUCTION

ElectraTherm, Inc. offers the only proven, currently available power plant that can operate on the available resource. The ElectraTherm "Green Machine" is a complete packaged ORC power plant including an induction generator, twin-screw positive displacement expander, evaporator heat exchangers, condenser heat exchangers, refrigerant pump, and controls, all assembled in a standard 20-ft shipping container. A recent quote from ElectraTherm showed an estimated production of 35 kW from the resource under summer average conditions, with a geothermal exit temperature of 182°F. Estimated pumping energy is 14.5 kW for the geothermal wells and 1.5 kW for the condenser pump, leaving a net of 19 kW.

The ElectraTherm generator has a nominal capacity of 60 kW but is not currently optimized for the site conditions at Canby. Our expectation is that we can work with ElectraTherm between now and the purchase decision point in late 2013 to modify the power plant design to take a larger bite of the available geothermal heat. Our assumption for the heat and power balance calculations is that the geothermal temperature exiting the power plant will be reduced to about 175°F, and the gross power output will be closer to the nominal generator capacity.

We considered the option of a non-ORC power plant that offered the potential for significantly greater power generation from the available resource. More power from the same geothermal flow would obviously be desirable, and would result in lowering the fraction of the power output that is required to operate the geothermal pumps. As of now, we have been unable to validate the claimed performance of the ORC alternative power plant either through test data or thermodynamic analysis. Therefore, we chose to base the project design on proven ORC technology, as represented by the ElectraTherm Green Machine.

The goal of the geothermal power generation is to produce enough power to operate the critical system electrical needs including:

- Geothermal production pumps
- District heating circulation pumps
- Potable water pumps
- Aquaculture pumps, oxygen concentrator, ozone production
- Greenhouse and aquaponics pumps and fans
- Food service freezers and geothermal laundromat
- Dining hall and school buildings

The geothermal power production will normally be in parallel with the local utility, offsetting retail power purchase, at retail electric rates. The expectation is that at no time will power be exported to the grid, which may simplify the grid interconnection.

The listed electrical needs are or will be connected to an existing 140 kW propane-fired engine-generator. During off-grid operation due to a grid failure the geothermal power plant will operate in parallel with the standby generator, continuing to serve the critical electrical loads while reducing propane consumption by the engine-generator. We plan to evaluate alternative generator designs that may allow micro-grid operation of the geothermal power generation without need for continuous operation of the propane-fired standby generator.

CASCADED HEAT USES

The geothermal water at Canby is typically low in dissolved solids (850 ppm), which allows a low discharge temperature without scaling problems. The existing geothermal district heating system has operated down to about 100°F geothermal discharge temperature without scaling. Our performance target is to achieve beneficial use of heat extracted from the geothermal water approaching 100% in the winter, with a geothermal exit temperature of about 105°F.

Potential cascaded uses for Canby are anticipated to include:

- Serving the existing community district heating system, with potential expansion to be considered depending on demand and available resource
- Geothermally heated greenhouses
- Aquaculture and aquaponics

District Heating

The existing geothermal production well ISO-1 currently supplies a geothermal district heating system in Canby that provides space heat and domestic hot water for over 70,000 ft^2 of residential, commercial, and agricultural buildings, along with sustaining a Laundromat that washes AND dries domestic laundry. The district heating system currently saves over $100,000 per year in heating costs, offsetting propane and electricity.

This project will provide increased heating capacity, which could be used to expand the district heating system to serve the Canby Medical Clinic, Arlington Elementary School building and other new heating loads. As the project funding does not include expansion of the district heating system, the financial analysis includes only the energy cost savings from the existing system.

A possible later add-on application for space heating is a 40' by 120' Quonset style metal shop in close proximity to the ISO-2 well. The building currently uses wood and propane heat during the winter season with costs upward of $8,000 per year. If the ISO-2 well is selected as a geothermal injector, the warm discharge water from the rest of the project could be used through existing radiant floor system that was installed in the mid-1980s but never completed.

Lastly, there is a group of community owned buildings also within 250' away from the ISO-2 well site that currently use propane and electrical resistance heat for heating approximately 8,000 ft^2 of residential buildings whose annual energy costs are close to $13,000 per year. Water source heat pumps would be an easy and inexpensive energy alternative before re-injection.

While the last two applications are not a part of the current project, it demonstrates and sets the stage for continuing the geothermal cascaded systems practical application in a community setting.

Greenhouses

Waste heat from the existing district heating system currently heats a 30'x96', 2,880 sf greenhouse. The greenhouse supports an aquaponics operation producing fish, beans, tomatoes, and peppers for local consumption and sale. In an aquaponics operation, the fish are feed and managed to supply nutrients to the plants, which by removing nutrients from the recirculated water help maintain the water quality needed by the fish. The overall operation and nutrient balance can be somewhat tricky, but the existing system has operated successfully for 2 years. The estimated net value of the current fish and vegetable production is about $17,000 per year.

This project will allow expansion of the greenhouse and aquaponics operation to 6 greenhouses, with a total enclosed area of 17,000 sf. The expected net value of the greenhouse production is expected to increase to $100,000 per year. For our financial analysis we used $50,000 as the value of the heat supplied to operate the greenhouses.

Aquaculture

A critical design basis for the cascaded geothermal heat and power project is to maximize use of all available heat, including heat rejection from the power plant. An aquaculture operation provides a high-value use for the low-grade waste heat.

The Kelly Hot Springs Fish Farm, operated by Ron Ketler, is located two miles from Canby and produces over two million pounds per year of tilapia, catfish and bass. Ron will provide the technical expertise for design and operation of the aquaculture operation.

Six 50 ft diameter fish tanks plus a 200 x 100 ft (20,000 sf) cooling and containment pond will provide cooling for the power plant in place of a cooling tower. The tanks will be constructed inexpensively of concrete masonry units (based on successful designs at Kelly Hot Springs) and will be mostly buried with an open water surface. The cooling pond will be initially constructed as a containment pond for drilling and well development for the proposed new well ISO-3.

The aquaculture operation will be an intensive, recirculated aquaculture system, utilizing high fish densities in the tanks, which will be supported by high-purity oxygen generated by pressure-swing oxygen concentrators, California-tube oxygen transfer, and bio-filters for nutrient control. The technical and financial success of an intensive aquaculture operation depends on the ability to manage feed, dissolved oxygen, and water chemistry to optimize fish growth, and the market for the finished fish. Ron Ketler has the proven experience to help assure success.

The fish tanks will be heated using water recirculated through the tanks and the pond. Heat rejection from the power plant plus cascaded residual heat in the geothermal flow after the power plant, district heating and greenhouse loads will be adequate to maintain fish tank temperature of 70°F during coldest month average ambient temperature of 20°F. At a summer average temperature of 58°F, the tanks and pond will provide adequate heat rejection for the power plant at a fish tank temperature of 80°F.

The fish species will be determined by marketing and production considerations. One factor to be considered is the ability of the fish to survive water temperature down to about 50°F for operational flexibility in the winter. One probable selection is striped bass.

Use of aquaculture process water for power plant cooling is expected to create operational challenges due to the high levels of dissolved nutrients and suspended solids including algae. Return water will be treated prior the heat exchangers using:

- Mechanical screening to remove and collect algae for possible use as a component of the fish feed and/or composting for soil amendment.
- Sand or bead bed filtration for further suspended solids removal
- Ozone injection for disinfection and control of biofouling in heat exchangers

Ozone will be produced on-site from the concentrated oxygen produced for the fish tanks. In addition to reducing heat exchanger biofouling, the ozone will reduce the chance of disease spread between tanks, and will assist in denitrification of the recirculated water.

We anticipate that the condenser heat exchangers supplied with the ElectraTherm power plant will not be suitable for direct contact with the process water, even with the filtration and ozone treatment. Therefore we are designing for a secondary clean cooling water loop between the condenser heat exchanger and the process heat exchanger. We plan to use a readily cleanable heat exchanger, such as a spiral heat exchanger for the process heat exchangers. Some efficiency improvement could be realized if we could use an easily cleanable spiral heat exchanger as the condenser heat exchanger in the power plant. We will be discussing that with the supplier.

Based on proven experience at Kelly Hot Springs, we anticipate producing 30,000 to 40,000 pounds per year of market-ready fish per 50 ft diameter tank, or 180,000 to 240,000 pounds per year total for six tanks. At a net profit of $1.50 per pound, the anticipated net revenue is $270,000 to $360,000 per year from the aquaculture operation. Without the thermal energy availability, there would be no aquaculture operation, thus no net revenue. However, for purpose of the financial analysis we assigned a value of $100,000 per year for the thermal energy supplied to the aquaculture operation. The balance of the anticipated net profit would cover the cost and risk of establishing the aquaculture operation.

TASK 3.0 INJECTION SITE STUDY

The Canby Project has identified an attractive site for drilling the proposed ISO-3 well and will be used for injection or production based on project needs. This task selected an injection site based upon chemistry, temperature, stable isotopes in groundwater, fracture trace analysis, and a 2012 magnetotelluric survey.

The objectives of the Injection Site study were to:

A. Confirm one or several geothermal drilling sites in the Canby area.
B. Develop a conceptual geothermal system model of the Canby Geothermal Field.
C. Prepare drilling and injection/production test plans as needed.

The project site selection was based on collecting and analyzing the following data and considerations:

1. Chemistry, temperature, and stable isotopes in ground water to identify geothermal anomalies and characterize ground water and geothermal flow systems.
2. Vertical temperature profiles in geothermal wells and irrigation wells.
3. A fracture trace analysis by inspection of low altitude stereographic photos, combined with the results of a Magneto-Telluric survey.
4. A review of the scientific literature and technical reports.
5. Cultural Resources
6. Pipeline logistics
7. Project budget

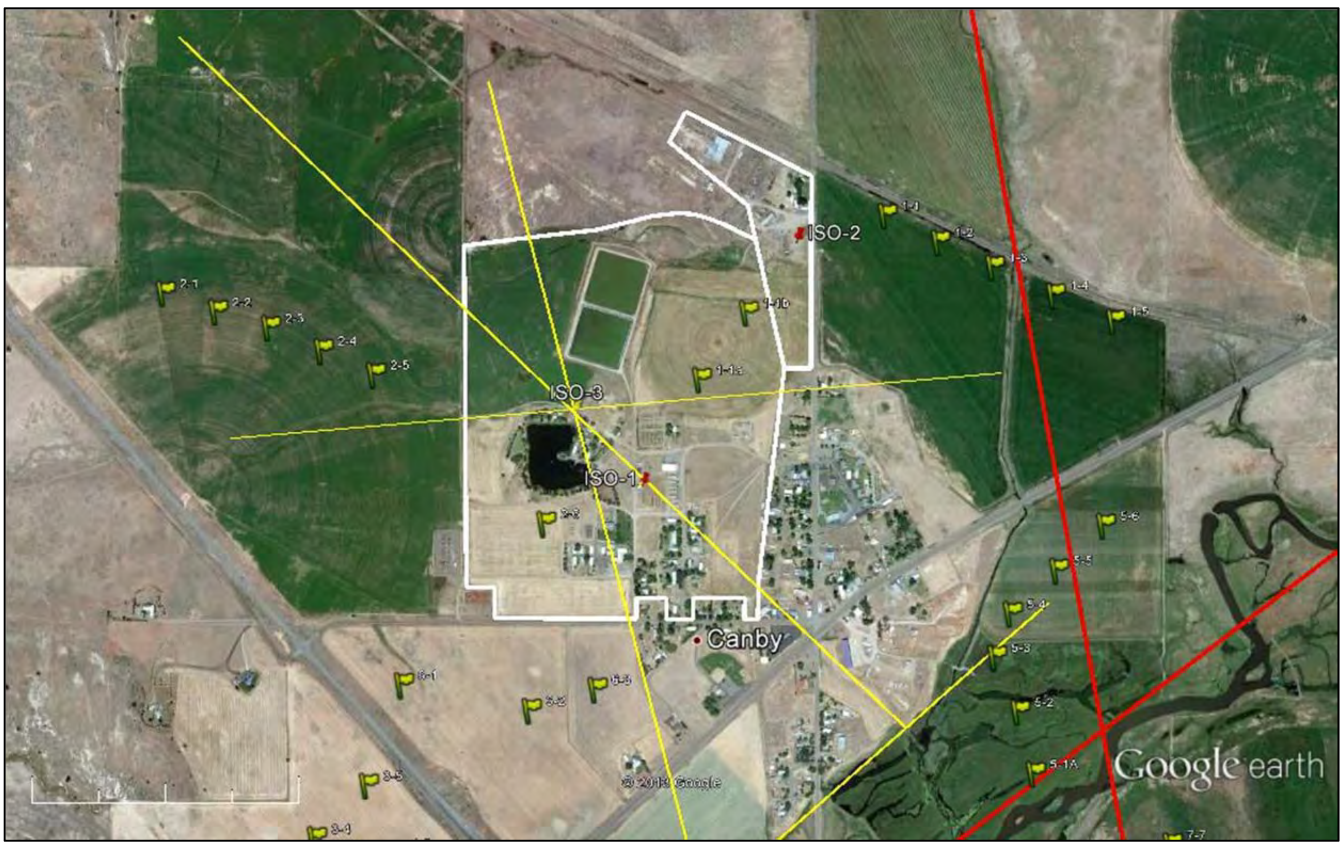


Figure 1 Recommended Drilling ISO-3, flags are MT stations, yellow lines interpreted fault traces.

The recommended method of drilling is air rotary when drilling in the production zone between 2100'-2500'; mud rotary or flooded reverse circulation drilling is recommended other above 2100'.

Resource

An additional analysis that was included in this task attempted to address the available geothermal resource needed to accomplish project goals for 50 kW power generation and cascaded geothermal system.

Data from ISO-1 and ISO-2 were reviewed and evaluated by project geologist Burkhard Bohm, Ph.D of Plumas Geo-Hydrology and Benjamin J. Barker, Ph.D.:

1. Current ISO-1 production trend logs and a pump test completed in 2000.
2. ISO-2 Rig Injection Test –Canby Geothermal Project by Geothermal Science, Inc. 2011.
3. ISO-2 Pump Test, September 2012.
4. ISO-2 Injection Test, Feb-March 2013.

The final analysis was approached from differing viewpoints and it is clear that there is adequate resource presently to generate 50 kW of power, particularly since well injection testing during the last two months has changed the ability of the ISO-2 well to accept fluids. Further, drilling an additional well could provide supplementary options. The following paragraphs are excerpts from the two resource reports.

Burkhard Bohm, Ph.D

"Given the uncertainty by how much further development will improve the drawdown response, with the currently available data productivity estimates by minimizing wellbore skin factors are tentative and need to be applied with caution:

a) For Well ISO-1 pumping 160 gpm, the tentative estimated drawdown would be about 525 ft. Correspondingly injecting 160 gpm the tentative estimated wellhead pressure would be about 227 psi.

b) For Well ISO-2 pumping 60 gpm the tentative estimated drawdown would be about 380ft. Correspondingly when injecting 60 gpm the tentative estimated wellhead pressure would be about 165 psi."

Ben Barker, Ph.D

"Your original question about ISO-2 productivity is essentially, "will ISO-2 have a productivity index greater than 0.32 gpm/psi?" I believe we can answer "yes" with reasonable confidence, since Figure 2 shows that the entirely of the last four injection tests have taken place with an injectivity index > 0.5, and there may well be a convergence on the value of 1 gpm/psi measured in the rig test. For comparison, ISO-1 has an index of about 0.7 gpm/psi. This is hardly an exact science, but as a business proposition I would recommend to management that the probability of ISO-2 having an index > 0.5 gpm/psi is better than 75%, or better than 3:1 odds." The entire report can be found in the Appendix.

The complete site study, resource analysis and drilling plan can be found under the Injection/Resource Study in the Appendix.

TASK 4.0 POWER SALES ARRANGEMENTS, INTERCONNECTION STUDY AND TRANSMISSION ANALYSIS

Preliminary work has been completed to determine the likelihood of interconnection of the proposed new power plant on the Canby community site. This work has contemplated the interconnection of the ElectraTherm Green Machine to existing 480 volt electric load panels in the community. I order that the entire generation be used on site, it will be necessary to interconnect a portion of the panels that are currently served by separate utility services. These include the services that currently power the central geothermal heating plant; the existing greenhouse; the building which houses the community food service facilities and the laundry; the school complex building and the geothermal well pump. In addition to providing power for these existing facilities, there will be new loads associated with the operation of an expanded greenhouse operation for growing vegetables and the four new 50 foot diameter fish tanks. These new facilities will require power for fans and pump motors in order to operate the fish growth and production operations.

In order to implement this plan, it will be necessary to accomplish two objectives: (a) the various electric power services must be aggregated into a single service metered by one meter; and (b) a net-metering agreement must be negotiated with Surprise Valley Electrification Corp.

The first will require the purchase of existing electric distribution facilities from Surprise Valley at their depreciated value. Negotiating an agreement to purchase these assets may require some time as they establish value for the facilities. Then it will be necessary to install a primary voltage meter to meter the aggregated load, and this meter must also measure generation that may be back fed into the utility system during periods of low load in the community.

The second activity will require negotiations of a net-metering agreement with Surprise Valley. Since this will be the first of its kind on their system, it will be a new activity for both the utility and CanbyGeo. Some assistance from professionals experienced with power contract negotiations will be required.

The first step in the whole process will be the completion of an interconnection study, carried out by Surprise Valley with their consultants assisting. This study will consider the design and specifications of the proposed installation, and identify the protection and isolation requirements necessary to protect the utility from safety considerations associated with power generation on its distribution system. This interconnection study is a routine activity for many larger utilities, and should be reasonably straightforward for Surprise Valley. A typical interconnect study with SVE includes a $15,000 fee.

One benefit of a small community power generation system is that no long distance transmission of the power must take place. No transmission agreements will be required for this installation.

The result of interconnecting the new generation within the load center of the I'SOT community is that there will be no need for a complex power sales agreement. The power will be used to offset or reduce the purchase of power from the utility, and the value of his power will be the established utility retail rate. Not including the capacity and customer charges, this rate is in the range of $0.06 per kilowatt-hour. As the utility rate increases, the benefit the plant will also increase.

If the plant produces a net output of 42 kilowatts after the motor loads to pump the well water and the pump to circulate the discharge water, then it will generate about 346 megawatt-hours yearly. At the current utility rate, this would be valued at about $23,000 per year.

This benefit to the Canby community, along with the income derived from the utilization of heat in the discharge water, make the project attractive. The new earnings and food cost savings associated with fish production and vegetable growing provide a strong additional benefit. This is estimated to result in at least $36,000 per year of net fish production income, and as much as $25,000 in fresh vegetable production. These two additional benefits represent meaningful revenue streams in the form of reduced food costs to the community.

APPENDIX

Cascaded System Engineering

Injection/Resource Study

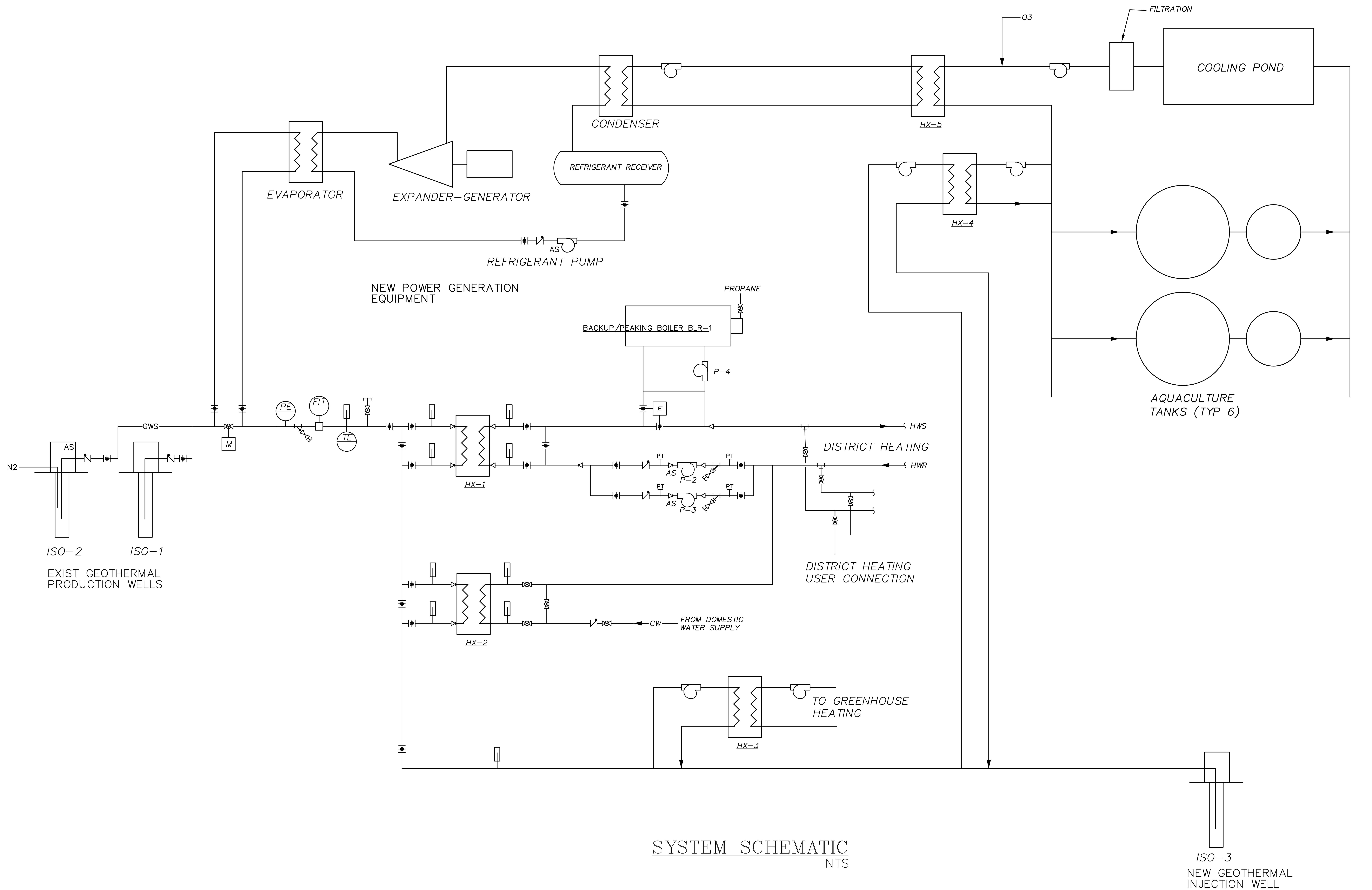
Project Financial Projection

Additional Information

Environmental Assessment

Cascaded System Engineering

Renewable geothermal energy is all about community.



SYSTEM SCHEMATIC
NTS

NO.	DATE	REVISION	BY

Project Title:
CANBY CASCADED GEOTHERMAL SYSTEM
CANBY, CALIFORNIA

SYSTEM SCHEMATIC

Engineering by:
Brian Brown Engineering
PO Box 563
Fort Klamath, Oregon 541-783-3347

REGISTERED PROFESSIONAL ENGINEER BRIAN BROWN M 27659 MECHANICAL STATE OF CALIFORNIA
Expires: 12/31/13

DESIGN BKB
DRAWN BY -
FILE NAME schematic.dwg
APPROVED BY
SHEET 1
DATE 03-15-2013
PROJECT NO.

CANBY CASCADED GEOTHERMAL HEAT AND POWER BALANCE.

Coldest Month Average Temperature; 20°F

	Heat Balance		Geothermal			Heat Loads			PUMPING			POWER	
	Btu/hr 10^3		Flow	T_in	T_out	Flow	T_in	T_out	TDH	Pump	Motor	Generated	Uses
	In	Out	gpm	°F	°F	gpm	°F	°F	ft	%	%	kW	kW
ISO-1 Well			35						370	60%	90%		(4.5)
ISO-2 Well			185						370	60%	90%		(23.9)
Power Plant heat In	3,370		220	205	174								
Power		210										61.5	
Losses		38											
Heat rejected to Aquaculture		3,122				750	60	68	20	60%	90%		(5.2)
District Heating	1,800		220	174	158	120	120	150	50	60%	90%		(2.1)
Greenhouses	2,700		220	158	133	250	98	120	20	60%	90%		(1.7)
Aquaculture supplemental heat	3,140		220	133	105	750	68	76					
Aqua Total		6,262										61.5	(37.5)
Geo Total	11,010									Net Power		24.0	

Net power available			24.0	
Domestic water				(2.0)
Greenhouse	Houses	kW ea		
Fans, aquaponics circulation and aeration	6	1.0		(6.0)
Aquaculture	Tanks	kW ea		
Pumping	6	2.0		(12.0)
O2 Generation	6	4.0		(24.0)
Ozone	1	0.2		(0.2)
Food service Freezers & Geothermal Laundromat				(7.6)
Dining hall, School buildings				(7.6)
			24.0	(59.4)
		Net Power	(35.4)	

Notes

1 Power output is estimated based on thermodynamic modeling of an ORC power cycle at the temperatures and flows stated

CANBY CASCADED GEOTHERMAL HEAT AND POWER BALANCE.

Average Summer Conditions; 58°F

	Heat Balance		Geothermal			Heat Loads			PUMPING			POWER	
	Btu/hr 10^3		Flow	T_in	T_out	Flow	T_in	T_out	TDH	Pump	Motor	Generated	Uses
	In	Out	gpm	°F	°F	gpm	°F	°F	ft	%	%	kW	kW
ISO-1 Well			24						266	60%	90%		(2.2)
ISO-2 Well			<u>136</u>						266	60%	90%		(12.6)
Power Plant heat In	2,282		160	205	176								
Power		153										44.9	
Losses		23											
Heat rejected to Aquaculture		2,106				360	66	78	20	60%	90%		(2.5)
District Heating	200		160	176	174	30	137	150	50	60%	90%		(0.5)
Greenhouses	100		160	174	173	30	113	120	20	60%	90%		(0.2)
Aquaculture supplemental heat	-		160	173	173	360	78	78					
Aqua Total		2,106										44.9	(18.1)
Geo Total	2,582					60				Net Power		26.8	

Net power available			26.8	
Domestic water				(4.0)
Greenhouse	Houses	kW ea		
Fans, aquaponics circulation and aeration	6	1.0		(6.0)
Aquaculture	Tanks	kW ea		
Pumping	6	2.0		(12.0)
O2 Generation	6	4.0		(24.0)
Ozone	1	0.2		(0.2)
Food service Freezers & Geothermal Laundromat				(7.6)
Dining hall, School buildings				(7.6)
			26.8	(61.4)
Net Power			(34.6)	

Notes

1 Power output is estimated based on thermodynamic modeling of an ORC power cycle at the temperatures and flows stated

Power Plant Cooling

Coldest Month Average; 20°F

		Fish Tank	Clarifier	Qty Tanks	Pond	
				6		
Pond						
L	ft	50	13.5		200	
W	ft	0	0		100	
Depth	ft	8	6		6	
Area	ft^2	1,963	143	12,640	20,000	
Volume	ft^3	15,708	859		120,000	Circulation
	gal	116,239	6,355	735,566	888,000	36.1 hours
Water	°F	70	67.7		67.3	
Vapor pr	psia	0.363	0.336		0.331	
Air	°F	20	20		20	
Vapor pr	psia	0.054	0.054		0.054	
	RH	25%	25%		25%	
Vapor pr	psia	0.01347	0.01347		0.01347	
Velocity	mph	7.0	7.0		7.0	
	ft/s	10.27	10.27		10.27	
Evap	lb/hr	167.60	11.30	1,073	1,556.21	
				2.2		
Evap Heat	Btu/hr	(175,978)	(11,868)		(1,634,017)	
Conv Heat	Btu/hr	(136,070)	(9,462)		(1,310,121)	
Radiant	Btu/hr	(82,041)	(5,665)		(783,310)	
Solar						
0	Btu/hr	-	-		-	
	Btu/hr	(394,089)	(26,995)	(2,526,501)	(3,727,448)	
Water						
Flow	gpm	125.00	125.0	750.00	750.0	
Temp in	°F	74	67.7		67.3	74
Pond T	°F	67.7	67.3		57.3	57.3
	Btu/hr	394,089	26,995	2,526,501	3,727,448	16.7
				Total Heat	6,253,949	Btu/hr

Power Plant Cooling

Summer Average Conditions; 58°F

		Fish Tank	Clarifier	Qty Tanks	Pond	
				6		
Pond						
L	ft	50	13.5		200	
W	ft	0	0		100	
Depth	ft	8	6		6	
Area	ft^2	1,963	143	12,640	20,000	
Volume	ft^3	15,708	859		120,000	Circulation
	gal	116,239	6,355	735,566	888,000	75.2 hours
Water	°F	77	73.0		72.6	
Vapor pr	psia	0.460	0.402		0.396	
Air	°F	58	58		58	
Vapor pr	psia	0.239	0.239		0.239	
	RH	25%	25%		25%	
Vapor pr	psia	0.05966	0.05966		0.05966	
Velocity	mph	5	5.0		5.0	
	ft/s	7.33	7.33		7.33	
Evap	lb/hr	135.10	8.49	862	1,167.23	
				1.7		
Evap Heat	Btu/hr	(141,858)	(8,917)		(1,225,591)	
Conv Heat	Btu/hr	(36,933)	(2,124)		(288,097)	
Radiant	Btu/hr	(35,456)	(2,015)		(273,048)	
Solar						
130	Btu/hr	63,814			650,000	
	Btu/hr	(150,434)	(13,056)	(980,936)	(1,136,736)	
Water						
Flow	gpm	60.00	60.0	360.00	360.0	
Temp in	°F	78	73.0		72.6	78.0
Pond T	°F	73.0	72.6		66.2	66.2
	Btu/hr	150,434	13,056	980,936	1,136,736	11.8
				Total Heat	2,117,672	


SHOP
ISO-2
144.2
384.3
49
CONTAINMENT
AQUACULTURE COOLING TANKS
ISO-3
DOMESTIC WELL
GH#1
GH#2
GH#3
GH#4
GH#5
ISO-1
EXISTING UNDERGROUND POWER LINES 480v 3-PHASE
2500
2000
1500
1000
500
100
CANBY CASCADED GEOTHERMAL SITE PLAN, CANBY, CA 96015

Injection/Resource Study

Kelley Hot Springs Fish Farm aquaculture.

Plumas Geo-Hydrology *P.O. Box 1922, Portola, CA 96122*
LAND AND WATER RESOURCES *tel. (530) 836-2208*

The Geothermal Resource of Canby in Warm Springs Valley, Modoc County, California

A review of the Canby Geothermal Field based on ground water chemistry, stable isotopes, temperature gradients, fracture trace analysis, magnetotelluric and drilling data

Prepared by

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For
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530-640-1477

Final Report

March 29, 2013

1. Executive Summary

The objectives of this study are:

A. To identify one or several geothermal drilling sites in the Canby area.
B. To gather all available data and new field data to develop a conceptual geothermal system model of the Canby Geothermal Field as a basis of a more systematic approach to geothermal resource development in this part of the Modoc Plateau.

The project was based on collecting and analyzing the following data:

1) A review of the scientific literature and technical reports.
2) Chemistry, temperature, and stable isotopes in ground water to identify geothermal anomalies and characterize ground water and geothermal flow systems.
3) Vertical temperature profiles in geothermal wells, residential and irrigation wells.
4) A fracture trace analysis by inspection of low altitude stereographic photos, combined with the results of a Magneto-Telluric survey.

The results were integrated into a comprehensive conceptual geothermal system model of the Alturas Basin and more specifically the Warm Springs Valley (WSV) geothermal resource.

RESULTS

Warm Springs Valley is underlain by an aerially extensive geothermal aquifer below 2000 ft, extending at least 4 miles from west to east, from Canby, through Kelly Hot Springs (KHS) to at least 2 miles east of KHS:

a) Drilling found rapidly increasing temperatures until a major lost-circulation zone was found at about 2000 ft (1600 ft at KHS), followed by isothermal (adiabatic) conditions to at least 3850 ft depth. These similar conditions were found in Canby, at KHS and in a hole drilled 2 miles east of KHS.
b) Maximum temperature measured in Canby is 106 °C, though it is possible that higher temperatures may be found (as high as 115°C as at KHS).
c) Lost circulation always occurred in lithified tuff and basalt units, or contacts between these and other rock types. The reservoirs in this area have been inferred as a succession of lavas and lithified tuffs, mudflows and breccias down to at least 6000 ft (GeothermEx, 1977).
d) Conditions are similar in the two Alturas geothermal wells, although no isothermal gradient was measured, probably since the wells were not drilled deep enough.

AERIAL EXTENT OF THE GEOTHERMAL AQUIFER

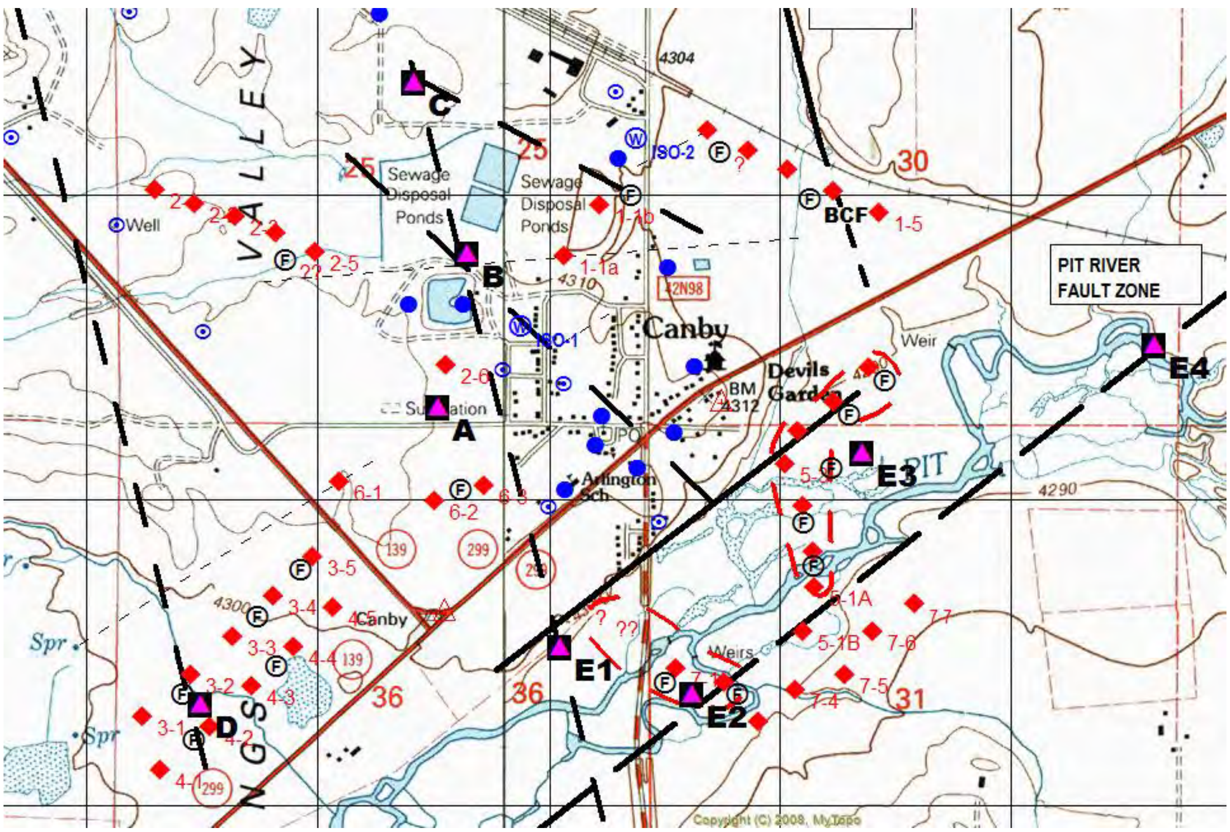
Resistivity data suggest a low resistivity layer extending several miles across Warm Springs Valley from east to west, which was substantiated in the Canby area by a recent MT survey. A gravity survey suggests that the lithology extending east from Kelly Hot Springs is relatively consistent.

Water chemistry and stable isotope composition (^{18}O and ^{2}H) in the KHS and ISOT well #1 (about 2 miles apart) are virtually identical, which can be seen as further evidence of an aerially extensive geothermal aquifer.

In summary, the similarities between the KHS and Canby deep wells suggest the presence of an extensive, internally communicative, geothermal aquifer underneath several square miles below 1600 in the KHS area and below 2000 ft in the Canby area. The isothermal gradients below about 2000 ft suggests that there is enough permeability in the lithified tuffs and lava formations permitting vertical fluid circulation, implying secondary permeability, if not fracture zones that can produce geothermal water.

PROPOSED DRILLING SITE

Our recommended preferred drilling alternative is at site B, within the bounds of the project area, about 2600 ft NW of the Canby intersection. The site is located on an intersection of two faults (and possibly a third lineament). It is in close proximity of several irrigation wells, the chemical composition of which is indicative of a geothermal anomaly.



2. Introduction

Background

In 1988 and 1991 two successful geothermal wells were drilled in the City of Alturas in Modoc County, northeastern California into a so far unknown geothermal resource producing 84°C water from below 2000 feet (GRC Trans. Vol. 19, Oct. 1995). Both wells produce from fractured hydrothermally cemented tuffs and mudflows, overlain by a “cap” of unconsolidated fine-grained tuffs and lacustrine sediments. An important realization growing out of this project was that even in the absence of hot springs geothermal manifestations can become evident in subtle indicators in the overlying cold aquifers. Another successful geothermal well was drilled in Canby in 2000, encountering conditions very similar to those found in Alturas.

The primary objective of this study is to identify one or more potential drilling sites for a geothermal injection well near Canby (ISO-3). The secondary objective is to establish a comprehensive framework for geothermal exploration in this part of the Modoc Plateau by characterizing the “Canby Geothermal Field” (US EPA, 2012), a geothermal resource of significant aerial extent.

The current Canby geothermal investigation is only the latest among several other investigations in this part of the Modoc Region, including not only Canby, but also Kelly Hot Springs, Big Valley and Alturas:

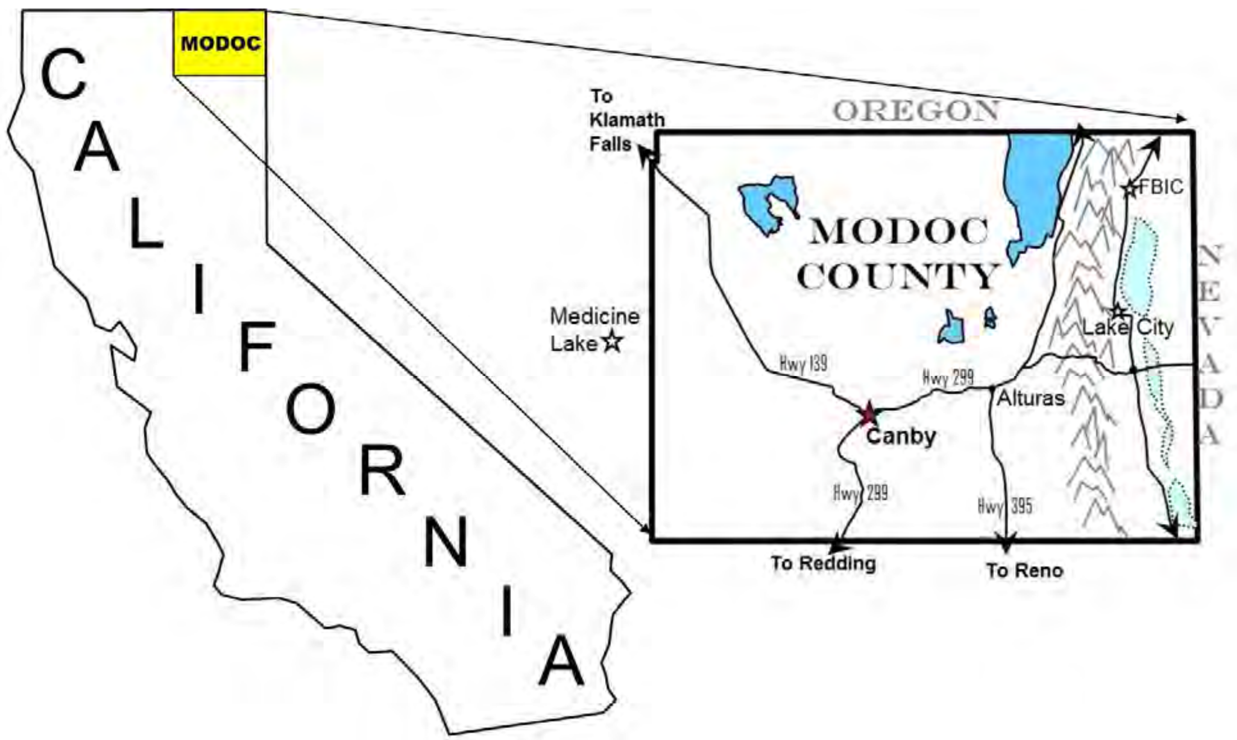
1. In the 1960’s and 1970’s two wells were drilled near the Kelley Hot Springs area to more than 3000 ft depth (Geothermex, 1977). Since the well yields and temperatures did not meet the operators’ expectations for power production further exploration was discontinued.

2. A 1985 investigation included an in-depth study of the geologic and hydrologic conditions to characterize the Big Valley geothermal system, applying hydrogeochemistry, temperature gradient measurements, and a gravity survey (Juncal & Bohm, 1985). One test well was drilled. Unfortunately, due to insufficient funding it was not possible to drill deep enough to access the resource (Juncal & Bohm, 1987).

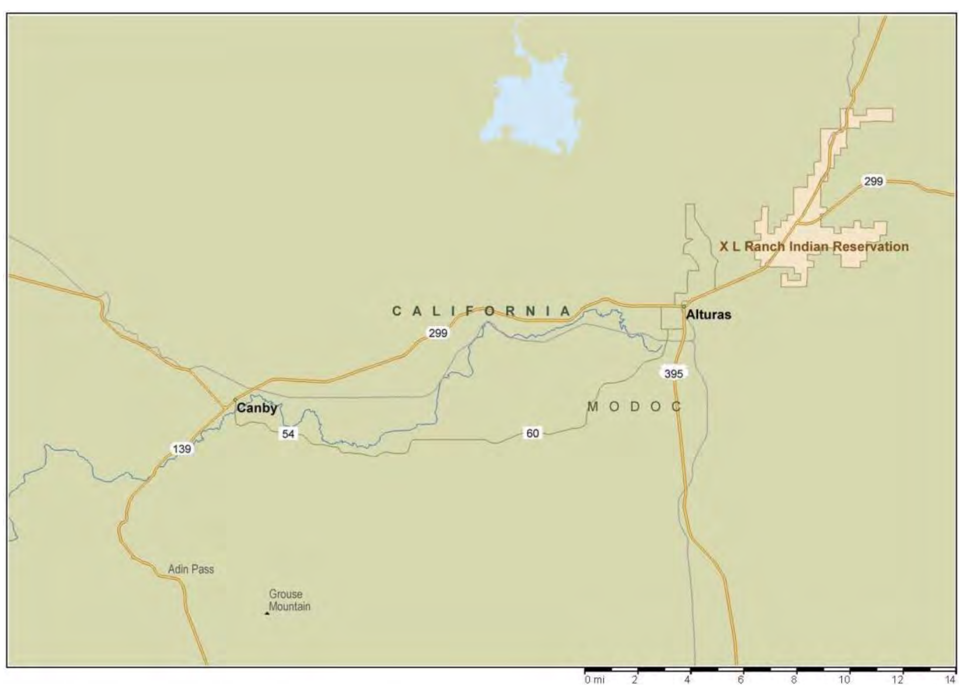
3. A four year investigation initiated in 1988 in the Alturas area resulted in drilling two successful geothermal wells (Juncal & Bohm 1988; Bohm and Fenske 1992a; 1992b; 1993). The first well has been used since 1990 to heat the High School complex. Due to acceptable water quality effluent can be discharged into the Pit River, obviating the need for an injection well. The second well (AL-2), although rated at 250 gpm, is not used due to the need of an injection well. What is remarkable is that the Alturas resource was realized with no geothermal surface manifestations (Kelly Hot Springs is about 20 miles west of Alturas).

4. An effort launched by ISOT in 2000 in the town of Canby resulted in drilling a successful 2100 ft deep production well (Bohm, 2000). To date this effort has been the second successful geothermal resource development in the Alturas Basin. Although the yield is

modest, the well supports a small district heating system (35 homes), a laundromat, and a greenhouse (Merrick, 2010).



Map 1A: Project location map (from Merrick, 2010).



Map 1B: Location of Warm Springs Valley (WSV), between Canby and Alturas.

Approach followed in this investigation

The objective is to provide a comprehensive overview of an aerially extensive geothermal aquifer, and to identify well drilling site. Based on a thorough review of preceding project reports and scientific literature, this project relied on gathering five data categories:

1) A review of geothermal drilling data from preceding projects in Big Valley and the Alturas Basin (including WSV).

2) Ground water chemistry and temperatures to identify aggregate parameters that can help pinpoint geothermal anomalies.

3) Stable isotopes of hydrogen and oxygen in ground water to characterize ground water and geothermal flow systems.

4) Vertical temperature profiles to determine geothermal gradients.

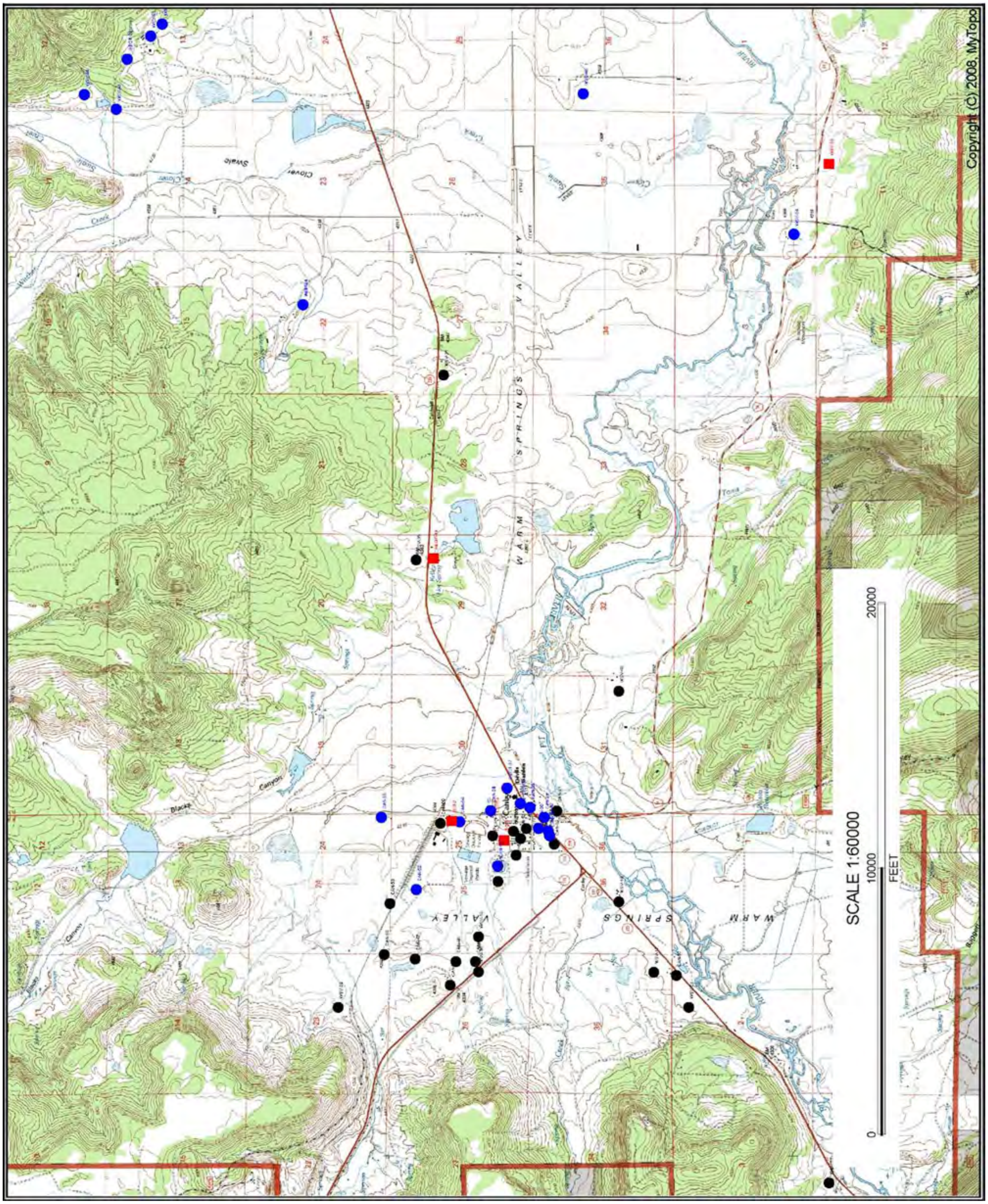
5) Geophysical surveys (magneto-telluric).

6) A fracture trace analysis based on inspection of low altitude US Forest Service aerial photos.

The results were integrated into a conceptual geothermal system model of the Alturas Basin and more specifically the Warm Springs Valley (WSV) geothermal resource.

It will be shown that WSV is underlain by an aerially extensive geothermal aquifer concealed under massive deposits of tuffaceous sediments. Even in the absence of hot springs, geothermal manifestations can become evident in subtle anomalous shallow temperature gradients and geochemical “fingerprints” in the overlying cold aquifers.

This kind of approach (at a fraction of the cost of drilling) has been recommended as far back as the mid 1970’s (GeothermEx, 1977). Although control over the exact location of the data points is usually limited, this approach permits skipping the first drilling phase, creating the basis of a more focused drilling effort.



Map 1C: Warm Springs Valley, well locations. Colors denote ground water chemistry types (see section 4). Red squares are geothermal waters.

3. Geology and hydrology

Geology

Warm Springs Valley (WSV) is a sub-basin of the Alturas Basin, an intermontane basin located in the Modoc Geologic Province of northeastern California. The Basin is a fault bounded graben structure filled with lacustrine sediments, pyroclastics and lava flows (Gay and Aune, 1958; McKee et al., 1983). The Modoc Plateau is deemed a transitional zone between the Great Basin in the east and the Cascade Range in the west. Its rock formations that resemble those of the Cascade Range, whereas the block faulted structure is reminiscent of the Basin and Range Province (Norris and Webb, 1976). Mariner et al. (1983) consider it part of the Great Basin. The general geology of the area is presented on the geologic map of the Alturas 2-degree sheet (Gay and Aune, 1958).

As in most of northeastern California, volcanism has been a prevailing geologic feature in the Alturas Basin for at least the last 30 million years leading many authors to attribute localized geothermal activity to intrusive magma bodies. However, a direct link between geothermal activity and shallow intrusives has never been demonstrated (Elliot Allen, 1986).

LaFleur and Kramer (2011) point out that the igneous activity (Alturas Formation) about 8 to 10 million years ago is no longer able to provide the heat necessary to maintain existing hydrothermal systems in the area. The local hydrothermal systems are typical Basin and Range Province geothermal systems, driven by meteoric water descending to sufficient depth to be heated by the high regional thermal gradient (Blackwell, 1983) and re-emerging along deep reaching fault zones.

Our understanding of the subsurface geology and structure in the Alturas Basin is limited. The valley floor is covered by Quaternary alluvial and lacustrine sediments underlain by the Alturas Formation, a sedimentary sequence (more than 1500 ft thick) of mostly tuffs and tuffaceous sediments deposited in a lacustrine setting. Basalt layers within the Alturas Formation have been used to establish stratigraphic correlations between wells and have in some cases been used to identify faults (Juncal & Bohm, 1988).

Typically three directions of fault lineaments dominate the structural geology, encompassing north-south, northeast, and northwest directional elements (see Section 7). Favorable settings for increased fracture permeability correlate with these lineaments, in particular wherever they intersect.

Hydrology of Warm Springs Valley

The Alturas Basin is divided into two sub basins - the South Fork Pit River sub-basin and the Warm Springs Valley sub-basin separated by several low mesas (DWR, 1967, 1982).

The sub-basin is a fault trough bounded in the north by the Pleistocene basalt of Devils Garden; in the south by the Plio-Pleistocene Warm Springs tuff and basalt; and in the west by Pleistocene basalt (Gay, 1968). The sub-basin is separated in the east from SFPRV by a low, a north-to-northwest trending highland, of the Plio-Pleistocene Alturas Formation, west and south of Alturas. Although the WSV and SFPRV have separate surface drainages, the ground water regime is believed to be continuous through the Alturas Formation.

Located in the northwestern margin of the Great Basin Province, the 3415 square mile Upper Pit River Watershed is between 3200 and 9833 feet elevation. Drained by the North and South Forks of the Pit River (VESTRA, 2004), which originate in the northern and southern Warner Mountains, the two forks merge in the town of Alturas. The Pit River then flows southwest through Warm Springs Valley, towards Shasta Lake and the Sacramento River.

Mean annual valley floor precipitation in Warm Springs Valley is about 12 inches, ranging between 13 and 19 inches (VESTRA, 2004). Precipitation in the eastern upland ground water recharge areas is up to 16 inches annually (DWR, 1967). A significantly larger amount of ground water recharge is to be expected from the Warner Mountains, where mean annual precipitation ranges up to 32 inches at the high elevations (more than 8000 ft), as snowmelt and by runoff infiltration in the extensive alluvial fans.

The Basin contains a number of excellent shallow cold aquifers made of pumiceous sands, jointed and scoriaceous lava flows, which are recharged through the alluvial fans on the western slopes of the Warner Mountains, and through the adjacent volcanics. Municipal and irrigation wells are up to 900 feet deep (in some cases up to 1200 ft).

Increasing demands for limited surface water has encouraged significant ground water development in the alluvial basins. Ground water supplies are reliable, although ground water level depletion can lead to limitations under severe drought conditions. Most ground water is developed in alluvial aquifers and to a lesser extent in fractured rocks.

Hydrostratigraphic units

Hydrostratigraphic units are bodies of rock with considerable lateral extent that act as a reasonably distinct hydrologic system, which may include a formation, part of a formation, or a group of formations (Maxey, 1964).

The Alturas Basin and WSV subsurface hydrology is characterized by two separate hydrostratigraphic units:

1. The upper unit makes the excellent “valley floor aquifers” that the hundreds of irrigation and municipal wells are drilled into.
2. The lower unit is the “deep geothermal aquifer” made of hydrothermally cemented fractured fine-grained tuffs and intercalated lavas, fractured to transmit geothermal water.

These two hydrostratigraphic units are separated by a thick sequence of unconsolidated fine-grained tuffaceous lacustrine sediments, forming an aquitard at least 500 ft thick, effectively isolating the shallow aquifers from the geothermal aquifer below about 2000 ft (LaFleur and Krahmer, 2011).

Well water level data in municipal wells up to 1200 ft deep have shown no response to extended testing of the deep geothermal wells (Bohm, 1993), suggesting there is no hydraulic connection between the shallow aquifers and the deep geothermal aquifer. Also the stable isotope data (deuterium, oxygen-18) indicate only two distinct groups of water, with no evidence of mixing. The non-indurated fine-grained tuffs act as an effective barrier concealing the geothermal system at depth.

Upper cold water-bearing formations

The three main upper water-bearing formations are (DWR, 1963):

1. Holocene sedimentary deposits,
2. Pleistocene lava flows, and
3. Plio-Pleistocene Alturas Formation and basalts.

Holocene sediments

The Holocene terrestrial sedimentary deposits include alluvial fan deposits, intermediate alluvium, and basin deposits, each up to 75 feet thick. Alluvial fan deposits are sand and gravel with clay lenses and poorly stratified silt, which generally make good aquifers with high yield wells, under confined and unconfined conditions. The intermediate alluvium of poorly sorted silt and sand and gravel lenses and the basin deposits of interstratified clay, silt, and fine sand make low to moderate productive aquifers.

Pleistocene volcanics

The Pleistocene volcanic rocks include 50 to 250 feet of jointed basalt, which serve as recharge zones wherever they outcrop in the surrounding uplands. In the basin their scoriaceous jointed zones make moderate aquifers, where they are interbedded in the upper member of the Alturas Formation.

Plio-Pleistocene Alturas formation

The Alturas Formation consists of moderately consolidated, flat-lying tuff deposits (sand, silt, and clay) and diatomite. The upper and lower sedimentary members of the formation are each about 400 feet thick, separated by a basaltic lava flow and the Warm Springs tuff. The Alturas formation sediments are the principal aquifers in WSV, with high yield wells under confined and unconfined conditions.

The concealed deep geothermal system

Geothermal drilling conducted at KHS, Alturas and Canby to depths beyond about 2000 ft has found no “basement rock” to at least 3850 ft (LaFleur and Krahmer, 2011). The formations found between 600 and 2400 ft in the Alturas and Canby wells were interpreted as upper and lower Alturas Formation (Juncal & Bohm, 1989). The Alturas Formation encompasses lacustrine clays, fine-grained tuffs, volcanic mudflows, with interbedded volcanic sands and basalt flows.

The fine-grained tuffs and mudflows below 1850 ft are slightly silicified due to low grade hydrothermal alteration, sufficient to hold open fractures that yield significant amounts of water (Juncal & Bohm, 1988; Bohm and Fenske, 1992a; Bohm, 2000).

4. Ground Water Chemistry

Ground water chemistry data were used to identify chemical anomalies indicative of geothermal activity - not only the hot springs but more so hidden geothermal manifestations found in specific ranges of anion ratios. Sometimes these manifestations can be tied to photo lineaments (faults).

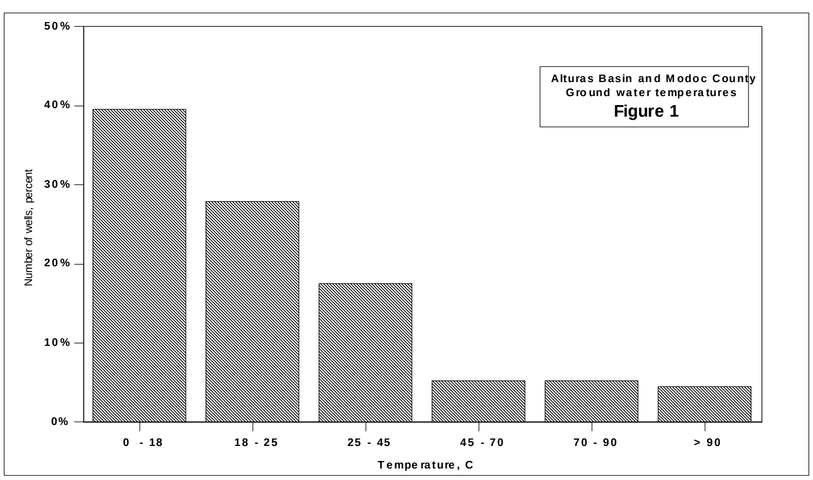
Using graphical and statistical analyses three major chemical types were identified to help identify geothermal anomalies, and allowing one to assign each data point to a certain hydrogeologic setting.

Unfortunately use of the State ground water chemistry data base was hampered by a policy that would not permit release of well ownership. Thereby it was not possible to augment the database by collecting samples for isotopes and other components or measuring vertical temperature profiles.

Data compilation

Ground water chemistry data sets were compiled from various literature sources, technical reports, and the ISOT files and from lab analysis of samples collected for this project. The data were screened (epm balance) and duplicates were sorted out so that every data point (wells) was represented by only one single data set. Thereby a total of 254 data sets were accumulated. Data sources and method of data base compilation are discussed in Attachment A, including a table of data used for this project.

Ground water chemistry and temperature



Anomalous regional heat flow in the Modoc Region is evident in elevated temperatures typically seen in wells in the area.

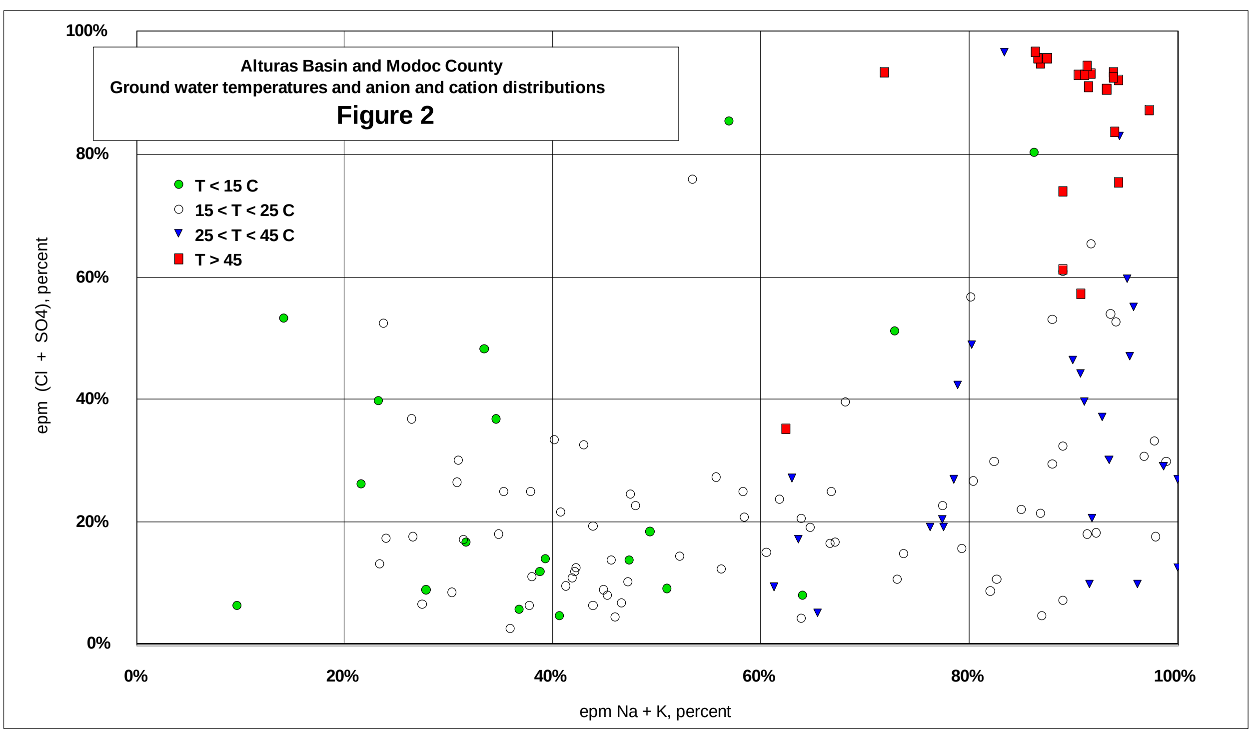
Figure 1 shows a frequency distribution of ground water temperatures (154 data sets). The pervasive presence of anomalous heat flow is indicated by the fact that more than 60% of all measured ground water temperatures are greater than the average annual ambient air temperature of 18° C. On the other hand, less than 10% are greater than 70° C, suggesting only localized occurrence of truly geothermal manifestations.

The elevated aquifer temperatures have imprinted themselves in slight alteration (changes in mineral composition due to elevated temperatures) commonly observed in the deposits below 100 ft, symptomized by greenish hues (chloritization) of light colored rock fragments and greenish looking fine-grained tuffs ("clays"). Occasionally rock fragments have silicic coatings, and vugs are lined with mineral deposits - all of which are indications of low-grade alteration. Since slight alteration affects mineral-water chemical equilibria, it is reasonable to expect that geothermal signals are noticeable in ground water chemistry data.

Figure 2 is an adaptation of the central diamond of the standard trilinear plot (Piper, 1944) frequently used in hydrochemical studies. The diagram includes all data points with ground water temperature data, showing the equivalent (epm) percentages of sodium-plus-potassium (Na + K) and chloride-plus-sulfate (Cl + S04). In a very general way temperature ranges correlate with certain ranges in chemical composition:

1. Cold waters cooler than 15 ^{0}C are typically calcium carbonate waters (less than 40% Cl+SO4 and less than 50% Na+K).

2. Warm waters with temperatures between 15 and 25 ^{0}C comprise most of the data. They are of a wide range in chemical composition, between Ca-HCO3 and Na-Cl-SO4 waters.



3. Waters with temperatures between 25 and 45 ^{0}C are distinctively Na-K waters with no more than 60% Cl+SO4.
4. The high temperature waters (>45 ^{0}C) form a distinctive group of sodium-chloride-sulfate waters (more than 60% Cl + SO4).

Although there are exceptions to these patterns, it is clear that elevated ground water temperatures due to high heat flow from the deep geothermal aquifers affects shallow ground water chemistry. This can help identifying geothermal anomalies in shallow aquifers.

Anion frequency distributions

The anion and cation distributions expressed in site-specific equivalent percentages, as shown in Figure 2, are too indistinct to permit a useful classification of ground water chemistry. Instead an analysis of anion frequency distributions was used to identify sub-populations of data.

Before delving into the procedure of statistical analysis a few comments are in order about whether the database is representative. After all, the data base covers two separate ground water basins: Alturas Basin (including WSV and the SFPRV) and Big Valley. Furthermore it contains the countywide ground water chemistry data base of Elliot Allen (1985), including ground waters with anomalous temperatures, and geothermal waters.

Most Modoc ground waters are of the Na-SO4-Cl type. Figure 3 is a SO4-versus-Cl cross-plot encompassing data from all three sources. Since data from each source covers approximately the same ranges of Cl and SO4, it is in our view justified to lump the data into one single database.

Anion sub-populations and threshold values

Threshold values between sub-populations where determined by adapting the method of Sinclair (1974), using cumulative frequency plots of chloride, sulfate and bicarbonate. When cumulative frequencies derived from close-to-normally distributed data are plotted on probability paper they are expected to plot on a close to linear pattern. Significant deviation from a linear pattern is either due to deviation from “normality” or because the data are comprised of several sub-populations. In other words each straight line segment in a cumulative frequency distribution plotted on probability paper represents a normally distributed sub-population. On a frequency plot those data that are part of a sub-population plot as a “bell shaped” curve. Curved segments between straight line segments constitute transitions between sub-populations.

Geochemical data are typically close to log-normally distributed (Ahrens, 1965) - and so are these data. The frequencies of logarithmic values of chloride, sulfate, and bicarbonate alkalinity were calculated for 30 class intervals (“bins”). The cumulative frequencies were then plotted on probability graph paper in Figures P-1, P-2 and P-3 (included at the end of Attachment A), including all data points from the Alturas Basin (including Warm Springs Valley), Big Valley and all Modoc County geothermal waters (Elliot Allen, 1986).

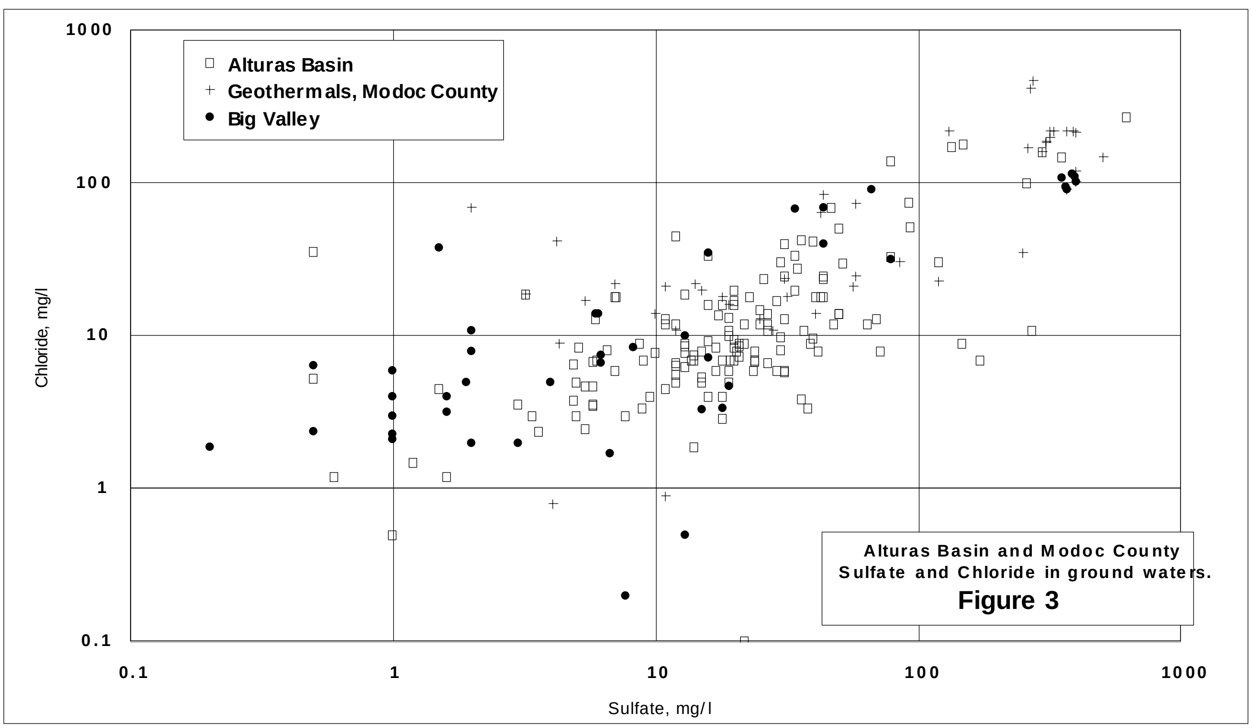
All three plots contain clearly identifiable straight line segments, each suggesting distinct geochemical sub-populations. The values between the segments represent the high end of the lower sub-population and the low end of the higher sub-population.

Three straight-line segments were identified for the anions sulfate and chloride, and only two were identified for bicarbonate alkalinity. For the purpose of this report each segment on the plot are assigned an integer number, i.e. 1, 2, 3, 4, and 5.

1. The sub-populations (straight-line segments) are referred to as "groups" and are assigned to the odd integers 1, 3, and 5.

2. The data plotting between the straight-line segments are called "transition groups", assigned to the even integers 2 and 4.

Added to each data point's group integer was a single decimal digit indicating the position in each group on a scale of 1 through 10. For example the sulfate group assignment 3.4 indicates that the data point is centrally positioned in group 3. A value of 5.9 would indicate positioning at the upper extreme of group 5, etc., etc.



How well a straight-line segment is defined depends on the number of data points in a group. Each one of the three cumulative frequency plots encompass at least one well defined centrally located straight-line segment. Due to the focus of the DWR monitoring program the data points in this large group are typically from wells located on the valley floors. The lower portion (lower concentration levels) of the chloride and sulfate plots is the most poorly defined due to the small number of data points (poor representation) from wells and springs along the valley periphery and the surrounding mountains. The uppermost group in the sulfate and chloride cumulative frequency plots is typically made of geothermal waters. This pattern is reversed in the bicarbonate cumulative frequency plot, with the lowermost group constituting geothermal waters.

Alturas Basin, Big Valley and geothermal waters in Modoc County. Groundwater chemistry types (groups), characterized by anion concentration subpopulations.

Table entries in mg/l

Chloride groups:

Groups:	1	2	3	4	5
upper boundary:	0.58	3.32	14.31	82.5	475.9
lower boundary:	0.10	0.58	3.32	14.3	82.5
range:	0.51	2.91	11.65	72.3	417.0

SO4-groups:

Groups:	1	2	3	4	5
upper boundary:	1.06	4.24	51.49	206.3	626.0
lower boundary:	0.10	1.06	4.24	51.5	206.3
range:	1.01	3.37	50.09	164.1	444.9

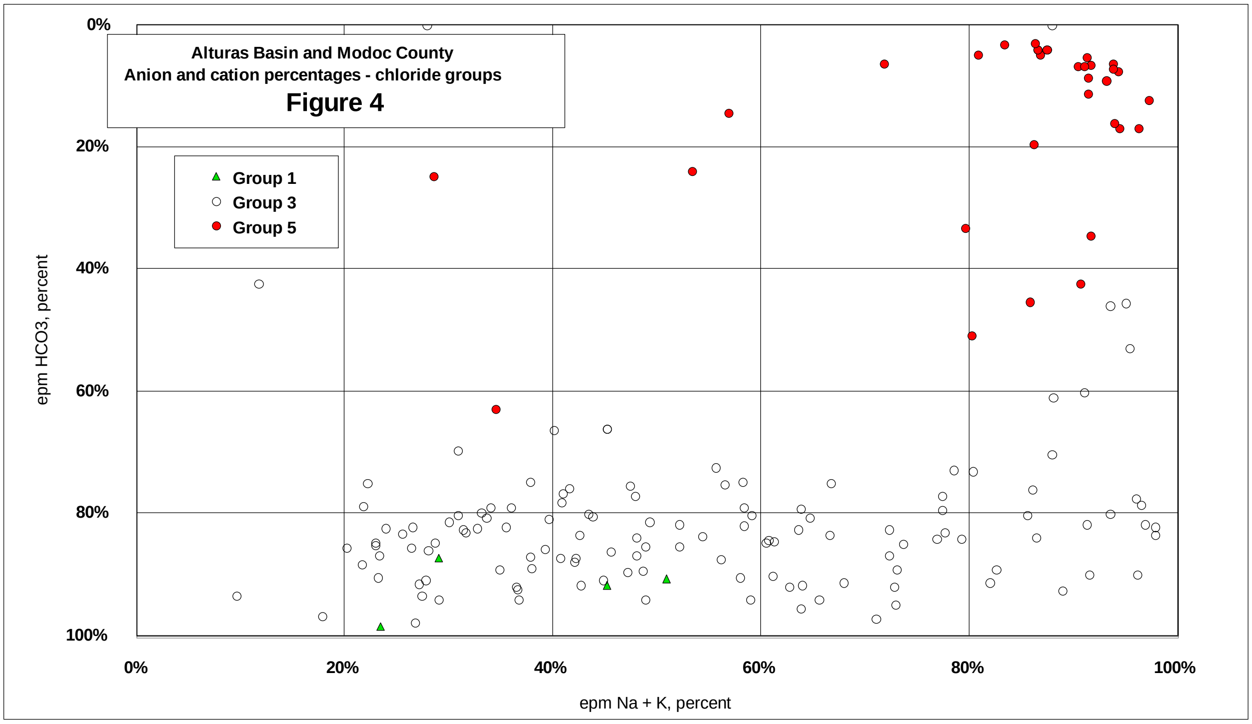
Bicarbonate groups:

Groups:	1	2	3
upper boundary:	31.9	91.5	594.1
lower boundary:	0.1	31.9	91.5
range:	34.1	63.7	537.9

Based on each data point's anion composition sulfate, chloride and bicarbonate group or transition group integers were assigned. Although the sulfate and chloride group integers do not always match, the assigned sulfate and chloride groups for each data point are generally fairly consistent, assigning higher group integers ("5") to geothermal waters. On the other hand the bicarbonate group assignments are different in that the highest bicarbonate levels are associated with low temperature waters, and the lowest bicarbonate levels with geothermal waters.

These group patterns are to be expected since Modoc thermal waters typically have relatively high chloride and sulfate concentrations (up to 115 and 400 mg/l, respectively) and relatively low bicarbonate values (20 to 38 mg/l), whereas bicarbonate concentrations in low and intermediate temperature waters range from 64 to 415 mg/l.

Compared to the very limited range of molar Cl/SO4 ratios (0.7 - 1.0) in thermal waters the colder waters' ratios fit into much wider ranges (1.0 - 1000).



Hydrologic significance of geochemical groups

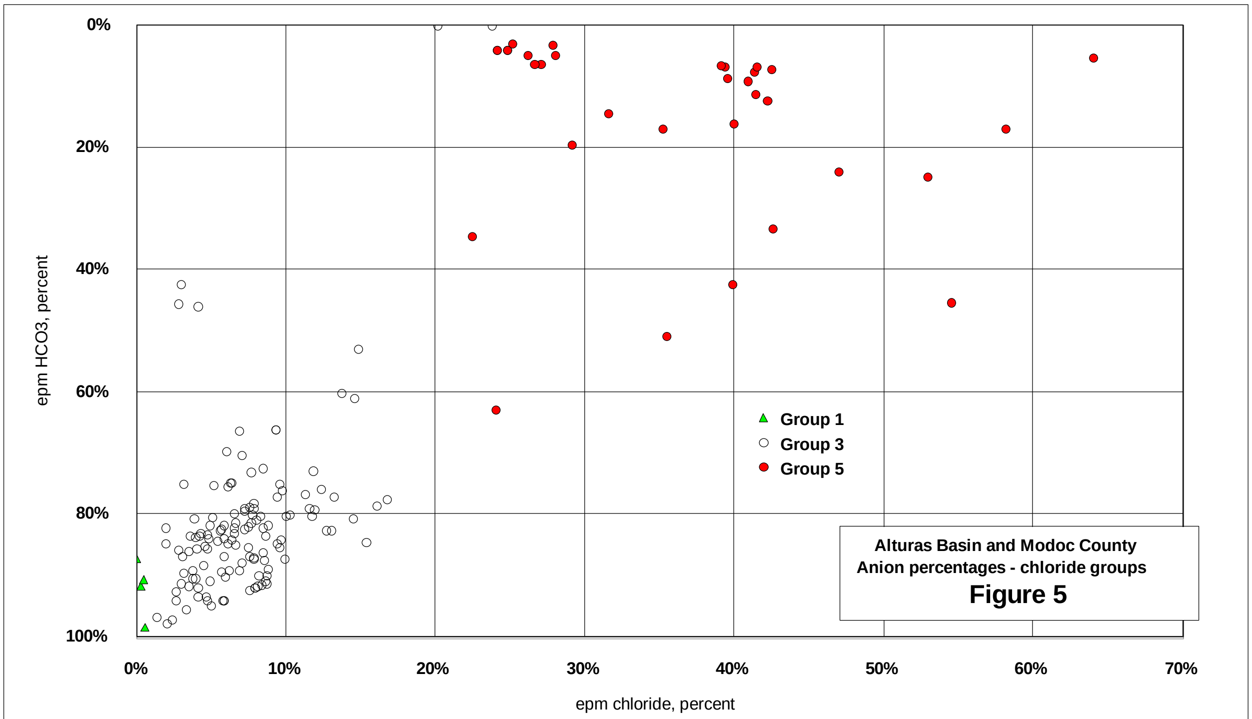
But what do each group and each transition group stand for in the hydrologic system? As it turns out this database verifies what has been concluded in Big Valley based on a much smaller data base (Juncal & Bohm, 1985).

Ground water residence time

The rationale for identifying ground water types by means of sub-populations of anion concentrations can be based in the concept of ground water "effective residence time", which is a function of flowpath length, permeability and temperature (and to some extent formation rock composition). In silicate rock terrain like the Modoc Plateau, a semi-quantitative measure of effective residence time is best indicated by the "conservative" solutes chloride and to a lesser extent by sulfate (at least in these low TDS waters, ranging between 115 and 1730 mg/l TDS by sum of the major ions). The relation of bicarbonate with residence time is more complex, since it is affected by precipitation of secondary minerals like calcium carbonate and in some cases by aquifer systems that are open to subsurface CO_2 supply.

Ground water hydrochemical facies

It is assumed that each segment (group) is linked to a geochemical environment dictated by distinct ground water flow conditions. In the absence of a better term these sub-populations could be called "hydrochemical facies" (Back, 1966) based on divisions defined somewhat arbitrarily within straight-line boundaries on a trilinear diagram (Piper, 1944). On the other hand the approach employed herein is based on observed abundances of certain concentration levels observed in the data matrix specific for this study area, rather than on arbitrary linear separations. Each "group" (sub-population) is associated with certain hydrochemical characteristics that are unique for the study area.



This point is demonstrated in Figure 4 and Figure 5. The chloride groups 1, 3, and 5 are plotted again in equivalent percentage plots, an adaptation of the central diamond and the anion triangle of a Piper diagram. Groups 3 and 5 are very distinct in Figure 4. On the other hand the number of data points in Cl-group 1 is so small that it probably should be lumped with group 3; however, it does not matter since only the distinction between groups 3 and 5 is of interest. A more distinct separation between all three groups occurs in the anion epm plot. Since trilinear diagrams are actually plots of ion ratios, the separation by groups in this kind of plot is interpreted as an indication that these Cl-groups do have a basis in general ground water chemistry of each data point. Thereby justification is seen for using them to map geothermal anomalies.

It should be noted that attempts to distinguish subpopulations by means of other variables failed to yield meaningful results (for example % Na+K and % Cl+SO4).

Water-rock interaction

There are other observations that further substantiate that anion groups correlate with specific geohydrologic settings:

1. The anion compositions of each group are associated with particular ranges in pH, though the patterns are of limited consistency due to the scarcity of good field pH data

(most pH data in the technical literature is of uncertain quality). The available lab pH data show an increasing average pH correlating with the chloride and sulfate groups.

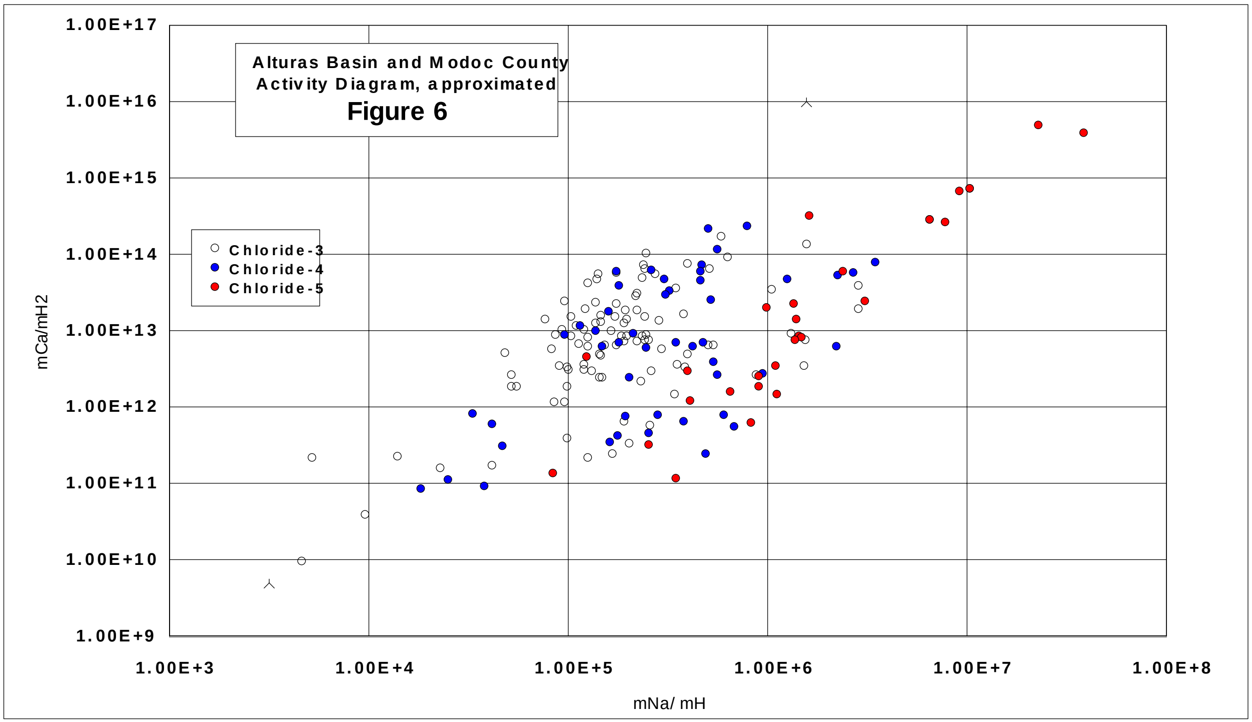
2. The relations between major cation molality and pH are characteristic of certain silicate mineral reactions, if not hydrothermal alteration at depth. A typical activity diagram was approximated in Figure 6. The molalities are herein assumed to be equivalent to the activities (which is a reasonable approximation for such dilute waters). A more accurate plot would require calculating the ratios with the WATEQ program (Plummer and others, 1975):

    a) The dilute waters of chloride groups 1 and 3 (lower TDS) occupy a wide field, similar as seen elsewhere in low TDS cold waters, for example waters from high elevation springs in the Sierra Nevada (Feth and others 1974).

    b) On the other hand the higher TDS waters of chloride group 5 are conspicuously aligned along a unique trend. This trend is typical for geothermal waters, due to intensified water-rock reactions in geothermal systems.

    c) The group 5 waters are relatively low in calcium, and high in sodium. This is typical for hydrothermal alteration of silicate minerals in geothermal waters, where the divalent cations like calcium and magnesium are integrated into secondary minerals.

    d) Although these groups cannot be fully explained in terms of geochemical processes, it is noteworthy that they correlate with certain stable isotope (D and 18O) composition ranges (see Section 5).



Geographic anion group trends

Chloride group trends and faults

To identify ground water chemistry patterns, the data points were plotted on a simplified schematic map with symbols indicating each data point's assigned chloride group (Figure 7). Although these maps are of limited resolution using only an approximate coordinate system based on the well numbering system (Township-Range-Section), they do reveal noteworthy geographic patterns that can be linked to fault trends. In other words under favorable conditions these maps can help pinpoint certain geochemical patterns that are indicative of geothermal anomalies.

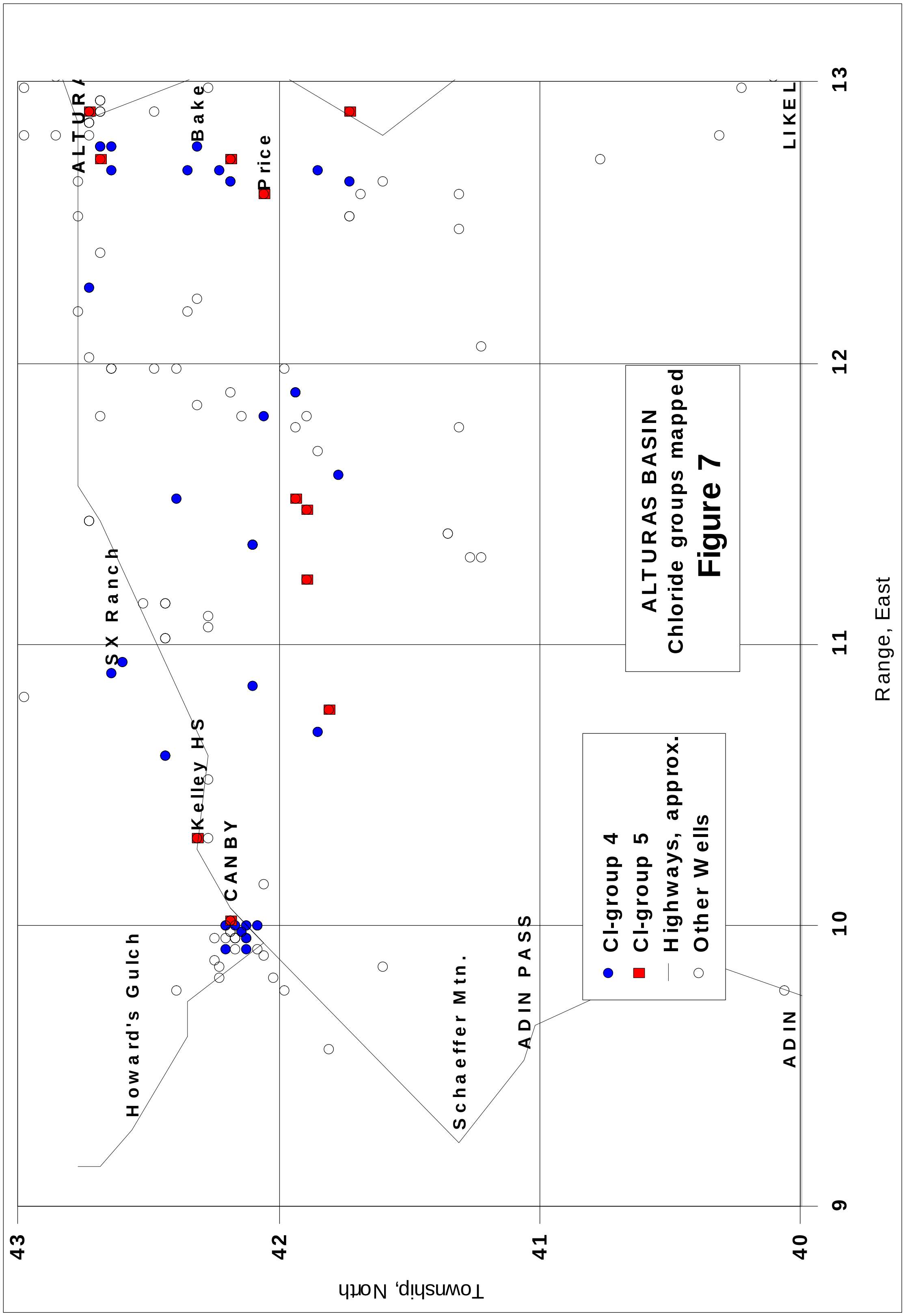
Based on what we already know about the geologic settings of geothermal resources in the Alturas Basin, certain associations can be identified between chloride transition-group 4 and group 5 and geologic structures:

- ❖ The north-south orientation of the South Fork Pit River Valley (SFPRV) is defined by a series of north-south striking normal faults (Eliot Allen, 1986). These north-south trending faults intersect a series of NW striking faults in the town of Alturas, where two successful geothermal wells were drilled in 1988 and 1991.
- ❖ A defining characteristic is that a large accumulation of Cl-transition-group-4 waters is associated with the western margin of the SFPRV, south of Alturas. This zone is characterized by prominent NS trending normal faults. However, it's not only group-4 waters that are to be found there, but also a few Cl-group-5 waters (which are geothermal waters).

On the other hand using the SO4-groups (not plotted) these geographic trends are far less convincing, if at all. This is probably so since highly soluble chloride increases are most definitely going parallel with the progress of silicate-water reactions (chloride being released from minerals without being involved in any mineral-water reactions), whereas sulfate is at least somewhat affected by mineral-water equilibria, including sulfide minerals and anhydrite.

Apparently chloride abundance (related to anion ratios involving Cl, SO4 and HCO3 – see Figure 4 and Figure 5) can be affected by proximity to certain faults, even when the isotope data and pumping test results show no evidence of geothermal waters mixing with the low temperature valley floor aquifers that support the hundreds of wells in the basin (see Section 5, isotope data).

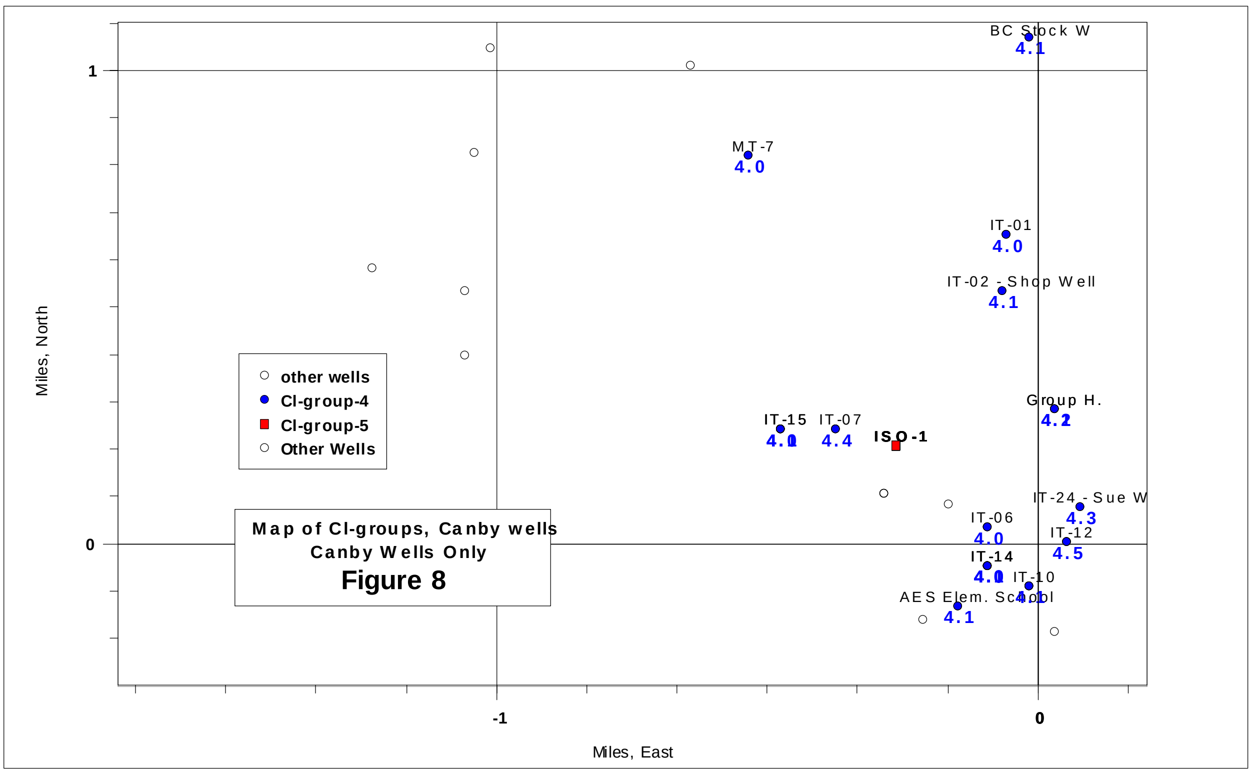
One plausible explanation is that the faults, although they can be traced at the surface (see Section 7, fracture trace analysis), are sealed in the "sticky clay" aquitard. Only rarely do these faults establish flow conduits through this aquitard, such as at KHS where two faults intersect, and have evolved into vertical flow conduits through hydrothermal alteration and cementation of the lacustrine tuff formations.


ALTURAS BASIN
Chloride groups mapped
Figure 7
Cl-group 4
Cl-group 5
Highways, approx.
Other Wells
Range, East
Township, North
9
10
11
12
13
40
41
42
43
ALTURA
Bake
Price
SX Ranch
Kelley HS
CANBY
Howard's Gulch
Schaeffer Mtn.
ADIN PASS
ADIN
LIKEL

Nevertheless, even in areas where faults are sealed by the aquitard these are settings of increased circulation in the geothermal aquifer beneath the aquitard, which leads to increased heat flow, intensifying the hydrogeochemical reactions in the aquifers above the aquitard. Needless to say, these are the attractive geothermal drilling targets.

Chloride groups in the Canby area

Of particular interest in Figure 7 for the Canby area is a near linear arrangement of transition-group-4 waters extending NE from KHS to the SX-Ranch wells, coinciding with the Pit River Fault Zone (PRFZ) which trends SW from KHS (Section 7). The town of Canby with a large accumulation of wells is located adjacent to and NW of the PRFZ. Most of these wells are Cl-group-4 waters. Unfortunately, due to poor geographic coverage this trend cannot be verified SW of Canby.



The Canby wells were plotted on a smaller scale in Figure 8. It is conspicuous that the transition-group 4 wells tend to plot in the area immediately around Canby. By comparison the irrigation wells located farther away from the PRFZ, N and NW of Canby, are typically “Cl-group-3” waters, indicative of “background” patterns. Apparently proximity to the PRFZ (if not NNW trending faults – see Section 7) affects a ground water becoming a transition-group 4 water. Incidentally, proximity to the PRFZ may also be one reason why geothermal well ISO-1 was a success - which, as expected, plots as a Cl-group 5 water amidst the Canby Cl-group 4 waters.

An interesting pattern evolves when adding to Figure 8 each well’s Cl-group ranking, plotted as a blue number under each transition-group 4 well location. While most Canby wells’ Cl-group ranking is “4.0” or “4.1”, a few wells in southeast Canby, those that are closer to the PRFZ, stand out with rankings ranging from “4.2” to “4.5”.

Whereas these patterns all point to an affinity between Cl-transition-group-4 waters and geothermal anomalies, for due diligence the chemistry of these wells needs to be further examined to assure that this feature is not just a sporadic coincidence.. It would help to have access to more wells in order to conduct a focused sampling program for isotopes, wellhead temperatures, T-logs, and other chemical components.

Also, it might be worthwhile to examine how group 4 waters correlate with faults elsewhere. For example at this point nothing is known about the structural geology (faults) in southern WSV (“Centerville Road”) where a few geothermal waters (red squares) have been mapped in Figure 7 (see also Map 1C).

5. Stable isotopes

The results of the stable isotope data interpretation (deuterium and oxygen-18) demonstrates that Cl-groups 3 and 4 are confined to the upper hydrostratigraphic unit, whereas group 5 is found only in the geothermal aquifer below the clay aquitard. The isotope data also help identify ground water recharge areas and flow paths.

Figure 9 shows a plot of deuterium and oxygen-18 (^{2}H and ^{18}O) including:

1. Geothermal waters from the region spanning from Surprise Valley in the east to Little Hot Springs west of the Big Valley Mountains, covering a distance of more than 70 miles.

2. Springs and wells sampled in the high elevation areas surrounding WSV.

The solid line in the upper left diagram of Figure 9 is the local meteoric water line (LMWL). This line is an approximation of snow composition in this region, derived by regression analysis of 15 snow data sets collected in the spring of 2011 and 2012 (R^2 = .94). These include 10 snow samples collected near Cedar Pass in the Warner Mountains, and other samples collected around WSV, including Howard's Gulch in the north, and Cooley Gulch in the south.

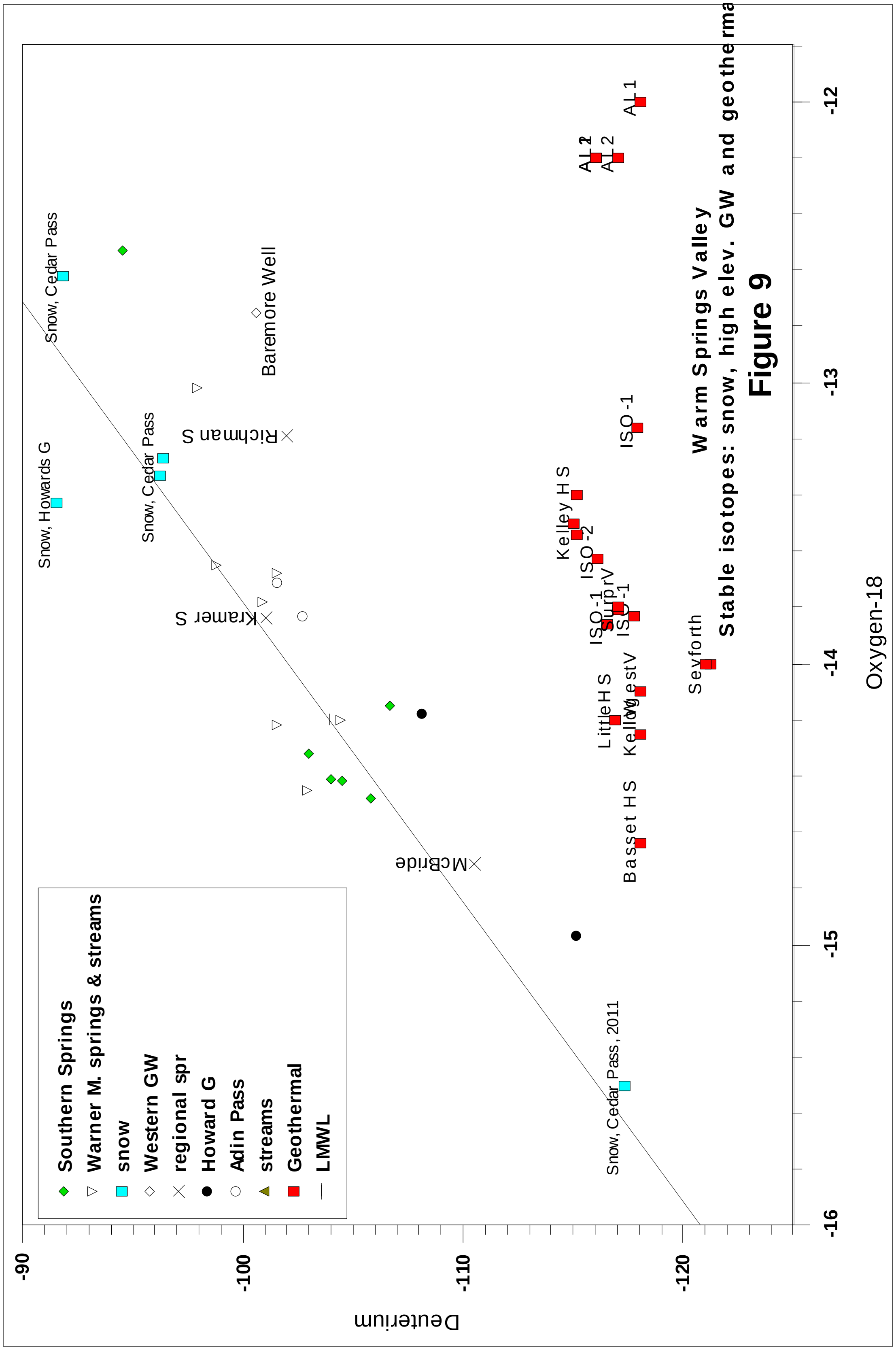
The snow samples collected in the mountains are assumed to represent snowmelt that infiltrates at high elevations to become ground water recharge. The wide ranges of snow composition (oxygen-18: -18 to -1.11; deuterium: -139 to -36) are much more than one would expect due to elevation differences, greater than the ranges observed in the local ground waters (not all snow data were included in the diagram).

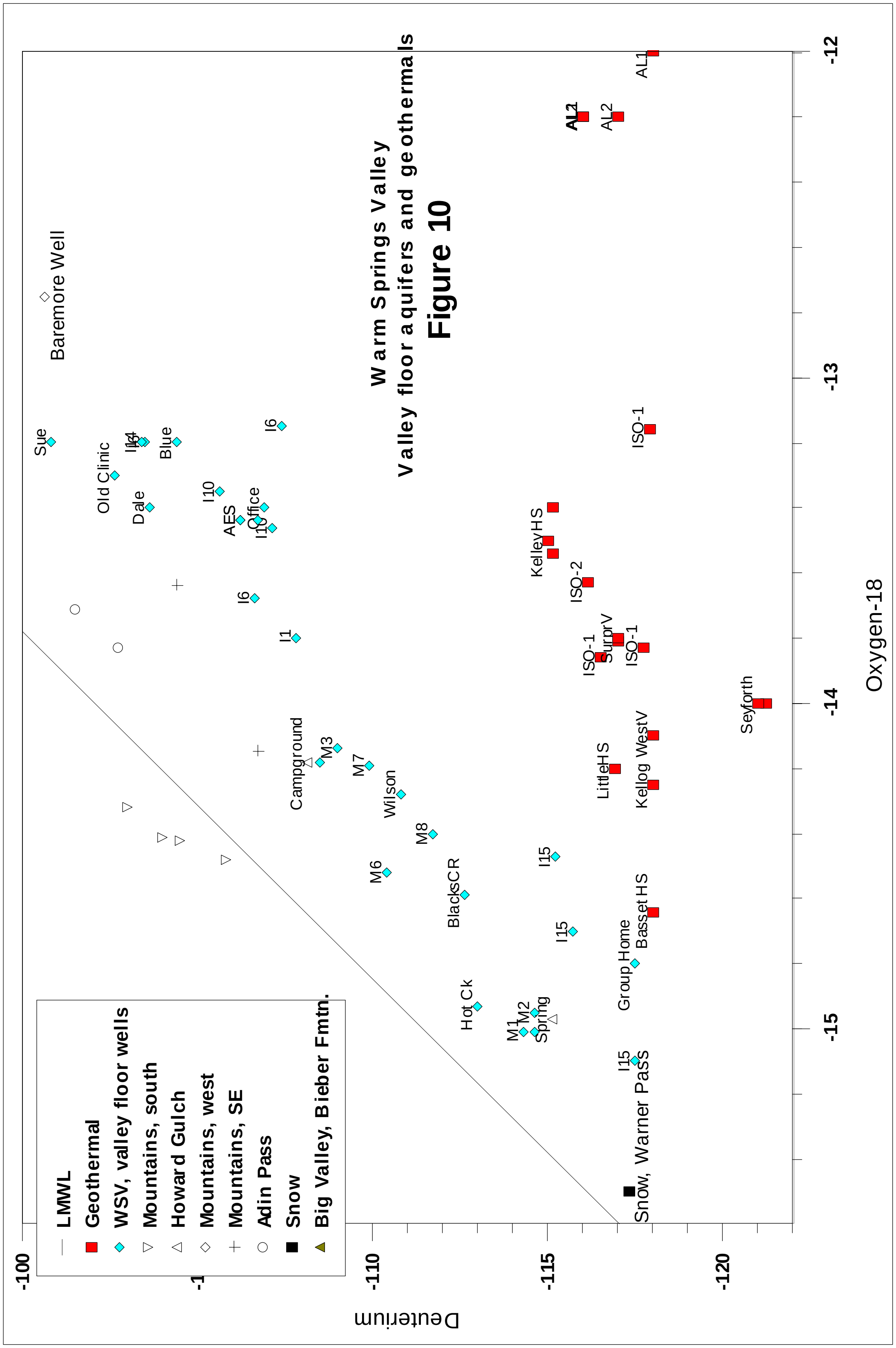
Geothermal waters

The geothermal waters in Figure 12 include Kelley HS, the two Alturas geothermal wells, Surprise Valley HS and wells, etc., and other hot springs from elsewhere in Modoc County. It is noteworthy that well ISO-1 isotope composition is virtually the same as KHS, an indication that these waters are from the same aquifer. (No data are available from well ISO-2).

The most conspicuous feature in Figure 9 is the horizontally elongated pattern occupied by the geothermal waters in the lower diagram. In other words oxygen-18 (O-18) occupies a wide range on the x-axis, whereas deuterium (D) occupies only a rather narrow range on the y-axis.

The shift of the geothermal waters to the right, away from snow and the local meteoric water line (LMWL) is called the "oxygen shift". It is caused by intensified rock-to-water interaction under elevated temperature whereby water becomes slightly enriched in O-18. This does not happen to deuterium. The magnitude of the oxygen-shift depends mostly on subsurface temperature, and less so on subsurface residence time and aquifer permeability. The oxygen shift is largest in the Alturas geothermal wells.

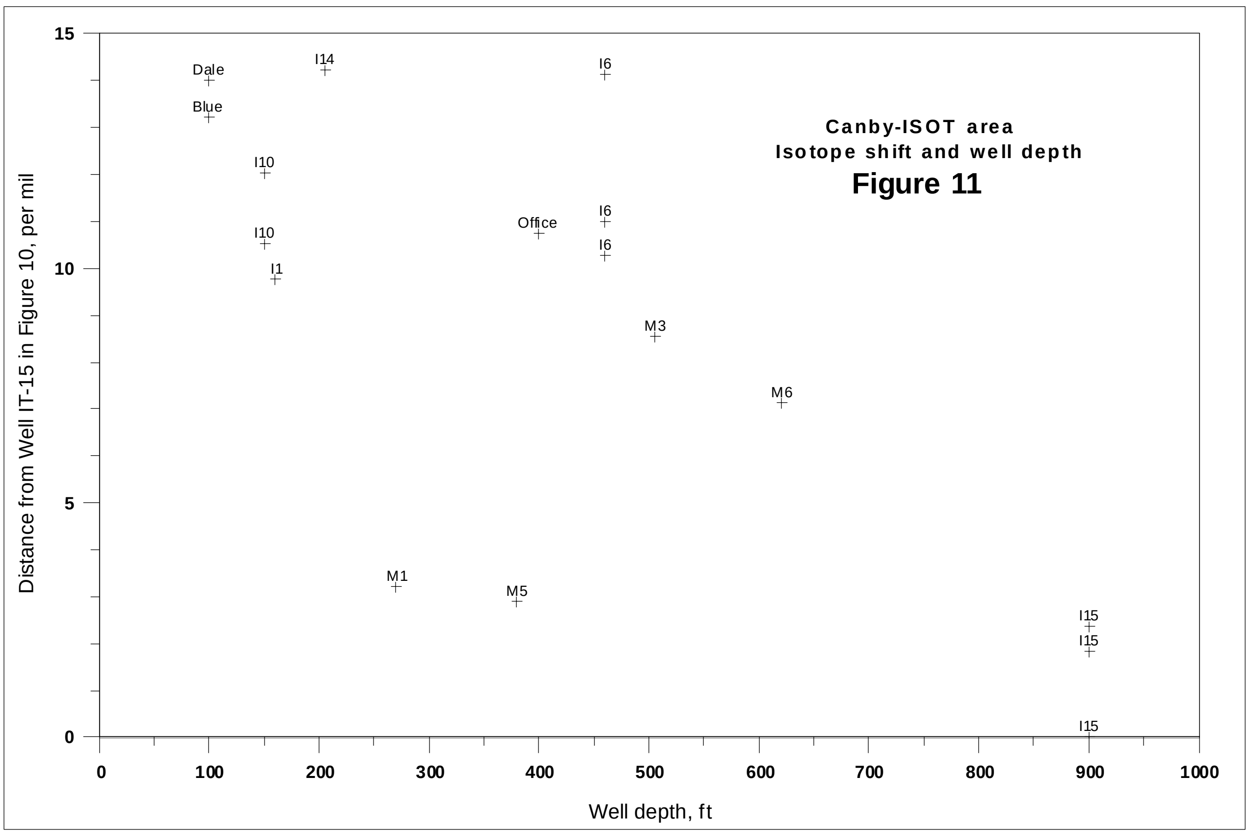

Warm Springs Valley
Stable isotopes: snow, high elev. GW and geothermal
Figure 9
Deuterium
Oxygen-18
-90
-100
-110
-120
-16
-15
-14
-13
-12
Southern Springs
Warner M. springs & streams
snow
Western GW
regional spr
Howard G
Adin Pass
streams
Geothermal
LMWL
Snow, Cedar Pass
Snow, Howards G
Snow, Cedar Pass
Snow, Cedar Pass, 2011
Baremore Well
Richman S
Kramer S
McBride
Kelley H S
ISO-2
ISO-1
ISO-1
ISO-1
Surp V
Little H S
Kellog
West V
Basset HS
Seyforth
AL 1
AL 2
AL 2


Warm Springs Valley
Valley floor aquifers and geothermals
Figure 10
Oxygen-18
Deuterium
LMWL
Geothermal
WSV, valley floor wells
Mountains, south
Howard Gulch
Mountains, west
Mountains, SE
Adin Pass
Snow
Big Valley, Bieber Fmtn.
Baremore Well
Snow, Warner Pass
KelleyHS
Seyforth
Kellog WestV
Basset HS
LittleHS
Group Home
Campground
Old Clinic

Ground water recharge areas

Ground waters sampled in the mountains surrounding WSV occupy a wide range of isotope compositions (Figure 9). No particular correlation between geographic location and plotting positions can be discerned.

As a rule the plotting range on the vertical deuterium axis depends on ambient air temperature (elevation) at the area of recharge (Clark and Fritz, 1997). It also depends on distance from the ocean. The latter has been convincingly demonstrated in the geothermal waters of the Great Basin, which includes this part of the Modoc region (see Mariner et al., 1983). Therefore the limited range of deuterium in these geothermal waters can be interpreted as an indication that these waters were recharged in a limited geographic area.



To some extent isotope composition of high elevation springs can be substituted as a close approximation of recharge water composition for deep (regional) ground water flow systems. Both snow and high elevation ground waters (mostly springs) occupy wide ranges of deuterium and O-18 composition, probably due to evaporation during infiltration at the recharge area. Yet the high elevation ground waters do not match the narrow deuterium composition range of the geothermal waters. This contradiction is apparent in most ground water systems of the Western US. One explanation is that geothermal waters are part of extensive regional ground water flow systems with very long residence times, recharged during a cooler climate (Mariner et al., 1983).

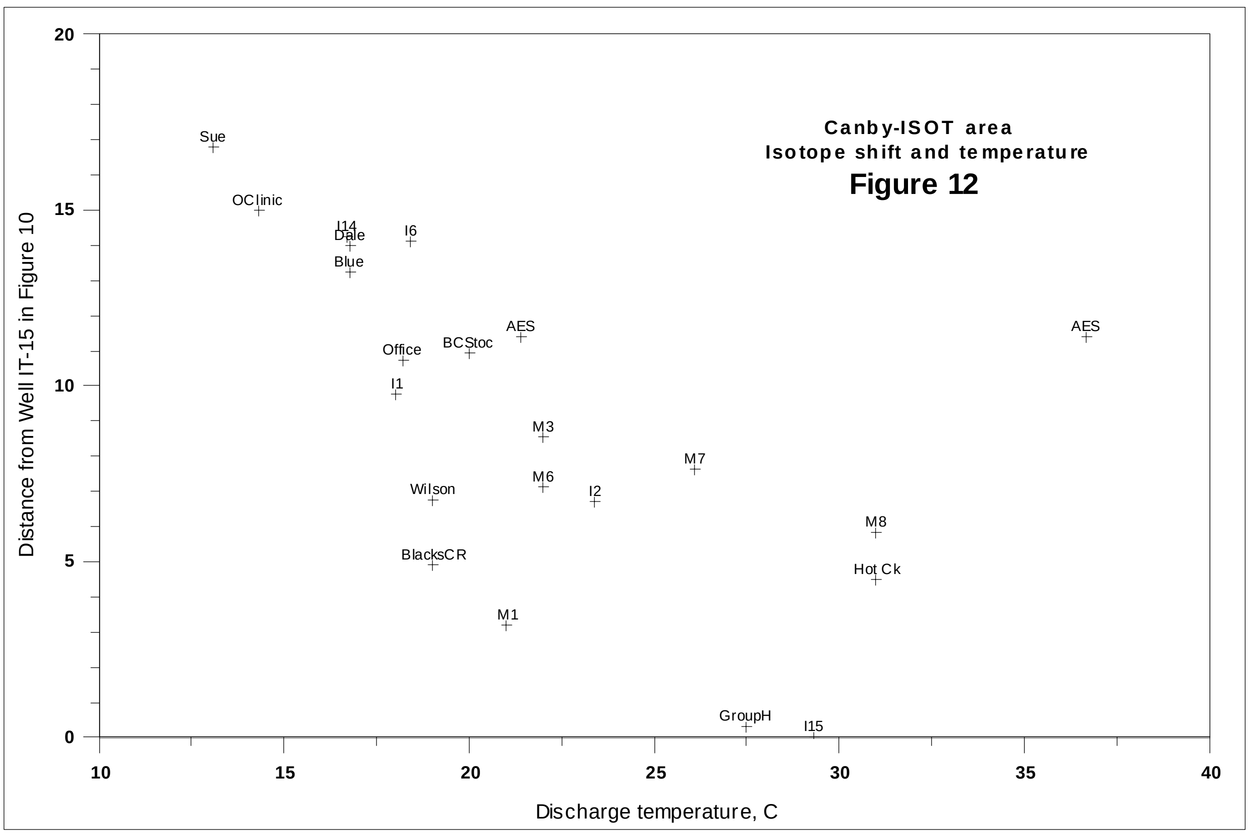
Nevertheless the wide range of Warner Mountain snow composition does not preclude the possibility of the same serving as recharge for the Modoc Plateau geothermal waters. After all, one snow sample collected at Cedar Pass plots in the same deuterium range in the lower left of the diagram.

Mixing in the WSV Valley floor aquifers

Figure 10 shows a plot of deuterium and oxygen-18 (D and O18) for all shallow ground waters sampled in Warm Springs Valley and all geothermal waters:

1. The valley floor wells plot on a slanted elongated pattern, stretching from the lower left to the upper right. These are irrigation, stock and residential wells with elevated temperatures that pump from the lacustrine aquifers that occupy the basin. Well depths range between 100 and 960 ft.

2. Also plotted in Figure 10 are waters sampled from springs and wells in the mountains ("mesas") surrounding WSV.



Those high elevation waters from the high lands surrounding the basin most closely matching waters sampled in valley floor wells would be expected to represent recharge to the shallow valley floor aquifers. Yet, none of these waters fits into the valley floor aquifer water plotting group, except one: the "Baremore" well, sampled in the highlands west of Canby. It plots at the upper end of the elongated group of valley floor waters. On the other hand on the lower left end of this trend plot the 900 ft deep well IT-15 and the Group Home well, both located in Canby.

Elongated plotting patterns that encompass changes in both O-18 and D suggest ground water mixing (unless evaporation is involved). If the valley floor well data group is indeed part of a mixing sequence, then the mixing end members would be represented by the IT-15 well at great depth (> 900 ft) and the Baremore well representing shallow (local) ground water recharge.

In other words, the upper mixing end member would be recharge in the mountains to the west and the lower mixing end member would have to be sought at great depth with an isotope composition similar to Well #15 (IT-15) (the lowermost "I15" in Figure 10).

Most importantly the lower mixing end-member represented by the 960 ft deep ISOT Well #15 ("I15" in Figure 12) is not geothermal water since it was not subjected to an oxygen-18 shift. Nevertheless, since its deuterium level is the same as in the geothermal waters (typically from depths greater than 2000ft), it is possible that it is from the same recharge source. The difference is that it did not penetrate as deep as the geothermal waters before arriving at WSV.

Ground water mixing, temperature and well depth

The mixing hypothesis was tested in Figure 11 and in Figure 12. The distance from the point where the cold water trend meets the geothermal trend (herein called the "distance") can be calculated by applying the rule of Pythagoras. In this case the distance was calculated for each data point from the lowermost data point gathered from ISOT Well #15 (I15). When plotting the "distance" against well depth (Figure 11) and discharge temperature (Figure 12) close to linear trends can be implied (with exceptions), suggesting a shallow and a deep mixing source – all within the aquifers of the upper hydrostratigraphic unit.

A similar mixing trend, albeit less pronounced, can be implied when plotting the "distance" versus the conservative tracer chloride and sulfate (not shown).

Therefore, the valley floor aquifer isotope trend in Figure 10 can be interpreted as a manifestation of subsurface mixing between a shallow cold water source associated with the NW Mountains, and a deep ground water exemplified by ISOT Well IT-15.

Chloride groups and hydrostratigraphic units

Isotope composition and chloride groups associate in a systematic fashion in Figure 13, a plot similar to Figure 10. For each plotting position the chloride group is indicated in color. The colors red and white denote groups 5 and 3, and blue denotes transition group 4.

The deep geothermal waters are all group 5 waters; whereas the waters pumped from the valley floor wells (shallow aquifers) are either group-3 or transition group-4 waters. Clearly, each chloride group is limited to one of the two upper hydrostratigraphic units:

1. Chloride groups 3 and 4 are associated with the upper hydrostratigraphic unit.
2. Chloride group 5 is associated with the lower hydrostratigraphic unit.

Most importantly a well's association with transition group 4 is not necessarily dependent on "plotting distance" from Well IT-15. In other words it is not tied to any particular depth or temperature regime, since its chloride level is associated with proximity to faults.

Also, since the groups are so distinctly confined to their unit, without "overlap", no mixing between the units is implied.

Source waters

The isotope data interpretation implies that the WSV ground waters are from three different sources:

1. The shallow and intermediate deep aquifers of the upper hydrostratigraphic unit are composed of a mixture of:

   a) Ground water that is recharged locally in the surrounding mountains.

   b) Ground water that is derived from a source outside the basin, water that has traveled at intermediate depth over significant horizontal distances, resulting in anomalous ground water temperatures sometimes exceeding 45 ^{0}C.

2. Geothermal water that "daylights" from depth in hot springs and wells tapping into deep reaching faults that allow hot water to rapidly rise from great depth to discharge at near boiling or higher temperatures.

The waters in the upper shallow valley floor aquifers are probably stream water infiltrated on the alluvial fans and the intermediate depth aquifers are probably recharged through the volcanic rocks in the surrounding mountains.

Again, the isotope data indicate that the valley floor aquifers are isolated from the underlying geothermal aquifer by the "clays" which have provided so many challenges for every deep drilling project. There is no interaction between these two units since there are no mixing trends between the geothermal waters and the overlying low temperature aquifers.

Regional ground water flow systems

The narrow range of deuterium values in the geothermal waters can be interpreted as having been recharged at a higher elevation and/or further east than the ground waters sampled in the mountains surrounding WSV.

For all practical purposes, the geothermal water sampled below 2000 ft depth in the ISOT and Alturas geothermal wells have the same deuterium levels as KHS, and many other geothermal springs, from Surprise Valley and as far south as Big Valley (Kellog and Basset HS) and as far west as Little Hot Spring (about ten miles west of Big Valley), covering about 75 miles from east to west.

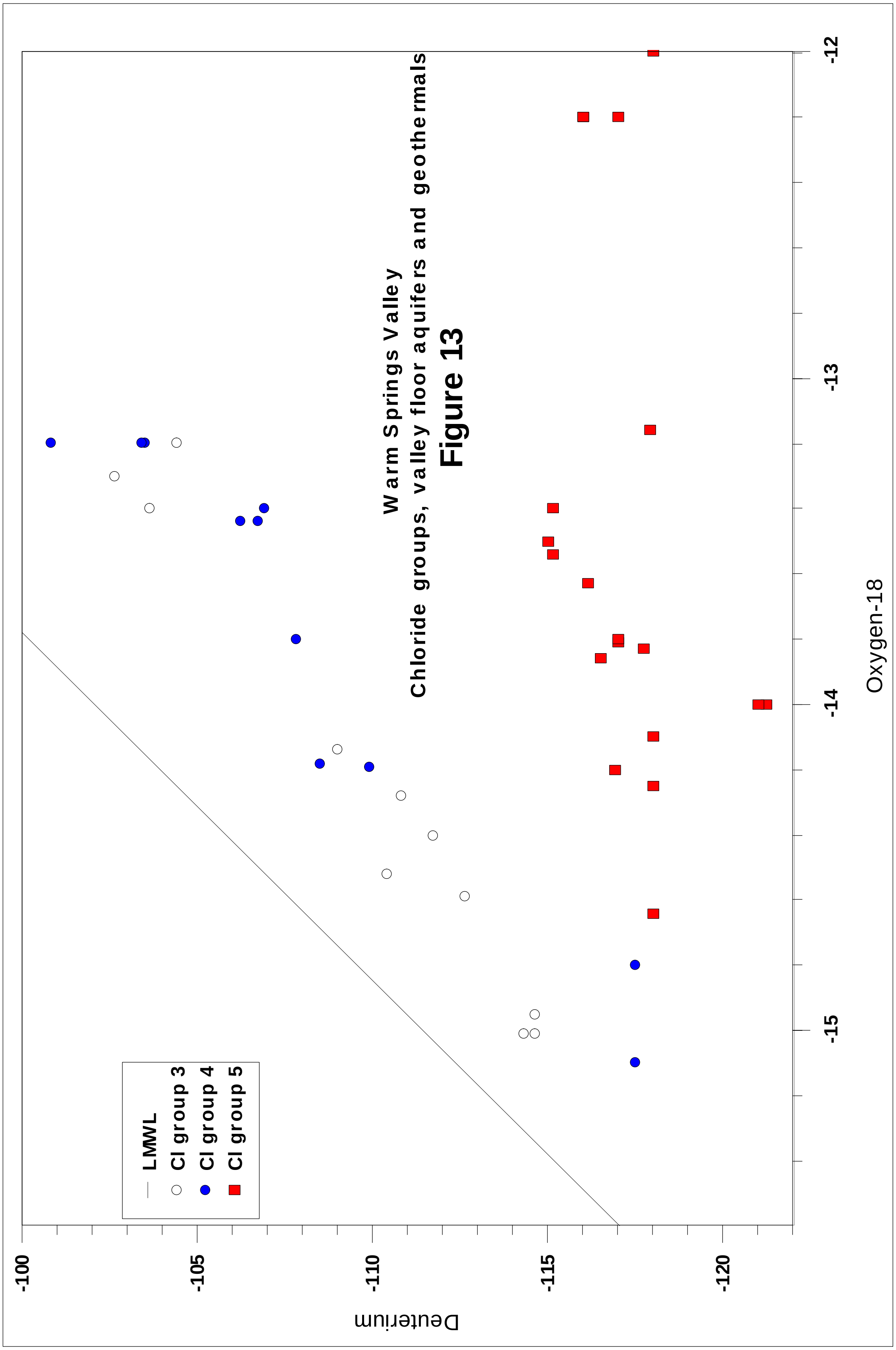


Figure 13
Warm Springs Valley
Chloride groups, valley floor aquifers and geothermals
LMWL
Cl group 3
Cl group 4
Cl group 5
Deuterium
-100
-105
-110
-115
-120
Oxygen-18
-12
-13
-14
-15

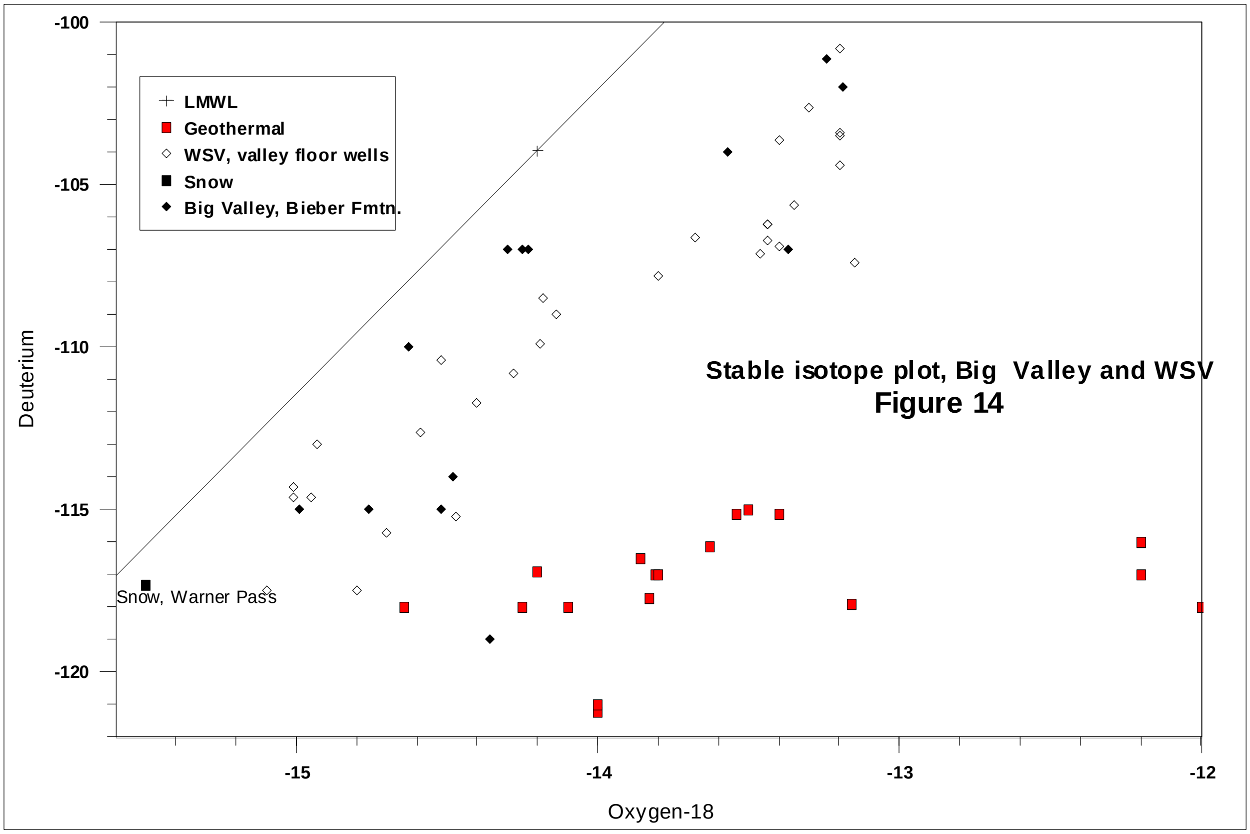
Since the Warner Mountains collect the highest amount of precipitation in the area, it may very well be the source area that provides most, if not all recharge for the geothermal waters in the area. The comparatively narrow deuterium range in the geothermal waters suggests that they were derived from similar areas, if not the same recharge area.

In other words the geothermal waters in the WSV and Alturas Basins may symptomize extensive southwest flowing regional flow systems facilitated by laterally extensive lithified tuff and volcanic flow units with significant secondary permeability.

Similarities in WSV and Big Valley

Based on the isotope data WSV and Big Valley apparently have very similar hydrogeologic settings. The Big Valley isotope data are plotted in Figure 14, showing the Bieber Formation valley floor aquifers. Also, the geothermal waters in the region are shown.

The valley floor aquifer waters from Big Valley display the same kind of plotting pattern as the valley floor aquifer waters in WSV. It may be that the hydrogeologic settings observed here are symptomatic of many other Modoc Plateau ground water basins.



Stable isotope plot, Big Valley and WSV
Figure 14

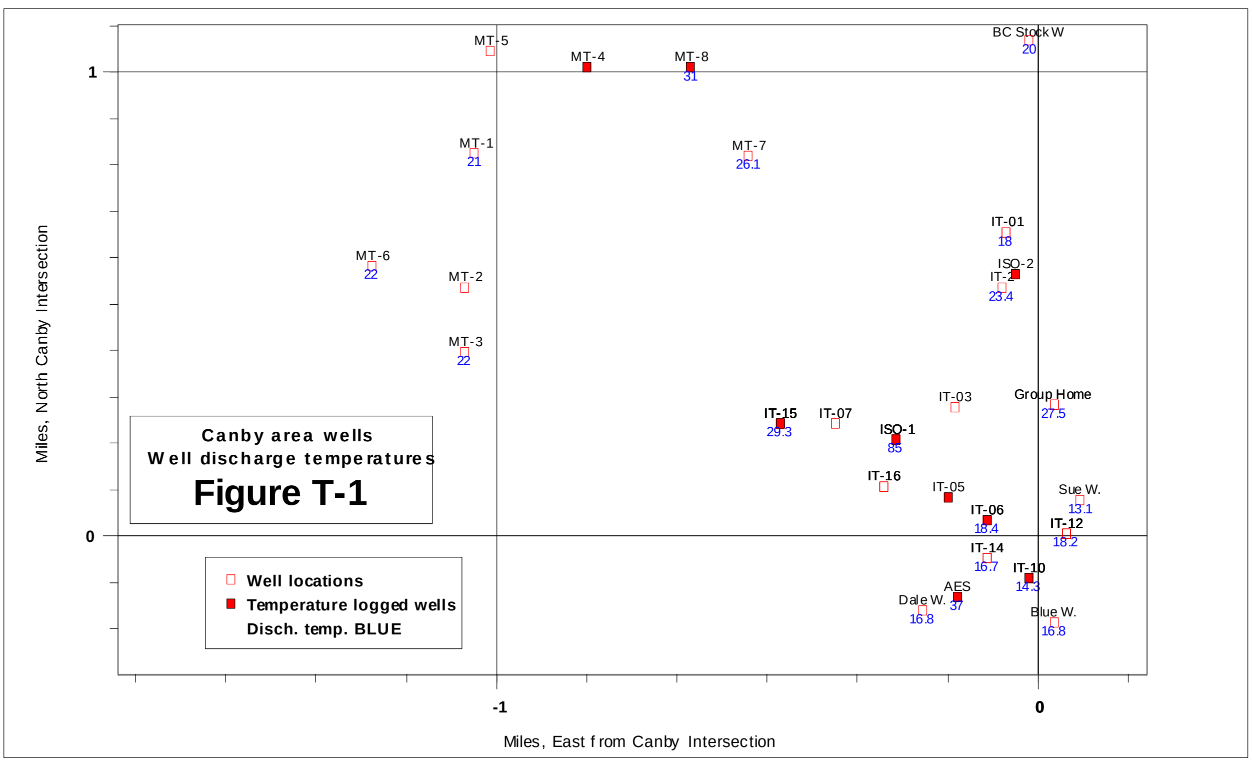
6. Temperatures and thermal gradients

A significant amount of field work was devoted to obtain temperature logs from wells in the Canby area. Suitable wells up to 700 ft deep were prioritized based on their depth obtained from the ISOT office files in Canby. Unfortunately many of the deeper wells were inaccessible due to wellhead plumbing, limited clearance around pump bowls, or cave-ins.

Well discharge temperatures in Canby irrigation and residential wells range between 13 and 36.7 ^{0}C, with the highest temperatures in the SE quadrant of the map in Figure T-1. But these discharge temperatures cannot be used to map subsurface anomalies, since discharge temperature increases with depth at a rate of about 3.63 ^{0}C/100 ft (Figure T-2). As expected, this rate is similar to the 3.94 ^{0}C /100' gradient measured in geothermal well ISO-1.

Temperatures measured at 500 ft range between 29 and 43 ^{o}C (the depth of a major aquifer). Unfortunately, with the small number of temperature logs, no temperature anomaly at 500 ft can be mapped.

The thermal gradient data for all wells less than 700 ft deep are plotted in Figure T-2. Also included, for comparison, is the log of ISO-1. In parts some of these logs contain patterns that resemble "stair steps", which are probably caused by vertical fluid movement in the annulus between well bore and casing between aquifers with differences in hydrostatic head. Some gradients project to more than the mean annual air temperature of 10 ^{o}C, i.e. up to about 16 ^{o}C implying that in some areas the shallow aquifers are heated by rising geothermal water.

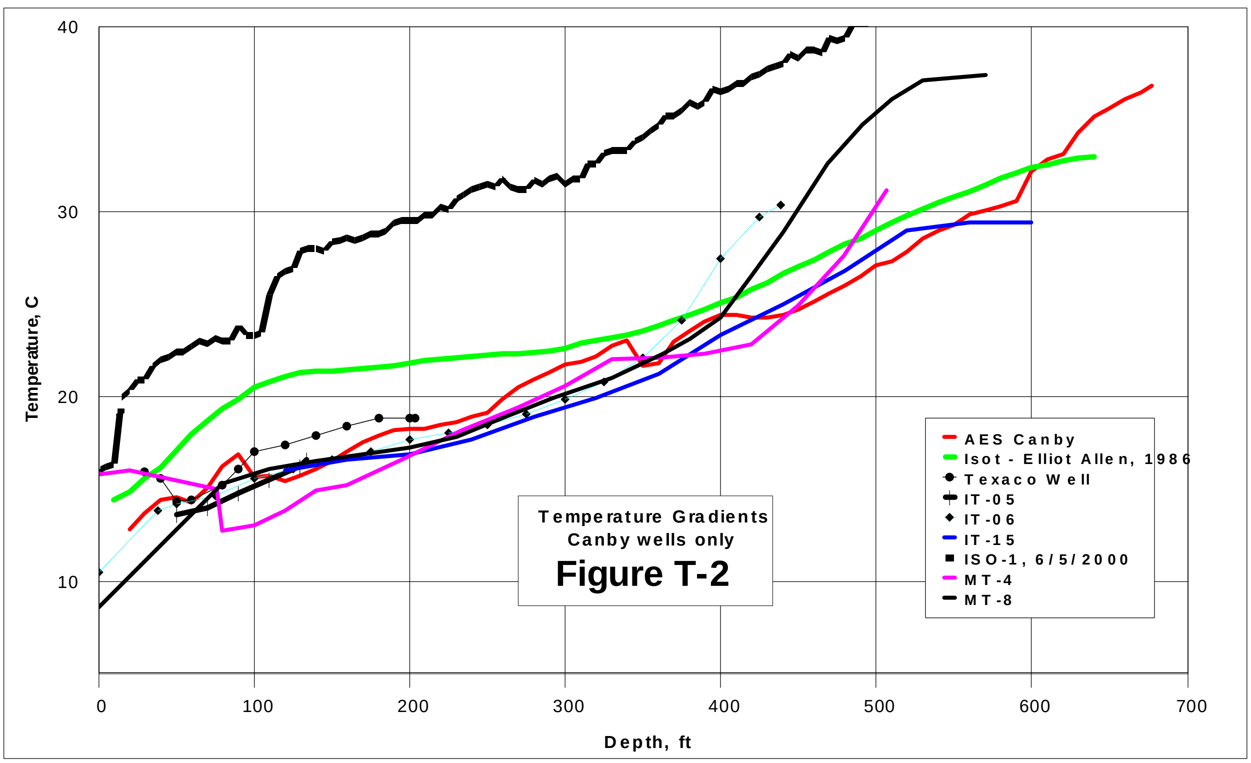


Shallow wells affected by convection are ill suited to infer valid conductive gradients to resource depth. Wells affected by convection, displaying the characteristic “S-shape” pattern, include MT-4, MT-8, IT-15, the ISOT well logged by Elliot Allen (1986), and maybe well IT-6. But the convection patterns can be used to deduct approximate shallow aquifer depths:

a. A shallow aquifer at a depth of 100-300 ft, with an average temperature ranging between 15 and 25 ^{0}C.
b. A deep aquifer between about 500 and 1000 ft with an average temperature ranging between 30 and 40 degrees ^{0}C.

However, even by approximating an average gradient from these wells and the AES well the estimated gradient is between 3.94 and 3.2 ^{0}C/100 ft, similar to the gradients measured in the two deep wells, ISO-1 and ISO-2 above 2100 ft. This is probably representative of the regional gradient in this area.

To overcome the effect of convection (fluid movement) in the shallow and intermediate depth aquifers temperature gradients need to be measured to depths greater than the near surface aquifers.



The temperature profiles in ISO-1 and ISO-2 are plotted in Figure T-3. Since the highest temperature of the ISO-1 profile is less than the maximum temperature of 106 ^{0}C measured during drilling, the ISO-1 profile is probably not fully equilibrated. The abrupt ISO-2 gradient decrease to 2.4 ^{0}C/100 ft below 1400 ft can be attributed to an intersecting fault, i.e. the targeted Blacks Canyon Fault. On the other hand it is conspicuous that the change in gradient occurs at the depth that coincides with the three month drilling break. Maybe the ISO-2 profile is also not fully equilibrated. Nevertheless, the data are suited to obtain at least approximate temperature gradients.

The average gradient in ISO-1 and ISO-2 above 2150 ft ranges between 3.5 and 3.94 ^{0}C/100 ft. Below 2150 ft the gradient in ISO-2 is for all practical purposes isothermal. The beginning of that isothermal gradient is also indicated in the lowermost 100 ft in ISO-1. The geologic log from well ISO-2 shows a sequence of lithified tuffs, intercalated by andesite lava flows (2180-2270 ft, 2660-2790 ft, 3360-3850 ft), which continue down to at least 3850 ft (LaFleur and Krahmer, 2011).

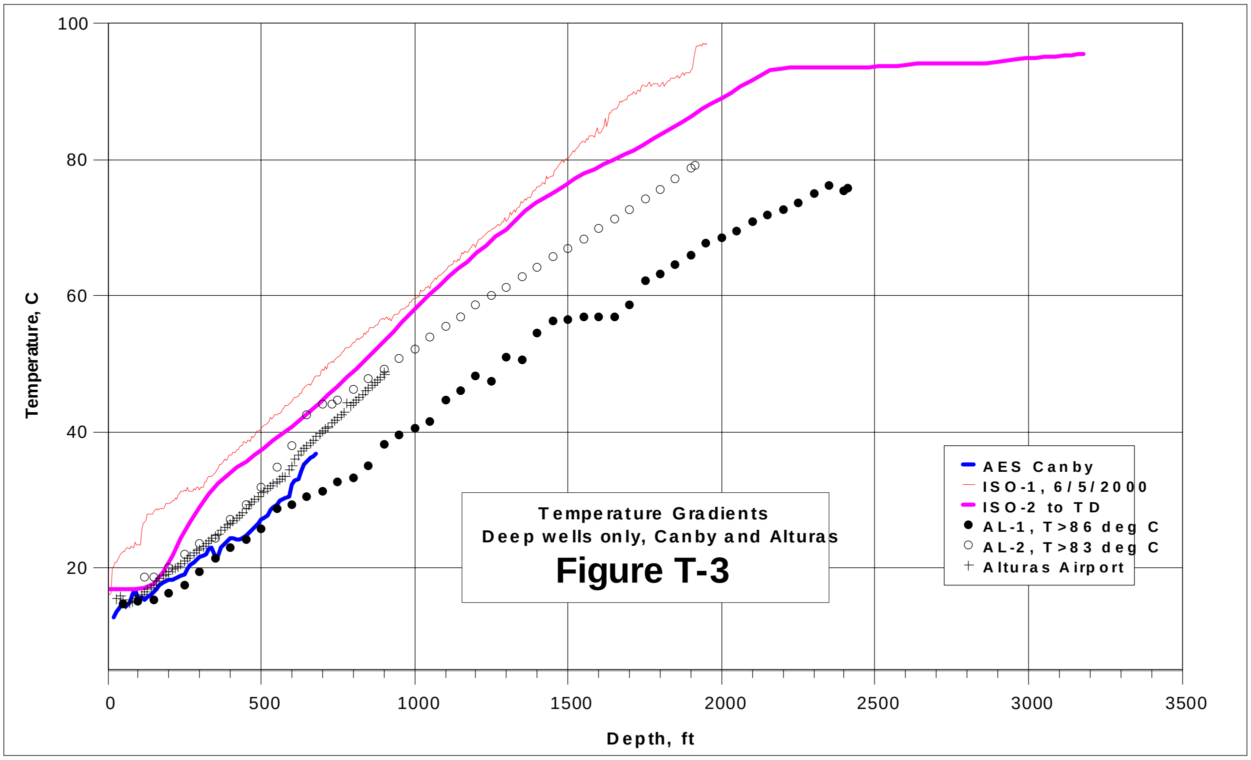


Figure T-3

An isothermal gradient is only possible when there is sufficient permeability to permit convection in the fractured lithified tuffs and andesite lava flows. It is therefore reasonable to assume that the fractured formations below about 2000 ft are the source of geothermal water in Warm Springs Valley.

It is peculiar that the ISO-1 and ISO-2 temperatures are about 10 ^{o}C higher than the gradients measured in the irrigation wells NW of Canby. Probably the temperatures in the geothermal wells are affected by proximity to faults – which is supported by the structural analysis (see Section 7). The ISO-1 geothermometer temperatures range between 104 and 116 ^{o}C. This matches the maximum measured 106 ^{o}C temperature (Dale Merrick, pers. Communic., 2012). However, the ISO-1 discharge temperature is only about 83 ^{0}C due to cooling in the wellbore.

7. Structural geology

Fracture trace analysis

A fracture trace analysis was conducted using a set of black-and-white stereographic aerial photos obtained from the US Forest Service. The photos were examined with a WILD mirror stereoscope to map lineaments as indicators of faults. The results were merged with the results of a magnetotelluric survey conducted in spring 2012 (HYDRO, 2012). For an in-depth discussion of both fracture analysis and MT survey, the reader is referred to the 2012 interim project report (Bohm, 2012).

The mapped lineaments shown on the topographic map (Map 2) adhere to at least four consistent trends, i.e. two NE striking directional sets and two NW striking sets. The repeated occurrence of these trends is a strong indication that these lineaments are fault traces. While the lineaments are usually discontinuous they can be traced over long distances, often up to several miles.

Fault trends

Blacks Canyon Fault (BCF), striking N15W

The Blacks Canyon Fault is identified on the aerial photo as a N15W striking fault scarp. On the aerial photo it looks like a normal fault with the “graben” block (down) in the west. The southern fault scarp shows a “serrated” pattern, which is apparently due to horizontal offset at three locations by northeast striking fault motion. The only other fault with the same direction as the BCF was mapped in the Cooley Gulch south of Canby (though this may also be a contact between two rock formations).

Pit River Fault Zone, striking N50E to N60E

The Pit River Fault Zone (PRFZ) is manifested in the SW flowing section of the Pit River, striking about N50E, projecting through KHS and the SX Ranch wells. A fault parallel to the PRFZ was identified about 2 miles north of Canby. Though not very prominent on the aerial photo it is mapped as a major feature on the satellite imagery.

Kelley Hot Springs Fault, striking N60W

The Kelley HS fault zone (KHSFZ) runs through Blacks Canyon and Kelley Hot Springs (KHS), striking N60W. The location of KHS coincides with the intersection of the KHSFZ and the PRFZ, where geothermal water emerges due to increased fracture permeability. Parallel to the KHSFZ runs another fault that defines the course of the Pit River SE of the PRFZ. In the absence of a better name this is called the “Levee Fault Zone” (LFZ).

Northeast striking en-echelon faults, striking N35E

A number of faults striking N35E intersect the KHSFZ between about one and two miles NW of KHS. These are probably normal faults as a by-product of shear along the nearby NW striking faults. The intersection of these faults with the KHSFZ coincides with at least two springs which are of possible geothermal origin. This fault orientation may also be the cause of the serrated pattern of the Blacks Canyon Fault scarp about ½ miles NE of Canby.

Other fault directions

The lineaments mapped on the satellite image include a number of NS striking faults, prevailing in the area north of Blacks Canyon. This direction element could be identified in WSV only in one location, about 1 ½ miles SSE of Canby, about ½ mile east of Cooley Gulch.

With the available images it has so far not been possible to identify a lineament equivalent to the Likely Fault, as mapped in the Alturas geological map, and in the latest geological map (draft) prepared for this area by Grose et al. (2004?).

Faults and geothermal manifestations

As elsewhere in the Great Basin and NE California, faults that are prominent enough to show on aerial photo typically are high angle faults, which are not more than 10 or 20 degrees from normal (70 to 90 degrees). No low angle faults have been deducted from how the fault traces cross topographical features.

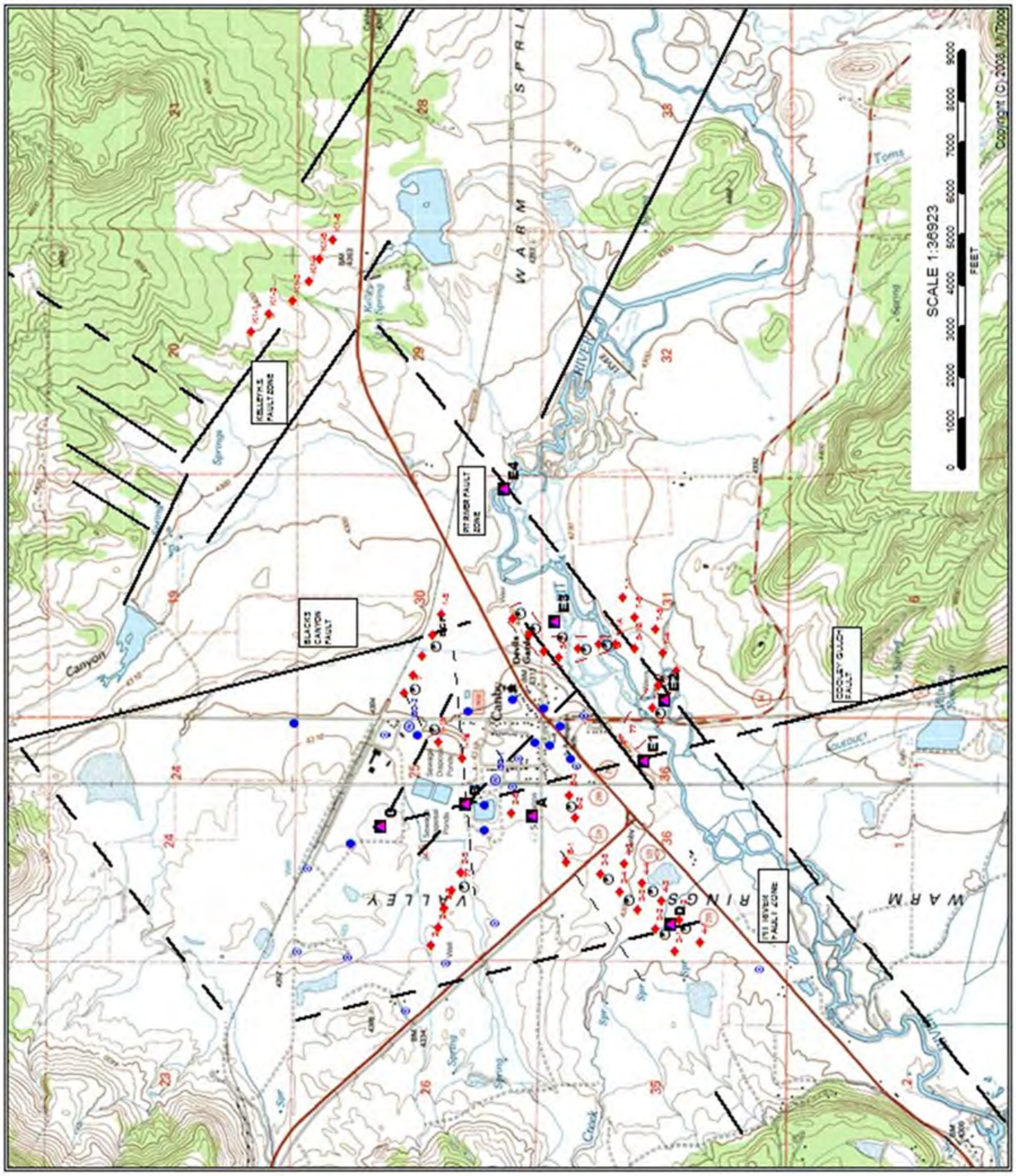
Typically increased permeability in bedrock and indurated sediments is tied to faults. In particular zones of increased permeability are to be expected wherever faults intersect, like at KHS. In our experience in NE California the chance of drilling higher yield wells is usually better near NE striking faults (which are usually normal faults), and more so where these faults intersect with NW or NNW striking faults (for example, in Alturas (Juncal & Bohm, 1988)).

It is reasonable to assume that similar situations create favorable locations in hydrothermally cemented tuffaceous sediments and lava. One objective of the MT survey was to verify this model.

Matching MT transects and fault surface traces

On Maps 2 and 3 all locations where faults are indicated in the MT profiles are marked with a black “F” in a circle. Typically, whenever a fault trace mapped in the aerial photos crosses an MT transect, it is matched by a black “F” on the MT image. On the other hand not every “F” is matched by a fault trace, either because some features have been misinterpreted as faults in the MT transects, or the fault trace cannot be identified due to erosion or cultural activity.

Map 3 is a larger scale depiction of the transects and faults in the immediate project area. Transect sections that show significant vertical geothermal flows are highlighted with a red band (hachured line). Since the fault map and MT transects were generated by two independently working parties, bias in data collection and analysis should be minimized.



Map 2: Canby area, Modoc County. Location of major fault traces (black), MT transects (red diamonds) with faults (black circled "F"), wells (blue).

The top of the fractured indurated tuffaceous sediments called for in the conceptual model are evident in most transects between 1850 and 2000 ft as a high resistivity layer indicating significant permeability. Nevertheless, in some transects the deeper section data have been invalidated by “cultural” interference, like near the electrical substation west of Canby (Kevin Rigsby, Hydro Resources, and pers. communic).

Fault traces in the Canby Town area

A few fault traces can be traced in the Canby town area (Map 4), sometimes by projecting lineaments that are mapped with confidence outside Canby. Lineaments are not expected to be very obvious in an area that has been affected by human occupation since at least 100 years. Nevertheless, one such lineament with the same trend as the KHSFZ appears to project through the location of geothermal well ISO-1. The location of ISO-1 was selected based on availability of open land, whereas the above mentioned lineament was not noted until after the well was drilled. Therefore ISO-1’s success may have been partly based on being located near a fault.

Section 36, SW of Canby

In this triangular area west of the junction between HWY139 and HWY299, MT Transects 3 and 4 indicate at least two fault locations. Only the one farthest to the SW has being matched by a lineament. The second signal cannot be matched with a fault trace, probably because its trace has been obliterated by erosion.

The results of the structural analysis will be further discussed under drill site recommendations Section 10).

8. Discussion

WSV is underlain by an aerially extensive geothermal aquifer which is hypothesized to be part of a larger resource that encompasses both Alturas and Canby. The current Canby investigation (including the ISO-1 investigation conducted in 2000), is only the latest among several other geothermal resource investigations in this part of the Modoc Region. The following discussion will bring together a number of observations common to the Canby, Kelly Hot Springs, Big Valley, and Alturas areas to help infer the nature of the geothermal resource.

Comparing Canby, Kelly Hot Springs, Alturas and Big Valley

Shallow aquifers in the upper volcani-clastic lacustrine sediments

Shallow (down to 1200 ft) ground water temperatures are typically elevated to no more than 45 ^{0}C. Temperatures tend to increase with well depth, since the aquifers are subject to heat flow from depth. Isotopes, conservative anion chemistry, and temperatures suggest that these aquifers are recharged from fractured lava flows in the surrounding highlands from deep fractured lava flows that are recharged outside the basin (regional flow). The shallow basin aquifers are thoroughly mixed, indicating good vertical hydraulic communication between shallow basin aquifers (down to 1000 ft). However, there is no communication between the shallow aquifers and the geothermal aquifer at depth.

Geothermal reservoir formations below 2000 ft

Geothermal exploration around KHS, located about two miles northeast of Canby, began in the late 1960's. One well was drilled in 1969, one-quarter mile south of Kelly Hot Springs. Temperatures increased rapidly until a major lost-circulation zone was found at 1600 followed by adiabatic conditions to 3200 ft (GeothermEx, 1977), with a maximum temperature of 110 ^{0}C. A second hole was drilled in 1974 about 2 miles east of KHS, on a small resistivity low. Here too temperature until lost-circulation zones below 1760 ft followed by near-adiabatic temperature conditions down to total depth of 3396 ft. A maximum temperature of 115°C was measured at 3350 ft.

As in Canby and Alturas lost circulation always occurred in lithified tuff (Juncal & Bohm, 1988; Bohm, 2000) and basalt units, or contacts between these and other rock types. The reservoirs in this area have been inferred as a succession of lavas and lithified tuffs, mudflows and breccias down to at least 6000 ft (GeothermEx, 1977).

Similar, in the recently drilled Canby well ISO-2 temperature steadily increases to 94 ^{o}C at 2180 ft. Below 2180 ft, the thermal profile becomes nearly isothermal, coinciding with the zone of competent formations found below 2180 ft. The beginning of a similar zone is indicated in the ISO-1 temperature profile, with an isothermal section below 1900 ft.

(Although no isothermal profiles below 2000 ft were observed in the Alturas wells, this may be only so because the wells were not drilled deep enough.)

What the Kelly Hot Springs wells, the Canby, Alturas and Big Valley wells, have in common is that they all penetrated through thick deposits of clays, silts, sands and gravels (and their lithified equivalents), and intermittent basaltic lava flows, with 115 ^{o}C maximum temperatures prevailing from 1600 ft down to more than 3000 ft (GeothermEx, 1977; Juncal & Bohm, 1985; Bohm and Juncal, 1995; LaFleur and Krahmer, 2011).

Aerial extent of the geothermal aquifer

Resistivity data suggest a low resistivity layer extending several miles across Warm Springs Valley from east to west (GeothermEx, 1977), and under Canby (Hydro, 2012). A gravity survey (Chapman et al., 1978) suggests that the lithology extending east from Kelly Hot Springs is relatively consistent. The higher resistivity under the Canby area being attributed to geothermal water diluted by river water (GeothermEx, 1977) must be rejected, since KHS and ISO-well water chemistry are virtually identical. Instead the high resistivity layer is attributed to a higher permeability zone (Hydro Resources, 2012).

In summary, since geothermal exploration began in the 1960's, it was concluded that WSV is underlain by an extensive geothermal aquifer below 2000 ft (1600 ft at KHS), reaching down to more than 3000 ft (GeothermEx, 1977). The more recent drilling data (Bohm, 2000; LaFleur and Krahmer, 2011) produced only data that support this. The similarities between the KHS and Canby deep wells suggest the presence of an extensive, internally communicative, geothermal aquifer underneath several square miles below 1600 in the KHS area and below 2000 ft in the Canby area. The isothermal gradients in the KHS and Canby wells give reasons to believe that there is sufficient permeability in the lithified tuffs and lava formations below about 2000 ft permitting vertical fluid circulation, implying secondary permeability, if not fracture zones that can produce geothermal water.

Confining layers: the unconsolidated fine-grained tuffs

The sections immediately above the fractured lithified tuffs (geothermal aquifer) are made up almost entirely of unconsolidated fine-grained tuffs, and volcanic mud flows, acting as a confining layer. This layer creates difficult drilling conditions due to "sticky gray-green clays". The top of these clay rich layers can be deducted from the maximum depth of the irrigation and municipal wells (1000 in Canby and 1200 ft in Alturas).

The "clay" zone acts as a very efficient confining layer:

1. Evidence of fault zones has so far not been found in these unconsolidated clay-rich formations, since clay is not capable of holding open fracture zones. An exception is KHS where geothermal water was able to emerge at the intersection of two fault zones, probably due to more intensive hydrothermal alteration and lithification.

2. The andesitic lava flows and volcanic lacustrine sand layers that occasionally break up the monotonous clay sequence show no evidence of producing water.

3. Water level changes in observation wells could not be linked to flow testing Alturas geothermal well AL-2 when it was flow-tested for 17 days at 400 gpm.

4. Isotope data from the Canby shallow aquifers show no evidence of mixing with geothermal water.

The pressure difference between the deep geothermal aquifer and the upper cold water aquifers can be significant. For example static wellhead pressure in the 1900 ft deep Alturas well AL-2 is 117 psi whereas nearby shallow well water levels are down to 100 ft below surface.

Geothermal fluids production from fractured lithified fine-grained tuffs

In Canby, as in Alturas and Bieber it is the fractured lithified sections below about 1850 ft that produce hot water instead of the fractured and scoriaceous lava flows. Below about 1850 ft there is increasing evidence of lithification, gradually changing into entirely lithified sections below 2000 ft. The drill cuttings from these sections contain predominantly angular chips in the cuttings with occasional evidence of hairline fractures filled with mineral deposits. Occasionally the chips show evidence of fractures, lined with pyrite and reddish-brown material, and white to greenish white mineral deposits (zeolites?).

Water Chemistry

Chemical composition of the deep geothermal waters is characterized by high percentages of Na and SO4 (and to a lesser degree Cl) and low alkalinity. An exception is the Alturas well AL-2 with its high bicarbonate. Characteristically geothermal water chemistry is very similar much like most other Modoc geothermal waters.

Similarity of water chemistry in KHS and ISO-1 indicates that these originate from the same aquifer. More so the narrow range of Deuterium isotope composition suggests that the geothermal waters from a wide region originate from the same source area. Again this can be interpreted as an indication of an aerially extensive geothermal aquifer.

Well yields

Based on well testing data, the bulk transmissivity ("permeability-thickness product, T= k * m) of the lithified tuffs is between 500 gpd/ft and 1000 gpd/ft. This results in highly variable well yields and significant pumping drawdown, depending on whether a well intercepted one or several major fracture zones that can act as "extended wells".

1. Alturas well AL-1 initially flowed 900 gpm at a static wellhead pressure of more than 40 psi, although the long term yield was eventually rated at no more than 50 gpm (WEN, 1989). Deepening the well to 2940 ft increased the yield to about 80 gpm.

2. By comparison AL-2, when tested flowed 400 gpm under artesian pressure (no pump) at 83 ^{o}C for 17 days. In that period the wellhead pressure decreased from 112 psi to 19 psi. Well AL-2 yield was eventually rated at 250 gpm.

As is typical in fractured rock aquifers, unless a major fracture zone (acting as an “extended well”) is intercepted, well yields will remain modest, although even the lower yields are remarkable for bedrock wells. Nevertheless, that does not mean it won’t be adequate for certain applications (for example well ISO-1). On the other hand, as AL-1 drilling data have shown, the yield can be increased by intercepting more aquifer formation by drilling deeper without necessarily having to intercept faults, relying on secondary permeability.

The modest yield of the ISO-1 well needs to be put into this perspective. During testing well ISO-1 showed a response that is typical for wells completed in fractured bedrock aquifers, i.e. a great portion of drawdown is attributed to friction losses (turbulent flow) in the fractured aquifer formation. Although the well was rated at 37 gpm, the transmissivity is about 800 gpd/ft - more than the 500 gpd/ft measured in the Alturas wells. The reason for ISO-1 more modest yield is that is not “blessed” with a major fracture zone that can act as an extended well.

Regional flow systems

The homogeneity of chemical and deuterium isotopic composition remains one of the more conspicuous features of Modoc geothermal waters, suggesting extensive regional geothermal flow systems (Juncal & Bohm, 1985). This is supported by the low TDS (not more than 1600 uS/cm) and comparatively low maximum geothermal water temperature of about 120 ^{0}C. The existence of regional flow systems has been postulated before given the frequent high well yields in lava formations, and the existence of numerous high discharge springs. Examples are Kramer Spring in Big Valley, Willow Springs about 7 miles south of Adin, and the Urutia Spring about 3 miles south of Canby. These are difficult to explain with the low average annual precipitation of 12 inches in most of the Modoc Plateau. On the other hand the Warner Mountains stand out as an isolated region with high average annual precipitation exceeding 28 inches at high elevations, which makes them a likely recharge area for a regional ground water flow system.

Summary

The top of the lithified tuff sections in the deep ISOT wells is at a depth similar as in Alturas, though certainly deeper than at Kelley Hot Springs. This may very well explain the increasing resistivity mapped in the 1970’s around the Canby area. The ISO bottom hole temperature of 106 ^{o}C is close to the minimum temperatures observed at Kelly Hot Springs.

The results of all four low temperature geothermal drilling efforts in the eastern Modoc Plateau (KHS, Bieber, Alturas and Canby) suggest a number of common features:

A. Production zones are associated with lithified tuffs, at depths not shallower than about 1850 ft.
B. Deep temperature gradients above the lithified zones are between 3.2 and 3.9 ^{0}C per 100 ft, suggesting formations with similar thermal properties (as confirmed by the drilling data).

C. Given the similarity in depth and gradients, the prevailing geothermal temperatures at depth are presumably similar in all three areas.

9. Conceptual geothermal system model

Geologic setting

The Alturas Basin (including Warm Springs Valley) and Big Valley are intermontane basins delineated by gravity (normal) faults, and dip-slip faults. The basins are filled by lacustrine sediments (deposited as fine-grained tuffs and mudflows/lahars) and occasional lava flows. Based on their composition, and their degree of alteration due to regional heat flow the basin fill deposits account for two hydrostratigraphic units:

A. The upper unit makes excellent aquifers supporting hundreds of irrigation and municipal wells, up to 1200 ft deep. Temperatures are typically elevated, up to 45 C.

B. The lower unit is made of hydrothermally cemented (lithified) tuffs and intercalated lavas. Able to hold open joints and sometimes fractures (faults) it permits significant flow of geothermal water, indicated by the isothermal gradient. Although the fractures can be in some cases huge, the bulk formation transmissivity is small, much as in most fractured hard-rock formations, providing for highly variable well yields. In Canby, below about 3500 ft the unit is made entirely of basaltic andesite.

The two units are separated by about 800 ft thick sequence of “sticky clays” (unconsolidated tuffs, “volcanic ash”). Approximate top and bottom of this sequence is between 1000 and 1850 ft (if not 2000 ft), acting as a barrier (aquitard) confining the geothermal waters in the underlying fractured tuffs.

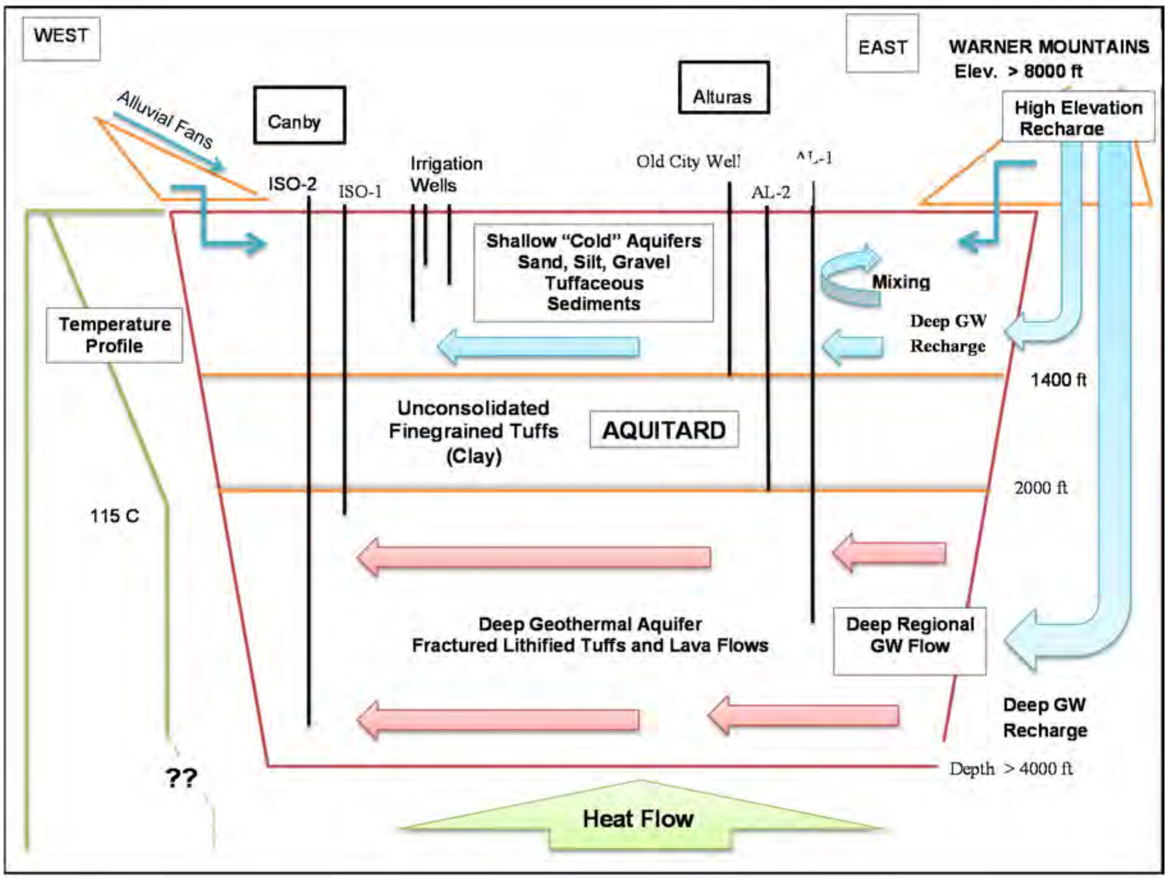
No information is available about the formations below 3950 ft (TD of ISO-2). However, an intriguing speculation was made by Mariner et al. (1993), hypothesizing a hotter aquifer at greater depth, based on geothermometry calculations. For Kelly Hot Springs the cation and silica geothermometers yield aquifer temperatures 116 – 123 ^{0}C, whereas the temperatures calculated from anhydrite saturation and the sulfate-water isotopes yields 186 ^{o}C and 198 ^{0}C. This discrepancy is consistent in the Na-SO4 geothermal waters of the Modoc region (Mariner et al., 1993), and is attributed to the cation geothermometer temperatures becoming readjusted during conductive cooling on the way to the surface.

General observations

As much as Modoc geothermal activity cannot be linked to shallow intrusives, evidence of the importance for regional flow for geothermal activity in the Modoc Plateau can be based not only on isotopic evidence found in this study, but also on geochemical evidence (Mariner et al., 1983; Juncal & Bohm, 1985) for regional ground water flow systems. Thus geothermal activity in

Warm Springs Valley (and the Alturas Basin) must be attributed to regional flow and high heat flow in the region.

On the other hand, the relatively small oxygen-isotope shifts and low TDS of Modoc geothermal waters suggest relatively short residence times, leading to the speculation that these regional flow systems are tied to continuous hydrostratigraphic units with comparatively high permeabilities. It is worth to further investigate the northern California regional flow systems by further researching the regional flow system hypothesis developed by Ingraham and Taylor (1984) using deuterium and oxygen-18 ground water data.



The evidence of faults is regionally pervasive, and the presence of open fractures in both the Canby and Alturas geothermal wells suggests that regional seismicity is adequate to keep faults from becoming plugged by secondary hydrothermal minerals. Zones of increased permeability allow geothermal water to emerge at the surface where faults intersect. Intersecting faults are a common occurrence given the two, if not three common fault directions (NW, NE, and NS). This is apparently the situation at Kelly Hot Springs. However, as the drilling results in Alturas have shown, due to secondary permeability faults may not necessarily be a prerequisite for geothermal fluid production.

10. Drilling recommendations

The history of geothermal drilling in Alturas Basin and Big Valley has taught us several important lessons:

- Drilling to depths greater than 2000 ft (penetrating through the "clay" aquitard) in the valley floor always has a reasonably good chance of finding geothermal water, due to the aerial distribution of a geothermal aquifer formed by lithification (regional heat flow, hydrothermal alteration) and fracturing of tuffaceous formations.
- Wells drilled on or near faults tend to be of higher yield, in particular at the intersection of two faults.
- Anticipating high well losses and large drawdowns in these formations, wells should be equipped with deep pump chambers.
- Wells should be drilled to at least 2500 ft, if not 3000 ft total depth.

Site selection criteria

Our drill site recommendations are based on three criteria:

1. The most preferable option is to drill on fault intersections.
2. If that is not possible the next preferable option is to drill on or near a fault.
3. The least preferable option is to drill away from faults.

Based on past drilling records, all three options promise to yield at least some geothermal water, provided they are drilled to at least 2000 ft. A minimum depth of about 2500 ft is recommendable, based on what was learned at the first Alturas well (AL-1).

On the other hand, from a practical standpoint drill site selection is usually a compromise between technical/geological arguments and infrastructure concerns. Seldom is it feasible to drill a well at a location based entirely on geologic reasoning. Instead, typically one ends up drilling as close as possible to an optimal location, having to satisfy non-technical concerns, like land availability, utility access, site accessibility, etc.

Potential drilling sites

These site recommendations are based on the structural analysis, which included recommendations made in the MT data analysis (Hydro Resources, 2012), in part since they are based in permeability considerations. As shown on the Map 3 there are five good areas to drill. The locations are marked with purple triangles, labeled A, B, C, D and E:

Site A

In the interim report (Bohm, 2012) this site was selected as the preferred alternative, based in part on parameters established by the project proponent. It is located near the southern project boundary, about 0.4 miles west of Highway 299. It has not been mapped with any particular MT transect, but is located on a N55E trending fault lineament. This lineament is rather faint on the aerial photo at this location, but is more convincing in the SW where it can be mapped through a spring and the alluvial fan further SW. Given its direction it is probably related to the PRFZ movement trend.

Site B

This site is located on the intersection of two fault trends; sub parallel to the Blacks Canyon and KHS Faults. Well ISO-1 is located on one of these faults, about 800 ft to the south. It is possible that a faint indication of an east-west trending photo lineament is an indication of a third fault. Also the site is in close proximity of several irrigation and municipal wells classified as Cl-transition group 4 waters.

Site C

This site, like site B, is located on the intersection of two fault trends, which are sub parallel to the Blacks Canyon and KHS Faults, about 1800 ft north of site B.

Note: Also plotted on Map 3 are all irrigation and municipal wells. There is an apparent affinity between transition-group 4 waters (solid blue dots) and the faults that define Sites B and C. By comparison the irrigation wells located farther away from these faults, NW of Canby, are typically "Cl-group-3" waters (blue dots in a circle), indicative of "background" patterns. This observation is seen as further indication that sites B and C are favorable drilling sites.

Site D

This site is located in section 36, SW of the Junction HWY139 with HWY299, on the N15W fault between MT Stations 3.1 and 3-2. However, this location is outside the project area.

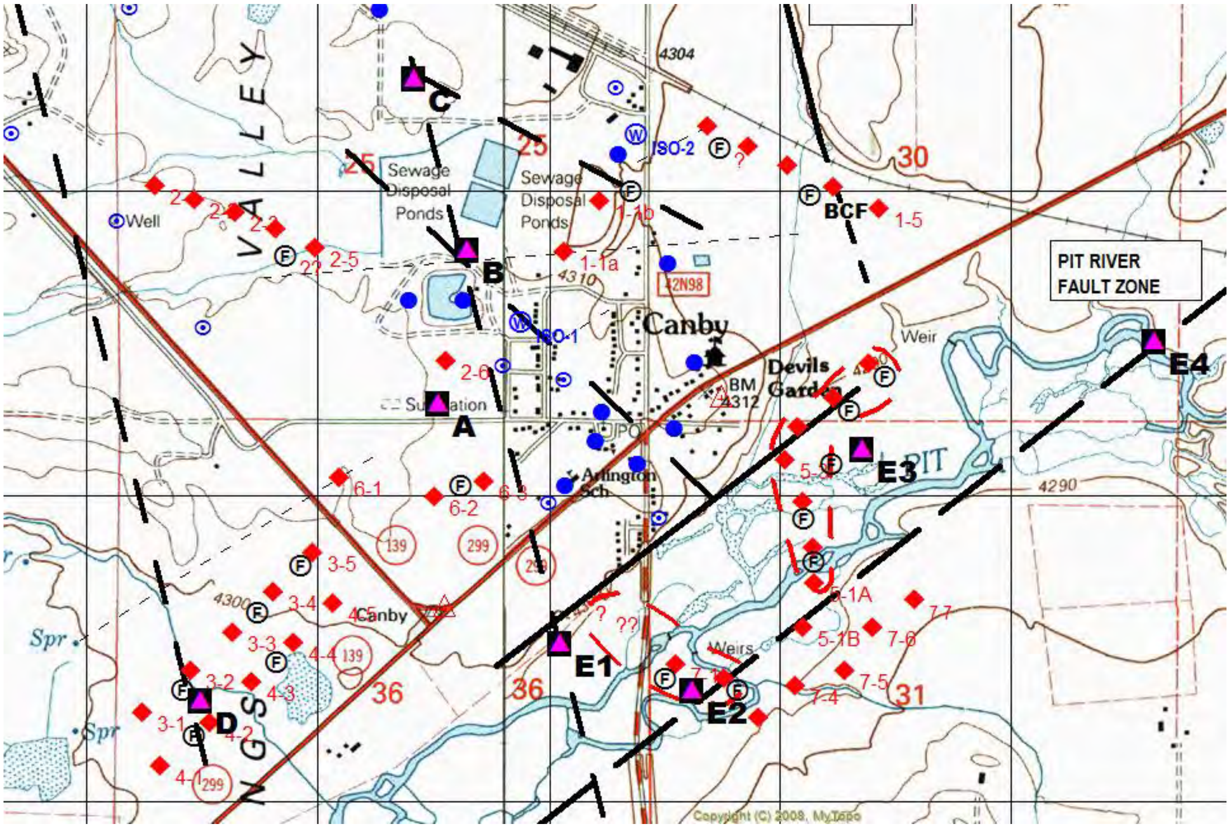
Sites E1, E2, E3, E4

Given the results of the MT survey, of particular interest are drilling locations in the Pit River Fault Zone. The patterns observed in MT transects #5 and #7 in this area very much look like the resistivity patterns in the transect that runs through KHS. A most intriguing location to drill into would be at location "E4" at the northernmost bend of the Pit River, about 4800 east of Canby. In this area the PRFZ is intersected by the SE trending "Levee Fault Zone".

Unfortunately ISOT does not own property here, making this site infeasible, unless an agreement with current landowners can be reached.

Preferred drilling site alternative

The preferred drilling alternative is site B on Map 3. The main reason is that it is located at the intersection of two faults inside the project area. A faint indication of an east-west trending photo lineament maybe indicative of a third fault. Also the site is in close proximity of several irrigation and municipal wells classified as Cl-transition group 4 waters.



Map 3: Recommended geothermal drilling sites, indicated as purple triangles. Canby area, Modoc County.

Proposed drilling method

Based on the experience of drilling the two Alturas wells and the two ISOT wells it is important to employ a drill rig large enough to accommodate the difficult drilling conditions in the unconsolidated tuffaceous sediments (clay!) overlying the fractured lithified tuffs below 1850 ft. However, mud rotary can have difficulties in lost circulation zones requiring drilling mud additives that will at least partially plug the fracture zones. Although using mud additives is an acceptable method to control lost circulation, subsequent complete removal of mud from the formation near the wellbore may not be possible. This will constrain well productivity.

Instead it is recommended to drilling in the consolidated (lithified) tuffs and lava flows with the air rotary method. Deepening well AL-1 in Alturas showed that this is feasible as long as one can employ an air compressor capable of pushing air to the desired drilling depth. The fact that deepening AL-1 by 500 ft resulted in a 60% productivity increase without intersecting a major fault zone indicates that productivity from joints and fracturing can be significant (Bohm, 1993). The concern is to prevent loss of productivity due to mud invasion.

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12. Attachments

Attachment A: Ground water chemistry data base compilation

Field data

All of I'SOT's water well records were examined to identify wells suitable to sample for major ion chemistry and stable isotopes (^{2}H and ^{18}O) and to measure vertical temperature profiles using an in-house thermistor probe.

Wells were then sampled with help from ISOT personnel who were acquainted with local ranchers and other property owners. Standard field water sampling procedures included adequate purging, proper sample handling, and chain of custody procedures - subject to directives from the labs.

In an iterative process further field data were collected after preliminary examination of the data using a number of cross plots, and by seeking out locations that were of particular interest within the larger geohydrologic setting of Warm Springs Valley. Field data were collected from:

1. Collecting a total of 17 samples, focusing on Canby and surrounding area. Major ion chemistry analysis was conducted by Sierra Environmental Monitoring Labs in Reno Nevada.

2. A total of 59 samples were collected in 20 ml glass vials and analyzed for the stable isotopes deuterium and oxygen-18 by the Stable Isotope Facilities Lab of the University of California, Davis. Note that not every isotope data set is matched by a water chemistry set.

3. Field data were measured at the time of sample collection, including temperature and electric conductivity (EC).

Other data bases

Data from technical reports and scientific literature:

1. Water chemistry and temperature data sets from 40 wells and springs were scanned from the very thorough geothermal data compilation conducted by Elliott Allen in 1986 (Eliot Allen, 1986), covering Modoc County in its entirety.
2. Screening the files of the ISOT office in Canby an additional 41 ground water chemistry data sets were obtained from the Canby area.
3. Extracting a total of 44 ground water chemistry data sets from the 1986 Big Valley geothermal study (Juncal & Bohm, 1985).
4. Obtaining an additional 19 isotope data sets (D and O-18) from various scientific publications (Mariner et al., 1983, 1993).
5. Data from Department of Water Resources

A data "dump" was requested from DWR covering Warm Springs Valley and the entire Alturas Basin (including the southern Pit River Valley). A State mandated ground water monitoring program, initiated in the 1950's covering the NE California ground water basins, has accumulated a bonanza of well drillers logs, ground water level, chemistry and temperature data in the CA Department of Water Resources (DWR) databases. Due to the cumbersome data formats it is difficult to determine exactly how many data sets there are in DWR's files. However, based on the "raw" data that were received it is estimated that DWR has been collecting as part of the ongoing monitoring program since the 1950's, more than 500 samples were collected from about 105 wells in the Alturas Basin alone

Unfortunately DWR decided to withhold the exact well location descriptions and well owner names claiming that they are proprietary information. Therefore without exact well location data our maps show only approximate well locations based only on “well-numbers”. But it would have been desirable to develop a more extensive data base including exact data point well locations with longitude-latitude coordinates, well-owner information, wellhead elevations, depth to water, well depth, screened interval depths, estimated discharge rating, and more. With this additional information it would have been possible to conduct a more expansive, though focused sampling program for stable isotopes (and other components).

The data obtained from records of the Department of Water Resources in Red Bluff comprise the bulk of the chemical data sets used.

Data base compilation

The data were screened and duplicates were sorted out so that in the end every data point (wells) was represented by only one single data set.

In the end a comprehensive database was collected comprising a total of 258 data points (wells), including the major ions, silica, EC and temperature. The data base covers mostly the Alturas Basin (including WSV) and the Big Valley Basin, covering an area of about 1400 square miles. The data base includes 30 wells in the immediate Canby area. Most of these data are from wells located on the valley floor. A summary of data sources is given in Table 1. Data point duplicates (i.e. time series data) were retained in a separate data base.

Table 1: Ground water chemistry data sets used.

Chemistry:		
Warm Springs Valley (incl. Canby)		53
Alturas Basin (incl. Southern Pit River Valley)		109
Geothermal waters in Modoc County		48
Big Valley		44
	total	254
Data sources, isotopes (Deuterium & Oxygen-18):		
Data collected for this project		59
Data from reports		19
	total	78
Data Sources, chemistry		
ISOT files		10
DWR ground water monitoring data archive		128
from Elliot Allen (1986)		43
GJ&A, 1985		44
Miscellaneous technical reports		4
Samples collected for this project		25
	total	254

Given the inability of DWR to provide more explicit well location information, each data point’s location on the map had to be approximated with the “well number” (township-range-section). Based on the California well numbering system well locations were approximated within 2.5 acre square parcels, i.e. within a 1320 by 1320 ft square area. This approximate location was then converted into a North (township) versus East (range) decimal based coordinate system.

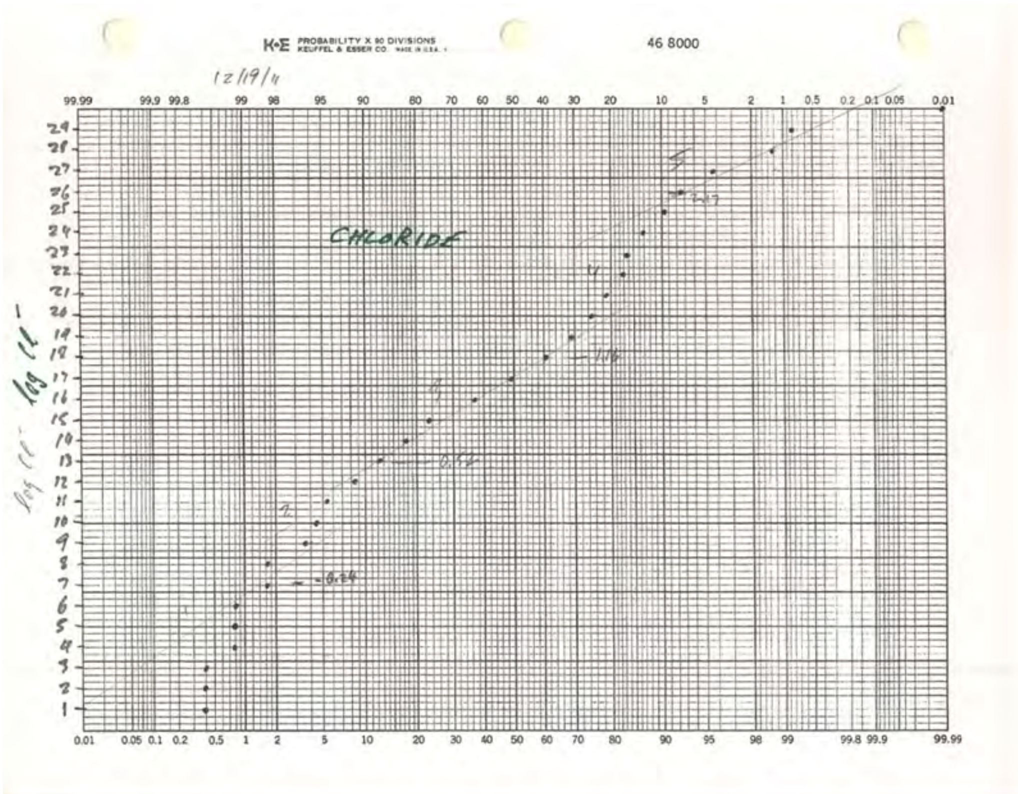
Locally, within the immediate area of the town of Canby it was possible to identify well locations more accurately with help from ISOT personnel, by identifying them on a topographic map.

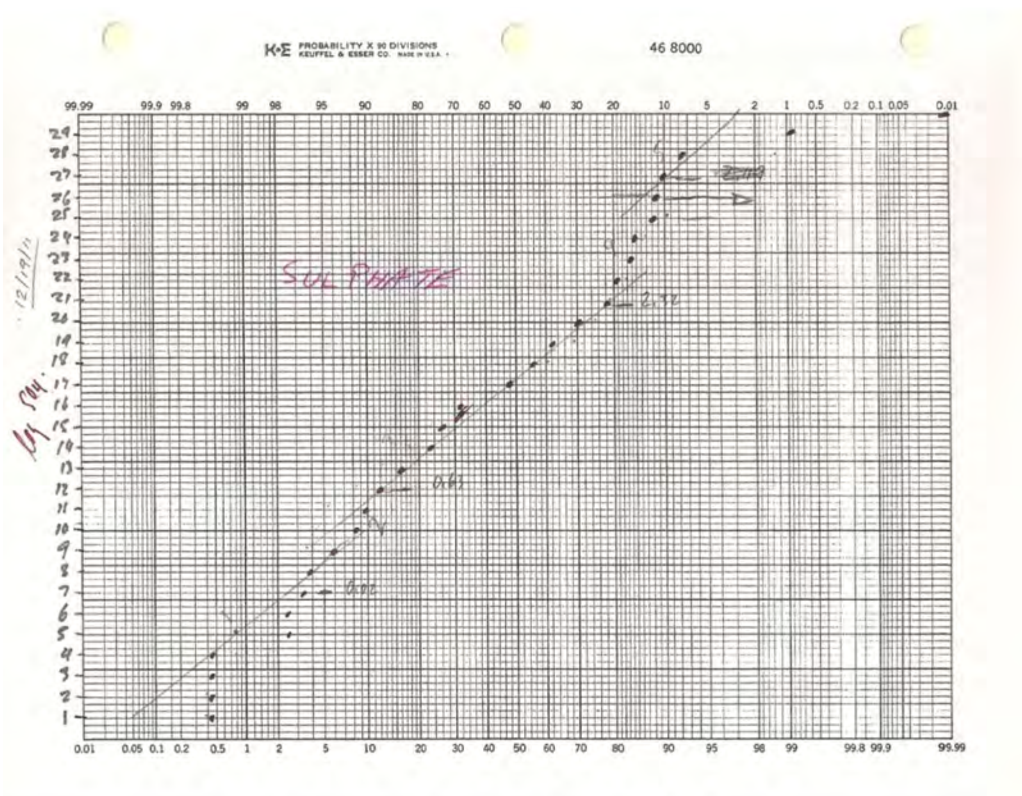
Data Quality

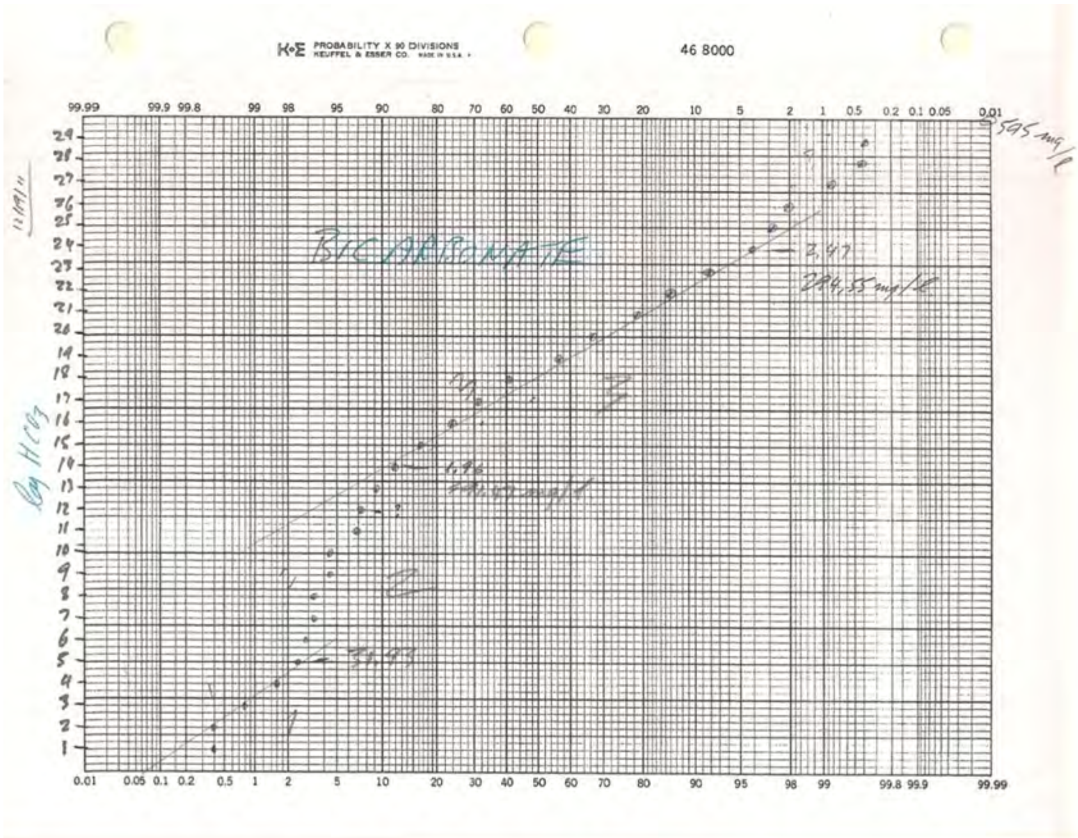
Among the 254 chemistry data sets only ten percent were incomplete (i.e. had at least one major ion missing). Data quality of all water chemistry sets was checked with the ion-equivalency balance ratio, comparing the cation sum with the anion sum. The ion balance varied within +/-10% for 95% of all the data sets used in this study, which is deemed adequate for the purpose of this study.

The isotope data are reported in parts per thousand deviations from Standard Mean Ocean Water (SM0W). The isotope lab’s analytical precision is +0.3 per mil for 0-18 and +3.0 per mil for deuterium.

Probability plots:







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Attachment B: Water chemistry and isotope data

Data sets with isotope data																			
Seq#	Well No.	Date	Name	R-East	T-North	Temp. C	Ca	Mg	Na	K	SO4	Cl	HCO3	B	F	NO3	SiO2	O-18	Deut
BV03	38N07E02P01	08/10/1960		7.73	38.85	18	30	19	42	11	1.5	38	244		0.1		72	-14.99	-115.00
BV09	38N07E32A06	06/11/1960		7.31	38.15	17	10	8	14	3.6	3	2	106					-14.63	-110.00
BV23	37N07E13B01	08/21/1978		7.94	37.65	16	63	45	53	6.2	34	68	275					-13.24	-101.10
BV26	40N07E28R	09/01/1984	Flowing Well,	7.48	40.19	36	1.38	0.49	61.77	1.8	2	8	151		0.1		51.25	-14.36	-119.00
BV27	38N07E12K	09/01/1984	Bassett HS	7.94	38.73	82	33.4	0.49	250.6	4.23	370	92	27		1.7		87.5	-14.64	-118.00
BV29	38N07E12D	09/02/1984	Aker's Hot w	7.85	38.81	62	29	0.49	215.8	3.43	367	95	20		1.7		68.2	-14.52	-115.00
BV30	38N07E19N	09/02/1984	Howard Hennii	7.02	38.35	31	2.13	1.7	58.29	6.69	2	11	195		0.2		82.24	-14.76	-115.00
BV31	39N08E21B	09/02/1984	Connor well at	8.44	39.48		12.46	7.94	18.8	3.52	13	10	106		0.3		80.28	-13.37	-107.00
BV32	38N08E14N	09/02/1984	Kellog HS, Cist	8.69	38.52	78	29	0.49	236	6	400	103	30		2.4		97.88	-14.25	-118.00
BV33	38N08E23G	09/02/1984	Richman Sprim	8.77	38.44	21	29.48	11.33	18.1	4.83	4	5	195				57.96	-13.19	-102.00
BV35	39N07E30E	09/27/1984	Kramer Spring	7.02	39.27	18	14	6	15	3	-2	6	104				44	-13.84	-101.00
BV36	39N09E28C		Ash Ck. under	9.40	39.31	16	12	6.3	18	5.4	7.7	0.2	114		0.6		40	-13.57	-104.00
BV37	39N09E04J		Tim Cobb Well	9.48	39.90	20	13	3	14	6	2	2	127		0.1		56	-14.25	-107.00
BV38	40N07E11A		Shaw's wari	7.81	40.81	27	40	0.49	235	2	386	115	23		1		69	-14.48	-114.00
BV39	39N08E23B		Spring ineado	8.77	39.48	25	10	6	17	5	-2	3	103		0.1		56	-14.23	-107.00
BV40	40N09E35K		Jim Kopp well,	9.77	40.06	24	4	1	38	9	-2	2.1	122		0.2		94	-14.30	-107.00
CAN-01	42N10E31E	04/26/2011	Blue W.	10.02	42.10	16.8	16	8.8	38	10	30	9.9	146	0.16	0.4		71	-13.2	-104.4
CAN-02	42N09E36G	04/26/2011	Dale W.	9.94	42.10	16.8	27	11	63	16	48	12	244	0.21	0.3		74	-13.4	-103.6
CAN-03	42N10E30M	04/26/2011	Group H.	10.02	42.23	27.5	0.6	0.5	120	8.7	35	28	227	0.97	0.6		92	-14.8	-117.5
CAN-05	42N10E31D	04/26/2011	OfficeW. IT-12	10.02	42.15	18.2	1.2	0.6	110	10	44	24	195	0.4	0.3		69	-13.4	-106.9
CAN-06	42N09E36A	04/26/2011	Old Clinic W. IT	9.98	42.15	14.3	29	15	50	17	27	14	256	0.17	0.2		65	-13.3	-102.6
CAN-07	42N10E30N	04/26/2011	IT-24 - Sue W.	10.02	42.19	13.1	39	23	63	28	0.5	36	390	0.1S	0.2		66	-13.2	-100.8
CAN-08	42N09E36B		AES Elem. Sch	9.94	42.15	37	3.2	8.7	65		3.2	19	156				87	-13.44	-106.2
CAN-47	42N09E25D	07/14/2011	MT-1	9.85	42.31	21	9	7	56	17	16	9.4	207	0.2				-15.01	-114.3
CAN-48	42N09E25E	07/14/2011	MT-2	9.85	42.27		8	6	60	19	20	9.5	207	0.2				-14.95	-114.6
CAN-49	42N09E25M	07/14/2011	MT-3	9.85	42.23	22	23	14	40	13	40	9.7	207	0.1				-14.14	-109
CAN-50	42N09E25D	07/14/2011	MT-5	9.85	42.31		7	6	55	16	11	13	195	0.2				-15.01	-114.6
CAN-51	42N09E26H	07/14/2011	MT-6	9.81	42.27	22	13	9	51	13	31	5.8	207	0.1				-14.52	-110.4
CAN-52	42N09E25C	07/14/2011	MT-7	9.90	42.31	26.1	3	2	72	17	18	16	195	0.2				-14.19	-109.9
CAN-53	42N09E25N	07/14/2011	MT-8	9.85	42.19	31	9	6	64	18	27	11	207	0.2				-14.4	-111.7
CAN-54	42N09E25J	08/04/2011	IT-2	9.98	42.23	23.4	7.8	3.9	70	11	20	20	140	0.25				-14.18	-108.5
CAN-55	42N09E02Q	07/14/2011	W-01 - Blacks	9.77	42.85	19	9	3	41	4	4.9	6.6	146	0.1				-14.59	-112.6
CAN-56	42N09E24R	07/14/2011	W-02. BC Stoc	9.98	42.35	20	5	1	83	13	13	19	218	0.2				-13.44	-106.7
CAN-57	42N09E35R	07/14/2011	W-03-Wilson	9.81	42.02	19	5	4	58	9	11	4.5	183	0.1				-14.28	-110.8
GEOT-44	38N07E12K		Bassett HS, Bi	7.94	38.73	82	33.4	0.49	250.6	4.23	370	92	27		1.7		87.5	-14.64	-118.00
GEOT-45	38N08E14N		Kellog HS, Big	8.69	38.52	78	29	0.49	236	6	400	103	30		2.4		97.88	-14.25	-118.00
GEOT-48B	42N12E11P	10/18/1991	AL-2	12.73	42.69		16	0.6	480	50	275	475.9	239		3		188.9	-12.2	-116
WSV-46	IS-301	08/02/2012	SX Well-1									2.6						-14.21	-108.1
WSV-47	IS-302	08/02/2012	SX Well-3									11						-15.25	-118.1
WSV-48	IS-303	08/02/2012	SX Well-4									25						-14.48	-113.6
WSV-49	IS-304	08/02/2012	SX Well-5									31						-14.58	-115
WSV-50	IS-305	08/02/2012	SX Ranch Spring															-15.06	-116

Canby Area:																								
Seq#	Latitude, North	Long. East	Well No.	Date	Name	R-East	T-North	Temp. C	TD, ft	F-EC	L-EC	F-pH	L-pH	Ca	Mg	Na	K	SO4	Cl	HCO3	B	F	NO3	SiO2
CAN-01	41.44075	-120.87	42N10E31E	04/26/2011	Blue Well	10.0000	42.0833	16.8	100	334				16	8.8	38	10	30	9.9	146	0.16	0.4		71
CAN-02	41.44117	-120.875	42N9E36G	04/26/2011	Dale Well	9.9167	42.0833	16.8		507				27	11	63	16	48	12	244	0.21	0.3		74
CAN-03	41.44768	-120.87	42N10e30M	04/26/2011	Group Home	10.0000	42.2083	27.5		536				0.6	0.5	120	8.7	35	28	227	0.97	0.6		92
CAN-04	41.44768	-120.87	42N10e30M	05/03/2009	Group Home	10.0000	42.2083			520			8.08	0.7	0.1	94	11	32.7	24.2	227		0.5		
CAN-05	41.4434	-120.87	42N10E31D	04/26/2011	Office Well	10.0000	42.1250	18.2	400	486				1.2	0.6	110	10	44	24	195	0.4	0.3		69
CAN-06	41.44218	-120.871	42N9E36A	04/26/2011	Old Clinic We	9.9583	42.1250	14.3		480				29	15	50	17	27	14	256	0.17	0.2		65
CAN-07	41.44497	-120.869	42N10E30N	04/26/2011	Sue Well	10.0000	42.1667	13.1		720				39	23	63	28	0.5	36	390	0.1S	0.2		66
CAN-08	41.44166	-120.874	42N9E36B		AES	9.9167	42.1250	37	965					3.2	8.7	65		3.2	19	156				87
CAN-09	41.45272	-120.872	42N9E25H01M	04/24/1979	IT-01	9.9583	42.2500		160	350			7.65	4.4	3.1	65		17.5	13.7	189		0.12	<0. 02	
CAN-11	41.4474	-120.874	42N9E25J01M	10/21/1998	IT-03	9.9583	42.2083		192													0.32		
CAN-12	41.44464	-120.874	42N9E25Q	05/08/1987	IT-05	9.9167	42.1667			400			7.90	22	14	29	16		9	175		0.5		
CAN-13	41.44385	-120.873	42N9E25R	09/25/2007	IT-06	9.9583	42.1667	16	460	390			8.13	8	4	60	15	37.1	11	181				
CAN-18	41.44688	-120.878	42N9E25K	10/11/1984	IT-07	9.9167	42.2083		208					18	5.8	33		12	49	181		0.09	2.52	
CAN-20	41.44218	-120.871	42N9E36A02M	06/17/1974	IT-10	9.9583	42.1250		150					25	15	19	15	34	20	163	0.09	0.3	2.8	
CAN-25	41.44339	-120.87	42N10E31	05/08/1979	IT-12	10.0000	42.0833		400	750			7.95	48	31	55		50.2	51.5	304			8	
CAN-30	41.44299	-120.873	42N9E36A03M	01/04/2005	IT-14	9.9583	42.1250		205	365			8.29	10	3. 38	73. 1		25	15	192		0. 24	0. 26	
CAN-35	41.44681	-120.88	42N9E25F	06/22/1981	IT-15	9.8750	42.2500		400	360			8.23	9.3	4. 33	68		20	8.5	211		0.2	<0. 2	
CAN-43	41.44516	-120.876	42N9E25R01M	06/09/1998	IT-16	9.9583	42.1667		165					2.6	7.4	36			6.9	125				
CAN-45	41.44516	-120.876	42N9E25R01M	??	IT-16	9.9583	42.1667		165	360										173				
CAN-47	41.45469	-120.89		07/14/2011	MT-1			21	270	381				9	7	56	17	16	9.4	207	0.2			
CAN-48	41.45081	-120.89		07/14/2011	MT-2									8	6	60	19	20	9.5	207	0.2			
CAN-49	41.44885	-120.89		07/14/2011	MT-3			22	505	430				23	14	40	13	40	9.7	207	0.1			
CAN-50	41.45782	-120.889		07/14/2011	MT-5				380					7	6	55	16	11	13	195	0.2			
CAN-51	41.45119	-120.894		07/14/2011	MT-6			22	620	396				13	9	51	13	31	5.8	207	0.1			
CAN-52	41.45486	-120.88		07/14/2011	MT-7			26.1		395				3	2	72	17	18	16	195	0.2			
CAN-53	41.45738	-120.882		07/14/2011	MT-8			31		411				9	6	64	18	27	11	207	0.2			
CAN-54	41.45079	-120.872		08/04/2011	MT-8 ?			23.4		395				7.8	3.9	70	11	20	20	140	0.25			
CAN-55	41.50441	-120.9		07/14/2011	W-01 - Blacks C. Ranch			19		249				9	3	41	4	4.9	6.6	146	0.1			
CAN-56	41.45819	-120.871		07/14/2011	W-02. BC Stockwell			20		497				5	1	83	13	13	19	218	0.2			
CAN-57	41.42858	-120.893		07/14/2011	W-03-Wilson			19		315				5	4	58	9	11	4.5	183	0.1			

Warm Springs Valley																								
Seq#	Latitude, North	Long. East	Well No.	Date	Name	R-East	T-North	Temp. C	TD, ft	F-EC	L-EC	F-pH	L-pH	Ca	Mg	Na	K	SO4	Cl	HCO3	B	F	NO3	SiO2
WSV-01	41.42729	-120.897	41N/09E-02B01	08/24/1982		9.7708	41.9792	23.9		238			7.60	14	8	18	12		1	135				
WSV-02	41.41283	-120.921	41N/09E-10C02	08/05/1958		9.5625	41.8125	12.8		290			8.20	25	10	15	5.6	5.4	4.7	150		0.2	10	48
WSV-03	41.39475	-120.888	41N/09E-13E01	08/07/1958		9.8542	41.6042	17.8		157			7.90	16	3.6	10	3.1			98	0.01		0.5	31
WSV-04	41.41645	-120.791	41N/10E-02N02	08/07/1958		10.6875	41.8542	17.2		688			8.20	4.5	1.9	138	5	94	52	187	0.21	0.1	1.5	57
WSV-08	41.41283	-120.782	41N/10E-11B01	08/07/1958		10.7708	41.8125	22.2		1340			8.10	21	0.4	272	5.1	261	101	267	1.5	1	23	44
WSV-09	41.46344	-120.897	42N/09E-23K01	08/05/1958		9.7708	42.3958	15.6		292			8.20	12	8.3	32	9.7	5.1	8.4	149	0.05	0.2	5.4	72
WSV-10	41.44899	-120.888	42N/09E-25M01	08/24/1982		9.8542	42.2292	20.6		357			8.00	9	7	53	18		6	196		0.2		
WSV-11			42N/09E-25R02	08/27/1990		9.9792	42.1875			444		7.3	8.2	25	14	35	18	50	14	172	0.1		0.1	
WSV-16	41.44902	-120.893	42N/09E-26J01	08/05/1958		9.8125	42.2292	13.3		430			8.20	30	19	28	7.8	27	6.7	226	0.06	0.4	0.6	59
WSV-17	41.4309	-120.893	42N/09E-35R01	08/05/1958		9.8125	42.0208	15.6		325			8.20	5.5	3.8	56	9.8	8.9	3.4	181	0.03	0.2	3.4	65
WSV-18	41.44225	-120.873	42N/09E-36A01	08/24/1982		9.9792	42.1458	16.1		303			8.10	17	9	28	12		6	166				
WSV-19	41.43452	-120.883	42N/09E-36L01	08/05/1958		9.8958	42.0625	12.8		394			8.30	34	9.2	31	7.8	18	2.9	206		0.4	7.2	58
WSV-20	41.48153	-120.762	42N/10E-13G01	08/05/1958		10.9375	42.6042	27.8		250			9.00			56	1.7	7.1	18	109	0.26	0.3	1	44
WSV-21			42N/10E-22G01	08/05/1958		10.6042	42.4375	15.0		593			8.60	56	27	29	4.8	44	25	277		0.1	9.5	50
WSV-31	41.4526	-120.811	42N/10E-27E01	08/05/1958		10.5208	42.2708	17.2		504			8.50	1.4	0.4	111	7.4	38	3.4	251	0.1	0.3	4	61
WSV-32	41.45621	-120.835	42N/10E-29A01	08/21/1957		10.3125	42.3125	92.2		1240			7.40	21	0.4	232	6.8	297	161	49	3.7	1.8	4.4	
WSV-35	41.4526	-120.835	42N/10E-29H01	08/05/1958		10.3125	42.2708	28.9		269			8.20			63	1.4	14	1.9	146	0.07	0.2	0.8	41
WSV-43	41.43452	-120.854	42N/10E-31J01	07/23/1956		10.1458	42.0625			351			8.00	12	5.5	60	5.6	13	7.8	200		0.2	3.9	64
WSV-45	41.43814	-120.772	42N/10E-36E02	08/24/1982		10.8542	42.1042	15.6		695			8.20	77	14	44	15		26	272	0.1	0.2		
WSV-46	41.513574	-120.777		08/02/2012	SX Well-1														2.6					
WSV-47	41.508672	-120.779		08/02/2012	SX Well-3														11					
WSV-48	41.486275	-120.774		08/02/2012	SX Well-4														25					
WSV-49	41.489556	-120.772		08/02/2012	SX Well-5														31					
WSV-50	41.482712	-120.764		08/02/2012	SX Ranch Spring														22					

Ground Water Chemistry Data

Alturas Basin and Modoc County — data entries in italics were calculated from epm-balance!

Seq#	Latitude, North	Long. East	Well No.	Date	Name	R-East	T-North	Temp. C	TD, ft	F-EC	L-EC	F-pH	L-pH	Ca	Mg	Na	K	SO4	Cl	HCO3	B	F	NO3	SiO2
Eastern Alturas Basin:																								
ALT001	41.24651	-120.555	39N12E02L01	06/02/1958		12.7292	39.8958				139		7.9	10	5	18	6.2	5.4	2.5	96		0.1	2.1	45
ALT002	41.25375	-120.502	39N13E05D02	06/02/1958		13.1875	39.9792				345		8.3	37	8.8	40	1.4	31	13	222		0.2	11	52
ALT003	41.2429	-120.521	39N13E06N01	07/22/1970		13.0208	39.8542				249		7.8	12	4.9	35	6.5	4.9	3.8	146			1.8	
ALT009			39N13E06N01	08/19/1982		13.0208	39.8542	19		250	261	7.3	8.3	14	5	33	6.3		5	140				
ALT021	41.22844	-120.521	39N13E07N01	06/02/1958		13.0208	39.6875				490		8.3	67	34	28	4.4	5.8	3.5	436		0.2	2.7	42
ALT022	41.23567	-120.497	39N13E08F01	07/10/1956		13.2292	39.7708				642		7.9	65	19	40	7.5	16	34	275			56	40
ALT023	41.23206	-120.492	39N13E08K01	11/18/1955		13.2708	39.7292				288		7.9	20	6.6	29	7.9	7	6	163		0.1	1.5	47
ALT025	41.22844	-120.492	39N13E08Q01	08/08/1985		13.2708	39.6875	21		500		7	8.7	39	16	36	6.9	16	16	217			37	
ALT031	41.23929	-120.483	39N13E09D01	06/02/1958		13.3542	39.8125				180		7.8	19	9.5	12	5.4	7.7	3	133	0.03	0.1	2.4	64
ALT032	41.21397	-120.487	39N13E17R01	08/23/1982		13.3125	39.5208	23		162	160	7.3	7.4	11	5	12	6	*3.4*	3	90				
ALT033	41.22482	-120.507	39N13E18A01	06/02/1958		13.1458	39.6458				400		8.3	51	23	27	6.4	14	7.5	295		0.2	15	44
ALT034	41.32244	-120.555	40N12E11F01	08/03/1977		12.7292	40.7708	21		165	165	7.9	8.2	7.9	1.7	21	5.9	5.8	4.7	78			3	
ALT035	41.27544	-120.526	40N12E25J01	08/03/1977		12.9792	40.2292	14		460	497	7.3	8.7	22	9.6	72	8.4	12	6.7	304			1	
ALT036	41.28267	-120.545	40N12E26A01	06/03/1958		12.8125	40.3125				210		8.3	17	7.5	29	8.2	1.6	1.2	181		0.2	0.8	52
ALT039	41.27183	-120.516	40N13E30P01	06/24/1992		13.0625	40.1875	16		272	300	8		9	1	46	6	44	18	66	0.2	0.1	<0.4	35
ALT044	41.2646	-120.521	40N13E31E01	06/02/1958		13.0208	40.1042				240		8.3	5	0.4	46	3.7	27	12	87	0.2	0.3	0.8	58
ALT045	41.42729	-120.642	41N11E01A01	08/05/1958		11.9792	41.9792				234		8	2.7	0.1	44	7.2	10	7.9	106	0.06	0.4	3.6	77
ALT046	41.42368	-120.651	41N11E01F01	08/07/1967		11.8958	41.9375				281		8	1.9	0.4	58	5.7	29	17	100	0.4			
ALT050			41N11E01F03	10/09/2008		11.8958	41.9375			292		7.6	7.9	23	4	26	11	9	7	138	<0.1		14.6	
ALT052	41.42368	-120.666	41N11E02G01	08/04/1958		11.7708	41.9375				256		8.1	27	3	17	9.1	5.8	6.8	131		0.2	5.1	69
ALT053	41.42006	-120.661	41N11E02J01	08/02/1977		11.8125	41.8958	21		253	254	7.5	8.5	23	2	20	9	6	7	123			5.1	
ALT054	41.41645	-120.676	41N11E02N01	06/23/1992		11.6875	41.8542	19		314	350	8.1		11	2	57	10	14	7	159	0.1	0.1	2.7	74
ALT060	41.42368	-120.695	41N11E03E01	04/20/1983		11.5208	41.9375	13		2400	2200		7.9	130	44	288	32	626	271	214	0.1			
ALT061	41.42006	-120.7	41N11E04J01	04/20/1983		11.4792	41.8958	13		1525	1470	7.3	8.1	22	10	261	28	353	148	171	0.1		7.5	
ALT062	41.42006	-120.729	41N11E05L01	08/04/1958		11.2292	41.8958				1330		7.6	120	36	71	19	79	140	113		0.2	310	78
ALT063	41.40921	-120.685	41N11E10G02	08/05/1985		11.6042	41.7708	16		460	460	8.4	8.7	1	0	101	7.6	41	18	194	0.2		0.4	
ALT064	41.37306	-120.709	41N11E21P01	08/04/1958		11.3958	41.3542				145		8.3	5.1	0.6	25	3.7	1.2	1.5	84	0.01	0.1	1.1	41
ALT065	41.36944	-120.666	41N11E26B02	08/04/1958		11.7708	41.3125				172		8.1	9.2	2.7	22	4.5	3	3.6	94	0.22	0.1	3.1	44
ALT066	41.36582	-120.719	41N11E29H01	08/04/1958		11.3125	41.2708				260		8.1	3.4	0	60	1.3	3.6	2.4	156		0.7	1	53
ALT067	41.36221	-120.719	41N11E29J01	08/04/1958		11.3125	41.2292				184		7.9	18	3.2	15	4.1	0.6	1.2	111		0.2	2.1	62
ALT068	41.41645	-120.56	41N12E02N01	06/03/1958		12.6875	41.8542				390		8.1	47	12	29	11	30	31	137		0.1	80	64
ALT069	41.4056	-120.565	41N12E10J01	11/18/1955		12.6458	41.7292				334		7.5	25	8.2	30	7.2	20	17	140	0.04	0.4	12	70
ALT070	41.4056	-120.579	41N12E10M01	08/24/1983		12.5208	41.7292				204		7.8	15	4	19	6.8	5	3	111			4.2	
ALT071	41.4056	-120.536	41N12E12L01	06/23/1992		12.8958	41.7292	17		1114	1100	7.6		77	14	120	20	150	180	159	1	0.1	4.9	71
ALT077	41.39475	-120.565	41N12E15H01	07/27/1971		12.6458	41.6042	21		270	263	7.3	8.1	17	2.3	32	7.8	6.6	8.1	126			13	
ALT078	41.36944	-120.569	41N12E27B01	06/24/1987		12.6042	41.3125	26		265	266	8.1		8	2	43	7.4	19	11	*117*			0.4	
ALT081	41.42729	-120.492	41N13E05B02	06/03/1958		13.2708	41.9792				245		8.2	40	9.5	14	7.2	36	3.9	157		0.1	0.7	52
ALT084	41.38752	-120.516	41N13E18P01	08/13/1981		13.0625	41.5208				904		8.1	109	46	23	9	272	11	268			2.4	
ALT098	41.36221	-120.632	41N13E30L01	06/02/1958		12.0625	41.2292				340		8.3	49	17	16	11	24	6.9	254	0.03	0.2	0.2	52
ALT099	41.44575	-120.872	42N09E25R02	08/27/1990		9.9792	42.1875			444	433	7.3		25	14	35	18	50	14	172	0.1		<0.1	
ALT104	41.46706	-120.801	42N10E22G01	07/10/1986		10.6042	42.4375	17		605	567	7.3	8.5	47	25	41	6.6	43	18	237	0.1		52	
ALT111	41.49237	-120.704	42N11E09K01	07/29/1960		11.4375	42.7292				219		8.1	1.5		47	1.5	5.4	12	101	0.12	0.3	0.7	42
ALT113			42N11E09K01	08/25/1959		11.4375	42.7292				224		7.9	1.6	####	48	1.9	5.9	13	104	0.1	0.3	0.4	49
ALT114	41.48875	-120.661	42N11E11R01	08/19/1982		11.8125	42.6875				386		8.2	30	10	32	13	*23.8*	6	206				
ALT115	41.48514	-120.642	42N11E13A03	09/02/1982		11.9792	42.6458	16		530	520	7.5	8.2	51	16	32	13	*64.7*	12	238		0.2		
ALT116			42N11E13A03	08/27/1990		11.9792	42.6458	16		589	602	7.3		59	21	34	13	70	13				8	
ALT120	41.47429	-120.738	42N11E18R01	06/27/1988		11.1458	42.5208	17		260	260	7.7	8.6	20	6	23	6.4	19	5	137	0.1		0.5	
ALT127	41.46706	-120.753	42N11E19E01	08/02/1977		11.0208	42.4375				474		8.8	2		104	7.5	29	6	240			0.7	
ALT128			42N11E19E01	08/24/1961		11.0208	42.4375				446		8.3	2.7	0.1	101	9	30	8.2	235	0.05	0.2	0.6	64
ALT139	41.46706	-120.738	42N11E19H01	06/22/1987		11.1458	42.4375	21		370	361	8.1		7	1	70	5.2	39	9	*155*			<0.1	
ALT140			42N11E19H01	06/22/1987		11.1458	42.4375	21		370	361	8.1		7	1	70	5.2	39	9					
ALT142	41.46344	-120.695	42N11E22M01	08/05/1958		11.5208	42.3958				489		8.2	0.9	####	99	7.7	36	43	159	0.05	0.2	0.5	59
ALT143	41.47068	-120.642	42N11E24A01	09/11/1997		11.9792	42.4792			218		7.3		20	6	15	5.7	5	5	*125*	0.1			
ALT148	41.46344	-120.642	42N11E24J02	08/19/1982		11.9792	42.3958	16		395	394	7.2	8	6	2	79	13	*9.6*	4	239				
ALT149	41.45621	-120.656	42N11E25D01	08/19/1982		11.8542	42.3125	22		305	292	7.3	7.8	19	1	36	9.9	*12.1*	12	138				
ALT150	41.44537	-120.651	42N11E25P01	08/04/1958		11.8958	42.1875				307		8.1	22	1.9	34	13	11	12	142		0.2	8.9	69
ALT151	41.4526	-120.748	42N11E30F01	06/15/1983		11.0625	42.2708				715		8.4	5	1	141	14	172	7	194	0.1		4.6	
ALT152	41.4526	-120.743	42N11E30G01	06/15/1983		11.1042	42.2708	22		650	630	8.1	8.4	6	1	121	14	148	9	173			2.4	
ALT153	41.43814	-120.714	42N11E33E01	06/15/1983		11.3542	42.1042	14		540	515	7.2	8.1	16	7	77	13	79	33	149	0.1		2.1	
ALT154			42N11E33E01	08/24/1982		11.3542	42.1042	16		480	471	7.4	7.7	7	3	81	10		33	109				
ALT156	41.44175	-120.661	42N11E35A02	06/24/1987		11.8125	42.1458	18		305	300	7.8		5	0	53	13	13	9	*144*	0.1		4.3	
ALT159	41.43452	-120.661	42N11E35J01	08/04/1958		11.8125	42.0625				421		8.1	18	0.2	63	8.2	52	30	116	0.56	0.4	3.9	80
ALT160	41.51406	-120.526	42N12E01A01	08/27/1990		12.9792	42.9792			303	309	7.4		30	10	17	6.5	16	4	*170*	0.1		4.9	
ALT161	41.51406	-120.545	42N12E02A01	06/04/1958		12.8125	42.9792				250		8.1	36	6.5	14	9	15	5.4	170		0.2	2.2	68
ALT162	41.50322	-120.545	42N12E02R01	06/22/1987		12.8125	42.8542	16		355	344	7.7		39	11	15	8.4	18	4	*197*			5.3	
ALT164	41.49237	-120.637	42N12E07M01	08/27/1990		12.0208	42.7292			522	507	7.3		54	19	22	12	24	8	257	0.1		29	
ALT165	41.49598	-120.618	42N12E08E01	06/04/1958		12.1875	42.7708				250		8.4	36	11	13	7.2	12	5.6	190		0.3	1.7	70
ALT166	41.49237	-120.608	42N12E08K01	08/19/1982		12.2708	42.7292				376		7.4	20	5	43	9.4	*31.3*	40	106				
ALT167	41.48875	-120.594	42N12E09F01	06/04/1958		12.3958	42.6875				280		8.2	21	17	21	11	21	7.4	187	0.02	0.3	2.7	78
ALT168	41.49598	-120.579	42N12E10E01	06/04/1958		12.5208	42.7708				250		8.3	29	5.8	25	9.6	19	13.3	155	0.06	0.3	3	66
ALT169	41.49598	-120.565	42N12E10H01	08/27/1990		12.6458	42.7708			293	301	7.3		20	3	32	14	15	8	*150*			2.6	
ALT172	41.49237	-120.545	42N12E11J01	07/07/1986		12.8125	42.7292	17		395	372	7.7	8.5	43	12	18	7.9	19	10	195	0			
ALT174	41.48875	-120.55	42N12E11Q01	07/29/1960		12.7708	42.6875				458		8.3	26	4.9	60	12	34	34	170	0.68	0.3	2.9	79
ALT181			42N12E11Q02	11/09/1963		12.7708	42.6875						8.3	34	7.8	37	*1.0*	20	16	184		0.2	0.8	
ALT182	41.48875	-120.536	42N12E12F01	06/03/1958		12.8958	42.6875				290		8.4	37	14	16	7.6	17	8.5	203		0.3	8.3	60
ALT184			42N12E12F01	12/06/1985		12.8958	42.6875				146		8.2	35	4.3	26		19	3	178		0.3	4.3	
ALT186	41.49237	-120.536	42N12E12L01	09/09/1981		12.8958	42.7292				283		8.1	19	4	35		17	4	146		0.2	2.6	
ALT189			42N12E12L01	02/25/1970		12.8958	42.7292						8.1	22	3.3	36	8.3	31	6	151		0.2	2.1	
ALT190	41.49237	-120.54	42N12E12M01	02/25/1970		12.8542	42.7292						7.9	38	12	24	9.7	22	12	200		0.2	15	
ALT191			42N12E12M01	02/07/1978		12.8542	42.7292				408		8.1	36	15	36		27	12	209		0.2	7.2	
ALT194	41.48875	-120.531	42N12E12Q01	09/09/1972		12.9375	42.6875						7.2	26	6	33	8.8	19	6	182		0.1	0.2	
ALT195			42N12E12Q01	02/07/1978		12.9375	42.6875				287		8.1	15	1.8	54		17	6	154		0.2	5.1	
ALT198	41.48514	-120.55	42N12E14B01	10/06/2008		12.7708	42.6458	17.3		532		7.6	7.8	25	5	74	12	40	42	188	0.9		6.1	
ALT202	41.45983	-120.618	42N12E20N01	08/19/1982		12.1875	42.3542				202		7.8	4	1	36	6.9	*13.8*	7	94				
ALT203	41.45983	-120.56	42N12E23N01	06/23/1992		12.6875	42.3542	22		551	600	7.2		10	2	100	21	47	70	159	1.7	0.1	11	100
ALT207	41.47068	-120.536	42N12E24C01	06/03/1958		12.8958	42.4792				300		8.1	33	8.9	35	12	25	12	214	0.09	0.2	0.5	68
ALT208	41.4526	-120.526	42N12E25H01	06/03/1958		12.9792	42.2708				310		8	31	4.8	56	9.6	13	6.3	264	0.23	0.2	1.2	66
ALT209	41.44899	-120.56	42N12E26M01	08/18/1982		12.6875	42.2292	25		305	306	7.3	7.9	5	1	56	10	*22.8*	18	124				
ALT210	41.44537	-120.555	42N12E26P01	08/18/1982		12.7292	42.1875	23		1160	1140	7.3	8.2	23	5	202	27		160	229	4.6			
ALT211			42N12E26P01	08/31/1990		12.7292	42.1875				1220		8.2	37	6	195	28	134	175	235	5.3		4.5	
ALT215	41.44537	-120.565	42N12E27R01	08/18/1982		12.6458	42.1875				355		8	26	7	34	8.2		19	148			8.4	
ALT216			42N12E27R01	08/08/1985		12.6458	42.1875	20		400	386	7.2	8.5	30	9	34	8	26	24	153	0.3			
ALT223	41.45621	-120.613	42N12E29C01	08/19/1982		12.2292	42.3125	23		202	201	7.7	7.5	7	1	30	7	*8.7*	9	90				
ALT224	41.51045	-120.43	42N13E02H01	07/18/1956		13.8125	42.9375				238		7.7	11	17	7.2	11	1	0.5	151	0.01		3.9	51
ALT225	41.51045	-120.492	42N13E05G02	08/16/1982		13.2708	42.9375				315		7.9	16	4	43	11		6	166				
ALT226			42N13E05G02	06/22/1987		13.2708	42.9375				361		8.1	20	6	46	12	18	7	188	0.1		7.4	
ALT230	41.50683	-120.502	42N13E05M01	06/04/1958		13.1875	42.8958				300		8.4	37	11	20	10	22	0.1	194	0.02	0.1	6.3	70
ALT231	41.51045	-120.512	42N13E06G01	06/04/1958		13.1042	42.9375				280		8.2	39	8.2	20	10	21	8.7	183	0.01	0.2	6.5	58
ALT232			42N13E06G03	06/15/1983		13.1042	42.9375				430		8.4	47	13	22	8.3	24	7	214			22	
ALT233	41.50322	-120.521	42N13E06N02	08/27/1990		13.0208	42.8542			321	328	8		26	4	35	9.7	20	7	*170*	0.1		6.1	
ALT234	41.50322	-120.516	42N13E06P01	06/14/1983		13.0625	42.8542				959		8.3	66	52	59	7.8		7	572	0.2		27	
ALT235			42N13E06P01	08/16/1982		13.0625	42.8542				938		8.4	59	46	58	7.3	72	8	594	0.1			
ALT236	41.48514	-120.502	42N13E17D01	08/17/1982		13.1875	42.6458				333		8	28	10	26	5.9		8	168				
ALT237			42N13E17D01	06/03/1958		13.1875	42.6458				220		8.3	23	8.7	20	6.2	13	8.7	146	0.03	0.3	4.8	68
ALT238	41.48153	-120.492	42N13E17G01	08/17/1982		13.2708	42.6042				322		7.9	33	12	14	4.9	*21.8*	9	162				
ALT239	41.47791	-120.497	42N13E17L02	06/22/1987		13.2292	42.5625	16		377	364	7.5		36	13	20	6.5	21	9	*196*			4.2	
ALT240			42N13E17L02	08/17/1982		13.2292	42.5625				364		8	36	12	20	6.5		10	188				
ALT243	41.47068	-120.492	42N13E20B02	08/17/1982		13.2708	42.4792				292		7.8	27	8	19	6.6	*19.4*	7	146				
ALT244	41.46706	-120.502	42N13E20E01	08/17/1982		13.1875	42.4375				300		8.1	27	8	22	6.7	*20.6*	8	151				
ALT245	41.47068	-120.473	42N13E21B01	06/14/1983		13.4375	42.4792	16		640	620	7.5	8.3	65	21	30	9.2	120	31	185			4.2	
ALT246	41.46344	-120.473	42N13E21K02	08/17/1982		13.4375	42.3958				345		8.1	32	8	25	8.2		8	160				
ALT247			42N13E21K02	06/27/1988		13.4375	42.3958	17		335	327	7.8	8.7	28	8	27	8	42	8	133			2.6	
ALT253	41.47068	-120.463	42N13E22D01	06/04/1958		13.5208	42.4792				190		8.2	19	4.8	16	7.2	12	6.5	113		0.1	0.5	65
ALT254	41.44899	-120.473	42N13E28K01	06/05/1958		13.4375	42.2292				350		8.4	39	19	16	5	7	18	204		0.2	13	64
ALT255	41.45621	-120.516	42N13E30C02	08/31/1990		13.0625	42.3125			452	455	7.4		31	5	52	10	31	25	159	0.3		31	
ALT257	41.43814	-120.512	42N13E31G01	08/28/1962		13.1042	42.1042				530		8.4	23	8.1	96	11	0.5	5.3	367		0.1		13
ALT270	41.43814	-120.507	42N13E31H01	06/23/1992		13.1458	42.1042	16		430	450	7.3		34	10	46	10	15	5	244	0.1	0.1	0.9	71
ALT272	41.4309	-120.516	42N13E31P02	06/23/1992		13.0625	42.0208	24		691	700	7.9		13	1	130	11	93	75	159	2	0.1	1.3	82
ALT274	41.44175	-120.497	42N13E32C02	08/18/1982		13.2292	42.1458				485		8.3	31	16	27	8.9		1	337				
ALT275	41.43814	-120.492	42N13E32G01	07/14/1969		13.2708	42.1042	14		378	342	7.4	8	33	9.8	29	6.3	5.8	3.6	218			0.6	
ALT289	41.43452	-120.454	42N13E34K01	06/05/1958		13.6042	42.0625				210		8.3	20	11	14	6.6	1.5	4.5	154		0.2	0.9	57

Geothermal waters:

Seq#	Latitude, North	Long. East	Well No.	Date	Name	R-East	T-North	Temp. C	TD, ft	F-EC	L-EC	F-pH	L-pH	Ca	Mg	Na	K	SO4	Cl	HCO3	B	F	NO3	SiO2
GEOT-01	41.23206	-121.409	39N05E9SW-NW		Little Hot Spri	5.3542	39.7292	76		2490			7.6	78	1	230	5.2	400	120	49	4.3	1.9		87
GEOT-02	41.1959	-120.377	39N14E29NE-NW		West Vly Re	14.2708	39.3125	77		2980			7.8	19	0.1	330	11	510	150	63	4.5	4		130
GEOT-03	41.23929	-120.044	39N17E07NE-NE		Menlo Baths	17.1458	39.8125	59		808			8.9	5.1	0.1	100	1.4	120	23	62	0.9	3.8		53
GEOT-04	41.19228	-120.029	39N17E29NE-SW		Spring Near S	17.2708	39.2708	41						2.4	0.1	62	1.1	41	14	86				40
GEOT-05	41.18144	-120.02	39N17E33NW-NW		Unnamed Spr	17.3542	39.1458	43					9	2.4	0.2	62	1.6	57	21	73	0.6	0.2		38
GEOT-06	41.27183	-120.516	40N13E30SW-SE		New Williams	13.0625	40.1875	29		200			7.3	9.6	0.9	44	6.6	31	24	110				31
GEOT-07	41.2646	-120.521	40N13E31NW-SW		Old Williams F	13.0208	40.1042	44		333			8.4	4.2	0.1	49	3.4	28	11	83	0.2	0.4		52
GEOT-08	41.37306	-120.709	41N11E21SW-SE		Macky	11.3958	41.3542	27		135			8.3	8.8	0.4	27	3.6		6	120				31
GEOT-09	41.51406	-120.777	42N10E02NE-		SX Ranch \	10.8125	42.9792	24		330				19	9	34	3	25	13	183		0.3		67
GEOT-10	41.48514	-120.767	42N10E13NW-NE		SX Ranch Sp	10.8958	42.6458	27		230				3.1		51		7	22	108	0.4	2.4		39
GEOT-11	41.45621	-120.835	42N10E29NE-NE		Kelly Hot Spr	10.3125	42.3125	92		2770			8.1	20		250	6.5	300	160	47	3.8	2.1		110
GEOT-12	41.45621	-120.55	42N12E26NE-NW		Baker	12.7708	42.3125	34		210			7.2	18	1.8	36	8.3	14.3	22	150				65
GEOT-13	41.43452	-120.569	42N12E34SE-NW		Price	12.6042	42.0625	27		520			7.2	22	3.7	121	18	44	85	210				42
GEOT-14	41.50322	-120.063	42N16E01SE-SE		Springs in M	16.9792	42.8542	98						15	0.1	285	6	310	186	60	5.7	5		99
GEOT-15	41.50683	-120.053	42N17E6SW-NE		Surprise Vall	17.0625	42.8958	98		2660			8.4	16	0.1	280	5.5	320	200	59	5.7	5.1		100
GEOT-16	41.50322	-120.058	42N17E6SW-SW		Benmac Hot	17.0208	42.8542	98						18	0.1	285	6	310	188	73	5.6	5		100
GEOT-17	41.51767	-120.502	43N13E32SW-SW		Wellman	13.1875	43.0208	22		250			7.5	33	6.4	24	5.5	15	20	160				43
GEOT-18	41.58637	-120.077	43N16E12NW-NW		Seyferth Hot	16.8542	43.8125	86		3280			7.7	26	0.1	300	9	370	220	63	7.6	5.4		110
GEOT-19	41.57191	-120.063	43N16E13NE-NE		Leonards Hc	16.9792	43.6458	65		2590			7.8	26	0.6	330	8.5	390	220	84	7.6	5.2		110
GEOT-20	41.57191	-120.068	43N16E13NE-NW		Leonards Hc	16.9375	43.6458	41					7.8	15	3.5	403	5.7	400	218	182	7.6	4.4		58
GEOT-21	41.6406	-120.184	44N15E24NE-SW		Magma Energ	15.9375	44.4375	160						19	0.2	339	16	330	222	155	6.3	6.7		179
GEOT-22	41.64422	-120.179	44N15E24WE-		Mud Volcano	15.9792	44.4792	97		3740			7.4	7.7	0.1	320	15	320	220	112	6.3	7.6		200
GEOT-23	41.68399	-120.174	44N16E06NW-SW		Unnamed	16.0208	44.9375	25					8	3.2	0.5	138	4	2	70	278	5.2	0.7		68
GEOT-24	41.7093	-121.293	45N06E28SW-NW		O. Ackley	6.3542	45.2292	18		396			8.1	23	10	45	7.7	10	14	216		0.3		49
GEOT-25	41.74184	-120.155	45N16E17NW-SW		Unnamed	16.1875	45.6042	53					7.9	23	3.8	320	12	132	222	407	5.9	2		134
GEOT-26	41.81053	-121.283	46N06E21SE-NW			6.4375	46.3958	21		260			8.1	18	1.4	33	7.9	11	21	160				28
GEOT-27	41.84307	-120.15	46N16E8NW-SE		Peterson's R	16.2292	46.7708	42						4.7	2.1	80	7.2	58	25	135	0.8			77
GEOT-28	41.83222	-120.145	46N16E17NE-NW		Fort Bidwell S	16.2708	46.6458	45		733			7.9	4.2	0.1	110	9.5	86	31	133	0.6	2.2		82
GEOT-29	41.93526	-120.003	46N16E17		Hydrotherma	17.5000	47.8333	46		550			7.6	9	1	94	9	253	35	134	1.1	2.4		79
GEOT-30	41.77799	-120.159	46N16E31SE-SE		Unnamed	16.1458	46.0208	28					8.3	4	0.3	62	7.5	32	18	121	0.6	0.9		72
GEOT-31	41.9443	-120.319	47N14E02NE-SW		Weidner Well	14.7708	47.9375	47					8.6	14		130	1	58	74	126	4	4		55
GEOT-32	41.20313	-120.912	39N09E22SE-NE		Wilson	9.6458	39.3958	24		150			7.3	8.7	0.8	21	4.1	5.4	17	180				31
GEOT-33	41.28267	-120.497	40N13E29NW-NE		Hamel	13.2292	40.3125	21		180			7.9	8.8	0.8	31	7.9		0.9	130				29
GEOT-34	41.40198	-120.569	41N12E10SE-SW		Petford	12.6042	41.6875	34		200			7.8	12	3.8	31	9.5	4.3	8.9	100				32
GEOT-35	41.4056	-120.579	41N12E10SW-NW		Ice	12.5208	41.7292	30		220			7.6	17	1.7	31	8.3	11	0.9	150				39
GEOT-36	41.36944	-120.584	41N12E28NE-NE		Knoch	12.4792	41.3125	26		170			7.5	15	0.5	29	9.1	4.1	0.8	120				41
GEOT-37	41.44537	-120.868	42N10E30SW-SW		Isot	10.0208	42.1875	22		240			8.3	7.2	1.1	55	5.8	18	18	190				30
GEOT-38	41.49237	-120.536	42N12E12SW-NE		City of Altura	12.8958	42.7292	23		210			7.9	20	2.4	35	6.2	12	11	130				36
GEOT-39	41.4309	-120.516	42N13E31SW-SE		Jobe	13.0625	42.0208	28		480			8	11	0.6	129	11	43	65	210		0.5		35
GEOT-40	41.63156	-120.427	43N12E34		Armstrong	13.8333	44.3333	23		210			8.8	4.8	1.1	46	6.8	19	16	190				34
GEOT-41	41.48514	-120.56	42N12E14NW-NW		Alturas Airpc	12.6875	42.6458	49		370			8	25	5.3	57	12	4.2	42	142				72
GEOT-42	41.44175	-120.873	42N09E36NE-NE		Canby Schoc	9.9792	42.1458	34		280			8	3.2	8.7	65	7.3	3.2	19	156				87
GEOT-43	41.18867	-120.936	39N09E28SE-NW		Adin School	9.4375	39.2292	21		65			8	12	3.4	30	3.3		11	104				62
GEOT-44	41.14529	-121.11	38N07E12K		Bassett HS, E	7.9375	38.7292	82					8.98	33	0.5	251	4.2	370	92	27		1.7		87.5
GEOT-45	41.1272	-121.023	38N08E14N		Kellog HS, Bi	8.6875	38.5208	78					8.80	29	0.5	236	6	400	103	30		2.4		97.88
GEOT-46B	41.44537	-120.868	42N/10E-30N	09/13/2004	ISO-1	10.0208	42.1875			1330			8.88	19	0.4	237	3.9	264	171	80		1.9	3.93	102
GEOT-46C				10/16/2012	ISO-2				3850		1400		8.77	6.7	ND	260	5	280	184	150				31.3 ?
GEOT-47B	41.49237	-120.536	42N/12E-12L	04/09/1988	AL-1	12.8958	42.7292	87					9.34	34	0.1	407	5.2	270	419	62	10.3	0.67	1.46	86
GEOT-48B	41.48875	-120.555	42N/12E-11P	10/18/1991	AL-2	12.7292	42.6875			2500			7.60	16	0.6	480	50	275	475.9	239		3		188.9
Big Valley																								
BV01	41.06936	-121.134	37N/07E-02P01	08/10/1960		7.7292	37.8542	14.40					8.00	11	6.4	20	4.1	1	2.3	118		0.1		59
BV02	41.05128	-121.11	37N/07E-13B01	08/10/1960		7.9375	37.6458	17					8.00	12	6.6	18	4.2	1.6	3.2	111		0.1		61
BV03	41.15613	-121.134	38N/07E-02P01	08/10/1960		7.7292	38.8542	18					8.40	30	19	42	11	1.5	38	244		0.1		72
BV04	41.13444	-121.129	38N/07E-14G05	08/10/1960		7.7708	38.6042						8.00	36	16	22	2.5	79	32	93		0.3		56
BV05	41.13082	-121.124	38N/07E-14J01	04/02/1968		7.8125	38.5625						7.80	19	10	19	2.7	5.9	14	134				
BV06	41.11275	-121.134	38N/07E-23P01	08/10/1960		7.7292	38.3542						8.20	16	10	24	2.7	6.2	7.5	144		0.3		63
BV07			38N/07E-23P01	09/06/1961		7.7292	38.3542	16					8.20	25	4.2	25	2.7	6.2	6.7	144		0.3		63
BV08	41.09828	-121.177	38N/07E-28N09	07/23/1968		7.3542	38.1875	14					7.40	8.2	8.6	15	4.3	0.5	2.4	98				
BV09	41.09466	-121.182	38N/07E-32A06	06/11/1960		7.3125	38.1458	17					8.10	10	8	14	3.6	3	2	106				
BV10	41.1272	-121.018	38N/08E-14P01	08/10/1960		8.7292	38.5208	49					7.60	31	0.1	235	5	395	111	37		2.8		82
BV11	41.13082	-121.071	38N/08E-17K01	09/07/1961		8.2708	38.5625	17					8.00	15	10	14	2.9	6.7	1.7	123		0.2		62
BV12	41.09828	-121.085	38N/08E-30R01	06/10/1960		8.1458	38.1875	15					8.10	30	24	21	5.2	16	35	122		0.3		60
BV13	41.1489	-120.965	38N/09E-08E02	08/10/1960		9.1875	38.7708	16					8.20	26	12	21	5.2	6.1	14	153		0.2		70
BV14	41.11636	-120.941	38N/09E-21L01	06/10/1960		9.3958	38.3958	21					8.30	17	4.2	44	7.5	1.6	4	198		0.1		81
BV15	41.23929	-121.124	39N/07E-11A01	08/10/1960		7.8125	39.8125	16					8.10	16	7	23	4.5	0.5	6.5	118		0.1		64
BV16	41.21397	-121.11	39N/07E-13Q01	08/10/1960		7.9375	39.5208	16					8.00	9.9	3	33	2	16	7.3	99		0.2		63
BV17	41.21397	-121.124	39N/07E-14R01	08/10/1960		7.8125	39.5208	15					8.60	82	46	94	2.4	67	92	415		0.3		53
BV18	41.21036	-121.008	39N/08E-23A02	06/10/1960		8.8125	39.4792	17					7.90	12	9	16	4.7	19	4.7	96		0.2		70
BV19			39N/08E-23A	07/23/1968		8.8125	39.4792	16					8.10	4.9	2.9	30			3	94				
BV20	41.18867	-121.008	39N/08E-26J01	08/10/1960		8.8125	39.2292	13					8.20	48	19	45	1	44	40	133		0.4		65
BV21	41.18505	-120.931	39N/09E-28R02	08/14/1963		9.4792	39.1875						8.00	20	9	33	6.7	8.2	8.4	166				
BV22	41.19228	-120.941	39N/09E-28F20	08/10/1960		9.3958	39.2708	21					8.10	14	8.3	14	6.5	0.2	1.9	127		0.1		56
BV23			37N/07E-13B01	08/21/1978		7.9375	37.6458	16					8.30	63	45	53	6.2	34	68	275				
BV24			37N/07E-13B01	08/16/1983		7.9375	37.6458	17					7.60	75	56				77	286				
BV25			38N/08E-30R01	07/28/1971		8.1458	38.1875	15					8.20	65	57	26	6.6	44	70	154				
BV26	41.27183	-121.163	40N/07E-28R	09/01/1984	Flowing Wel	7.4792	40.1875	36					9.03	1.4	0.5	62	1.8	2	8	151		0.1		51.25
BV27	41.14529	-121.11	38N/07E-12K	09/01/1984	Bassett HS	7.9375	38.7292	82					8.98	33	0.5	251	4.2	370	92	27		1.7		87.5
BV28	41.1489	-121.11	38N/07E-12G	09/01/1984	Well on Kram	7.9375	38.7708						8.40	40	3.6	218	6.2	353	109	33		1.6		90.96
BV29	41.15251	-121.119	38N/07E-12D	09/02/1984	Aker's Hot v	7.8542	38.8125	62					8.99	29	0.5	216	3.4	367	95	20		1.7		68.2
BV30	41.11275	-121.216	38N/07E-19N	09/02/1984	Howard Henr	7.0208	38.3542	31					7.90	2.1	1.7	58	6.7	2	11	195		0.2		82.24
BV31	41.21036	-121.052	39N/08E-21B	09/02/1984	Connor well	8.4375	39.4792						6.75	12	7.9	19	3.5	13	10	106		0.3		80.28
BV32	41.1272	-121.023	38N/08E-14N	09/02/1984	Kellog HS, Ci	8.6875	38.5208	78					8.80	29	0.5	236	6	400	103	30		2.4		97.88
BV33	41.11998	-121.013	38N/08E-23G	09/02/1984	Richman Spri	8.7708	38.4375	21					7.25	29	11	18	4.8	4	5	195				57.96
BV34	41.32606	-121.206	40N/07E-07B	09/27/1984	Cox Well, Tay	7.1042	40.8125	11					7.30	22	13	6	-1	2	4	138				59
BV35	41.19228	-121.216	39N/07E-30E	09/27/1984	Kramer Sprin	7.0208	39.2708	18					8.20	14	6	15	3	2	6	104				44
BV36	41.1959	-120.941	39N/09E-28C		Ash Ck. unde	9.3958	39.3125	16					7.10	12	6.3	18	5.4	7.7	0.2	114		0.6		40
BV37	41.24651	-120.931	39N/09E-04J		Tim Cobb We	9.4792	39.8958	20					8.20	13	3	14	6	2	2	127		0.1		56
BV38	41.32606	-121.124	40N/07E-11A		Shaw's wa	7.8125	40.8125	27					9.35	40	0.5	235	2	386	115	23		1		69
BV39	41.21036	-121.013	39N/08E-23B		Spring inead	8.7708	39.4792	25					9.35	10	6	17	5	2	3	103		0.1		56
BV40	41.26098	-120.897	40N/09E-35K		Jim Kopp we	9.7708	40.0625	24					7.77	4	1	38	9	2	2.1	122		0.2		94
BV41	41.17059	-121.211	39N/07E-31P	09/19/1957	Willow Ck. at	7.0625	39.0208	13					7.30	15	6	25	7.9	13	0.5	172		0.2		51
BV42	41.34775	-121.138	41N/07E-35M	09/17/1957	Pit River at A	7.6875	41.0625	14					7.00	16	11	22	5.6	18	3.4	176		0.8		34
BV43	41.01513	-121.153	37N/07E-27	09/17/1957	Pit River at M	7.5625	37.2292	19					7.90	21	10	27	6.8	15	3.3	204		0.8		39

Testing Geothermal Well ISO-2 in Canby Modoc County, California

April 1, 2013

Final Report

Prepared by
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For

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Table of Contents

Executive summary

1) *This is a summary of the testing results on two geothermal wells in Canby, Modoc County, California, to evaluate well productivity and feasibility of injection:*
   a) *Well ISO-2, drilled in 2011, was test pumped in October 2012 and subjected to a series of injection tests in February and March 2013.*
   b) *Well ISO-1 was drilled and tested in the summer 2000. This report includes only a review of the ISO-1 test data interpretation conducted in 2000.*
2) *Well ISO-2 was pumped at a 13 gpm constant rate for 8 days; maximum drawdown was 289.55 ft. Due to cooling in the wellbore discharge temperatures did not exceed 162 F.*
3) *Given the fractured aquifers (Hydrothermally cemented tuffs and fractured lava) the dual porosity model of Barker (1988) was applied:*
   a) *The ISO-2 hydraulic conductivity K is calculated at 1.54 gpd/ft^2, and ISO-1 hydraulic conductivity is K = 4.6 gpd/ft^2 – more than three times the ISO-2 conductivity.*
   b) *Both ISO-1 and ISO-2 test datasets indicate significant positive wellbore skin factors (Sw), suggesting that the aquifer near the wellbore is partially plugged, probably due to drilling mud infiltration.*
   c) *This comes of no surprise, since mud invasion during drilling operations has been a major concern in both wells. The test results suggest that to increase well productivity both wells should be subjected to further well development in order to flush out whatever drilling mud was left behind in the formation near the wellbore.*
4) *The ISO-2 injection data indicate that the well had developed during the February-March 2013 injection tests, indicating that increased productivity through further well development is feasible.*
5) *The low hydraulic conductivities measured in these wells seem to be contradicted by:*
   a) *Significant permeability expected for the zone of convection indicated by the isothermal temperature profile between 2000 and 3852 ft.*
   b) *Homogeneous chemical and isotope water composition in the ISO-wells and Kelley Hot Springs.*
   c) *This gives further support to the expectation that productivity and injectivity can be enhanced with more well development.*
6) *Given the uncertainty by how much further development will improve the drawdown response, with the currently available data productivity estimates by minimizing wellbore skin factors are tentative and need to be applied with caution:*
   a) *For Well ISO-1 pumping 160 gpm, the tentative estimated drawdown would be about 525 ft. Correspondingly injecting 160 gpm the tentative estimated wellhead pressure would be about 227 psi.*
   b) *For Well ISO-2 pumping 60 gpm the tentative estimated drawdown would be about 380 ft. Correspondingly when injecting 60 gpm the tentative estimated wellhead pressure would be about 165 psi.*

Introduction

The purpose of this report is to evaluate the productivity and feasibility of geothermal fluid injection at two geothermal wells located in Canby, Modoc County, California (Wells ISO-1 and ISO-2). While the data analysis for ISO-2 is detailed herein, the ISO-1 injection feasibility is based on a review of the productivity analysis conducted in 2000 (Bohm, 2000).

Well construction

ISO-1 construction

ISO-1 was drilled in 2000 to a depth of 2100 ft, producing from fractured cemented fine-grained tuffs of the Alturas Formation, in the interval below 1900 ft, though most production is probably from a fracture zone around 2050 ft depth. The well is cased to 1600 ft (cemented). The six inch open borehole from 1600 to 2100 ft is secured with a four inch liner with a 200 ft perforated section from 1900 to 2100 ft. For the purpose of this data analysis an aquifer thickness of b = 200 ft is assumed.

ISO-2 construction

Well ISO-2 was drilled in 2011 to a depth of 3852 ft. The well is cased from surface to 3280 ft. 13.375 inch diameter casing was set from surface to 1400', and a 9.625" liner was hung inside the 13.375" casing from 1400' to 3300 ft. The casing shoe at 3300 ft has a bottom cap with a 1 1/2 inch valve opening. It is not clear whether this is open or not (Mark McWatters, Hydro Resources, 11/12/2012, pers. communic.). Since the stabilized temperature log could not go deeper than 3280 ft it is possible that the valve is closed. In other words the lowermost 570 ft of this well (the formation from 3280 to 3850 ft) may be accessible for well production only through the annulus between casing and borehole (if at all).

a) The un-equilibrated temperature log (14.5 hours after mud circulation ended) indicates a gradual temperature increase with depth. Below 3600' the temperature profile changed to isothermal at about 170° F, down to the total depth of 3852'. The most pronounced temperature reversals at 2534'-2617' and 3780'-3852', and maybe other slight temperature inflections near 3030' and 3380' are interpreted as indications of significant permeability.
b) The equilibrated temperature log indicates a gradual temperature increase with depth reaching about 93^{o} C at 2100 ft, from whereon it remains essentially isothermal attaining a maximum temperature of 97^{o} C at 3300 ft. The isothermal temperature gradient indicates that the formations below about 2100 ft act as an aquifer.
c) The most pertinent zones of possible warm water entry identified by the wireline logs are at 2494'-2644', 2846'-2960', and at 3018'-3044' (LaFleur and Krahmer, 2011).

Looking at these data the situation allows for three possible values of aquifer thickness “b”:

1) Zones of temperature reversals, 2534'-2617' and 3780'-3852', b = 155 ft. (minimum).
2) Including only the zones of warm water entry (2494'-2644', 2846'-2960', 3018'-3044'), b = 290 ft.
3) A more conservative (but less likely) estimate is b = 3044 - 2494 = 550 at least.
4) The least likely: b = 3300 - 2494 = 806 ft (maximum)

For the purpose of this analysis a minimum “aquifer thickness” of b = 155 ft is assumed (our best estimate).

The aquifer parameter estimates and the subsequent productivity estimates depend on the hydraulic conductivity estimate, K, which is based on the transmissivity T (based on the slope of the late test data plotted on a semi-log plot) and the assumed aquifer thickness b.

Well development in ISO-2

Suspecting mud invasion into the formation near the wellbore, the well was developed on August 6, 2011 by airlift surging from 1100 ft depth for about 10 hours (Bohm, 2012a). Given the significant amounts of turbidity observed in the discharge it appears that at least some drilling mud was flushed from the formation. However, the discharge never cleared completely of turbidity since only about 1 ½ well volumes were removed.

The ISO-2 pumping test results are not only disappointing but are also contradicted by other data. The isothermal temperature profile in the 2000 to 3852 ft interval indicates a zone of convection, which implies significant permeability. Also the close similarity of geothermal water chemistry and stable isotope composition in the ISO-wells and the Kelley Hot Springs (located about 2 miles NE of Canby) are an indication of significant flow which would not be compatible with low permeability formations indicated by the test data.

These observations substantiate what is indicated in the significant wellbore skin factors, i.e. the formation near the wellbore is still partially plugged due to drilling mud invasion.

The ISO-2 injection test data suggest that the well already has developed somewhat, indicating that increased productivity through further development is feasible in both wells.

Constant discharge pumping test setup at ISO-2

The test pump was installed 300 ft below TOC. The wellhead discharge line was equipped with a totalizing flowmeter, a gatevalve to control flow and a sampling spigot. Water levels were measured with a 400 ft electric well sounder. Discharge rates were calculated from flow volumes read on the totalizing flow meter. Data were collected by ISOT personnel (Dale Merrick and Don Deardorf) under directives from the author of this report.

Discharge was dumped into the sump (mudpit) located about 150 ft west of well ISO-2. The well was pumped at a 13 gpm average constant rate for 8 days; with a maximum drawdown of 289.55 ft. Due to cooling in the wellbore discharge temperature did not exceed 162 F. The 31.9 ft below TOC water level at the beginning of the test was about 12 ft below the 19 ft static WL since the well had not fully recovered after pumping for an unknown duration and rate before the test.

Data analysis

ISO-2 pumping test data

The field data were entered into an MS-Excel spreadsheet to calculate time of pumping in minutes, and drawdown in ft. The average pumping rate was estimated from the totalizing flowmeter data.

The test data were then analyzed with the AQTESOLV software package (HydroSOLVE, 2002). The first step was to estimate the aquifer transmissivity (a.k.a. “permeability-thickness product”) by approximating the slope of the straight-line section in the semi-log plot, applying the Cooper-Jacob model (Attachment A). Thereby a transmissivity of T = 238 gpd/ft (gallons per day per ft) was estimated.

After careful review of the drilling records (LaFleur and Krahmer, 2011) it was decided that the most likely value for “aquifer thickness” is b = 155 ft. Thereby a hydraulic conductivity of K = T/b = 1.54 gpd/ft^2 was estimated, which was applied in the type-curve match.

Without observation well data the storativity cannot be estimated.

ISO-1 pumping test data

Based on the same methodology the transmissivity at well ISO-1 was estimated at T = 920 gpd/ft (semi-log plot). Assuming b=200 ft, K = 4.6 gpd/ft which is probably conservative since production is apparently from a single fracture zone. By comparison the ISO-2 hydraulic conductivity is less than 1/3 of that. This variability in ‘hydraulic conductivity’ estimates in fractured rocks depends on number and size of fractures intersected by each well.

Wellbore storage and linear flow

Radial and linear flow plots are shown in Attachment A.

The ISO-1 early data are not suited to determine wellbore storage and linear flow to a single fracture. If any, wellbore storage effects and linear flow to a single fracture zone in ISO-2 may have occurred in the first ten minutes of the test. Thereafter the drawdown pattern changed into a radial flow response that was.

Type curve matches

Given the fractured nature of the aquifer the shape of the data plot and the derivative plot was interpreted as indicative of an isotropic single or dual porosity system. The dual porosity model of Barker (1988) was applied, which is a generalized radial flow model for unsteady flow to a fully penetrating well with finite radius (rw), in an isotropic, single- or double-porosity fractured aquifer, with storage capacity (b) and skin factor (Sw). The estimated parameters are:

- K (fracture hydraulic conductivity)
- Ss (fracture specific storage)
- K' (matrix hydraulic conductivity)
- Ss' (matrix specific storage)
- n (flow dimension)
- b (extent of flow region)
- Sf (fracture skin factor)
- Sw (wellbore skin factor)
- r(w) (well radius)
- r(c) (nominal casing radius)

Type curve matches for both wells are shown in Attachment B, including drawdown data as ‘squares’ and the derivative plots as ‘triangles’.

It should be noted that it was not possible to fit the early pumping drawdown data to the type curves since the wellbore was warming up from 89 to 162 F. Something similar happened during the late recovery phase when the wellbore was cooling off after eight days of pumping.

Wellbore skin

Both ISO-1 and ISO-2 datasets indicate significant positive wellbore skin factors suggesting a zone of decreased hydraulic conductivity near the wellbore:

a. Positive skin indicates the aquifer near the wellbore is damaged, by mud infiltration, plugging of screen openings by coarse grains, mineral precipitation, or improper screen size.
b. Negative skin indicates enhanced permeability adjacent to the wellbore, due to natural fractures or well development.

Significant positive skin in these data comes of no surprise, since mud invasion during drilling operations has been a major concern in both wells. The effect of diminished wellbore skin was estimated by changing Sw in the curve fits to zero. Thereby maximum drawdown in the test data diminishes from 134 to about 60 ft in ISO-1, and from 290 to about 160 ft in ISO-2.

Based on the changes seen in the ISO-2 injection data, it is expected that the drawdown response to pumping in both wells would be diminished significantly by more well development.

ISO-2 injection tests

Between February 16 and March 25, 2013 a series of short injection tests (“pulses”) were conducted on ISO-2. The variable test durations and injection rates are shown in Table 1 below.

The specific capacity ratio Q/s in the last column on the right can be used as a subjective measure of the well’s injectivity. Although it depends on duration of injection (decreasing with time), an improvement of injectivity is definitely noticeable when comparing tests of similar duration (for example between Test 1 and Tests 4 & 5, and between Test 1 and Tests 7 & 8).

The injection data are not suited for a type curve match. Instead, using the injection rates, the sequence of injection events was simulated with AQTSolv based on the parameters derived from the earlier pumping test data analysis (see Attachment C). This was compared with measured injection wellhead pressures (see Attachment B). As can be seen, the blue curve (simulated pressure) does not match the pressure data. The simulated data (blue curve) were matched with the late stage injection data by decreasing the well skin factor Sw. Thereby it turns out that the early pressures are too high for an adequate match. Evidently the pressure response to injection has improved.

The negative skin factor can be interpreted as an indication of enhanced permeability due to opening up of natural fractures, formerly plugged by drilling mud. However, that could change the aquifer parameters, which can only be determined with another constant rate test.

A similar improvement is expected to occur in ISO-1 if it was subjected to further development.

It was not possible to match the results of the Rig Injection Test conducted in September 2011 (Geothermal Science, 2011) with our well-flow model. The reason maybe that the pre-test static water level is not known.

	Table 1 - Injection Tests, Well ISO-2 - February/March 2013.					
Test #	**Date**	**Test Duration, min**	**Volume injected, gal**	**Average injection rate Q, gpm**	**Maximum wellhead pressure build-up, s, psi**	**Q/s**
Test #1	2/16/2013	257	9478	38	149	0.25
Test #2	2/17/2013	356	14530	41	141	0.29
Test #3	2/17/2013	130	5855	45	144	0.31
Test #4	2/18/2013	240	10029	42	138	0.30
Test #5	2/19/2013	378	12901	34	120	0.28
Test #6	2/20/2013	911	24961	27	126	0.22
Test #7	2/25/2013	105	7297	70	124	0.56
Test #8	3/9/2013	23	3550	154	150	1.03
Test #9	3/9/2013	23	3655	159	151	1.05
Test #10	3/25/2013	120	10716	89	103	0.87

Well productivity estimates

Under the current conditions it is difficult to come to conclusive well productivity estimates. The ISO-1 pumping test data were collected more than ten years ago, and the well could have developed through that period of production. Evidently in ISO-2 things have changed since the constant discharge test, apparently for the better, and it is possible that the aquifer parameters have changed. To obtain 'updated' aquifer parameter values the wells need to be subjected to controlled constant discharge or injection tests, preferably after further well development.

Nevertheless, one can make some tentative productivity estimates with the currently available aquifer parameters. These estimates, however, are deemed conservative, in anticipation of productivity improvements due to further well development.

Tentative forward projections plots are shown in Attachment D. Projections are based on pumping each well continuously. Anticipating a demand for about 220 gpm, 160 and 60 gpm pumping rates for ISO-1 and ISO-2 were assumed.

1. With ISO-1 pumping 160 gpm, long term estimated drawdown would be about 525 ft. Correspondingly under an injection scenario of 160 gpm the long term estimated wellhead pressure would be about 227 psi.
2. For Well ISO-2 pumping 60 gpm long term estimated drawdown would be about 380 ft. Correspondingly under an injection scenario of 60 gpm the long term estimated wellhead pressure would be about 165 psi.

Depending on how the pumping or injection rates are divided up between the two wells, drawdown values are significant. As has been pointed out before (e.g. Juncal and Bohm, 1988), these are low permeability formations where wells require unusually deep pump chambers to accommodate significant drawdown. Production records indicate that drawdown as much as 480 ft is not uncommon in ISO-1. By comparison, production drawdown exceeding 270 ft is not uncommon in Alturas well AL-1 (PGH, 1992). Short term injection rates exceeding 200 gpm at about 140 psi have been observed during testing at ISO-2.

Well Interference

Hydraulic conductivity is the most important parameter that determines the magnitude of interference between two pumping (and injecting) wells. However, since well productivity in these aquifer formations is so much dependent on proximity to fracture zones (faults), it remains questionable if the wells will interfere with each other at all. These two wells are not located on the same fracture zone (see fault map in Bohm 2012b). Well ISO-1 is located on a NNW striking fault. ISO-2 is apparently not located on any fault; however, it is separated from ISO-1 by a NNW striking fault, about 200 ft SW of ISO-2.

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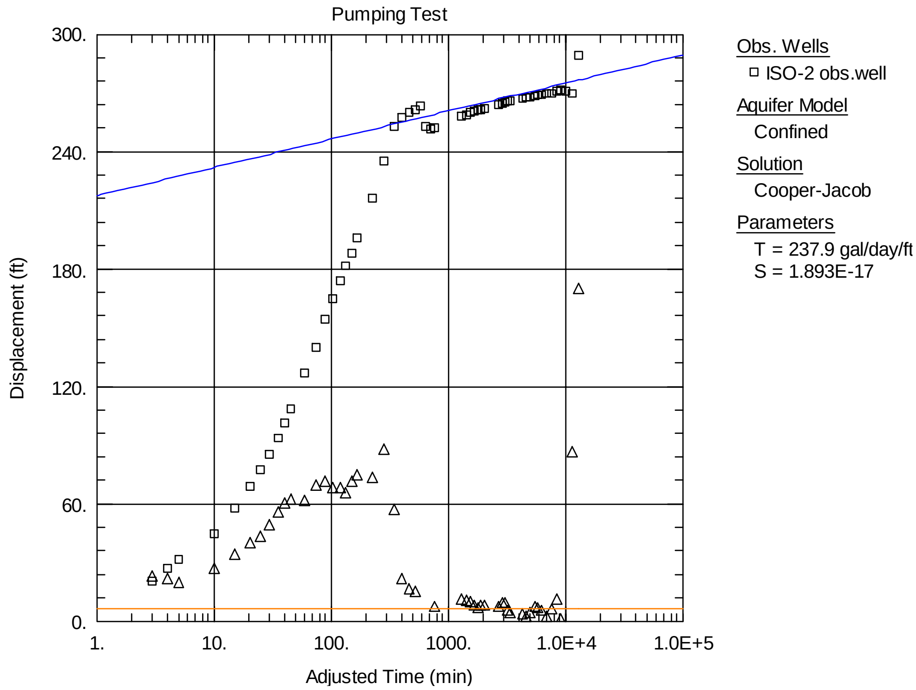
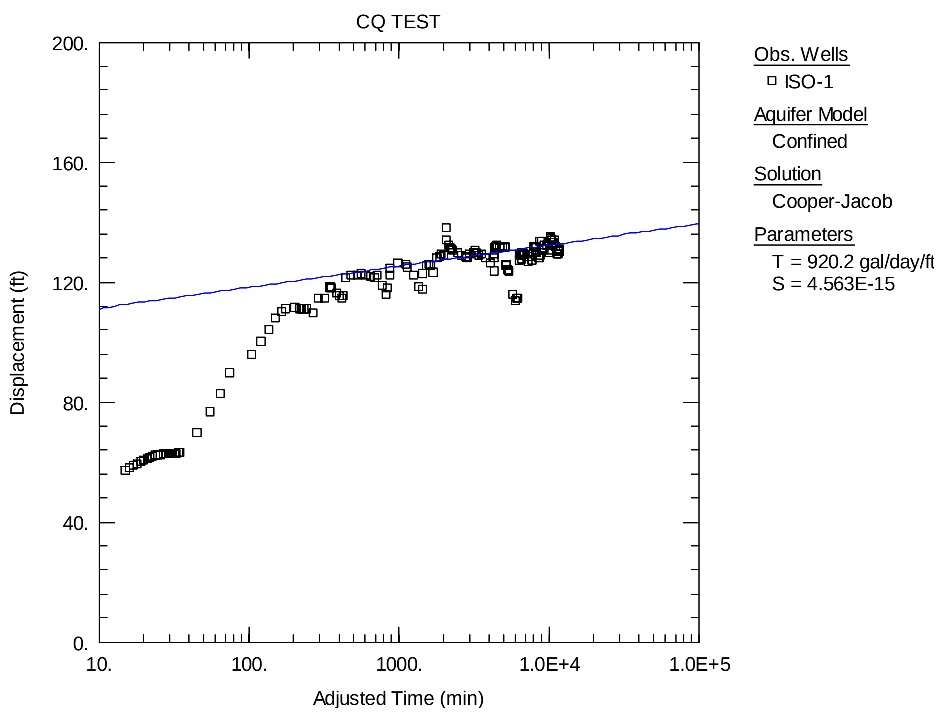
Attachment A: Transmissivity and wellbore storage

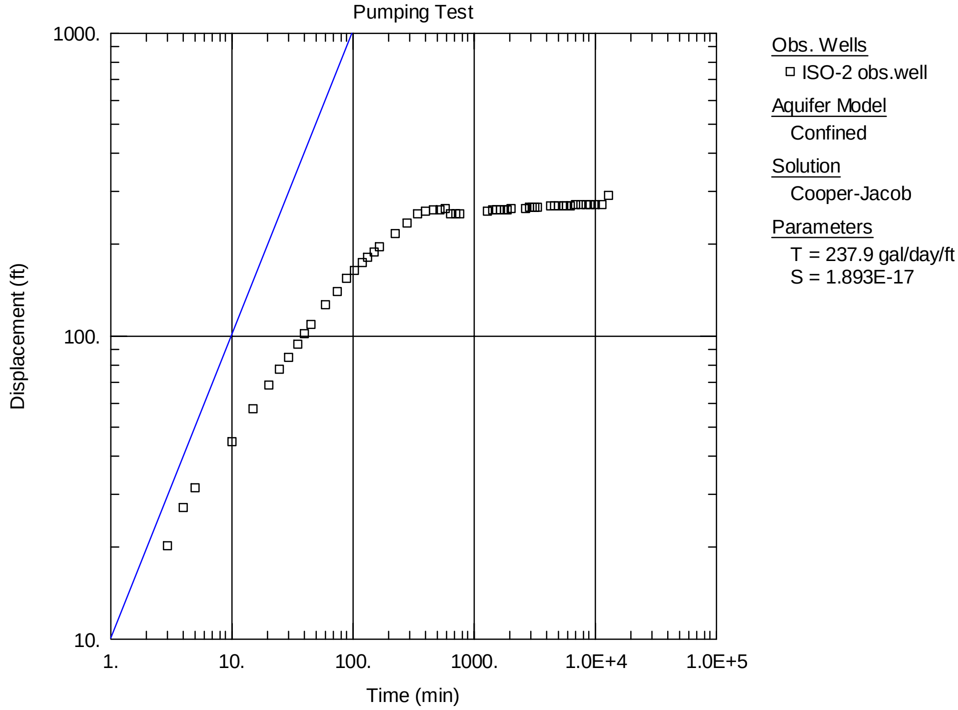


ISO-2: T = 238 gpd/ft, assuming b = 290 ft, then K = .802 gpd/ft

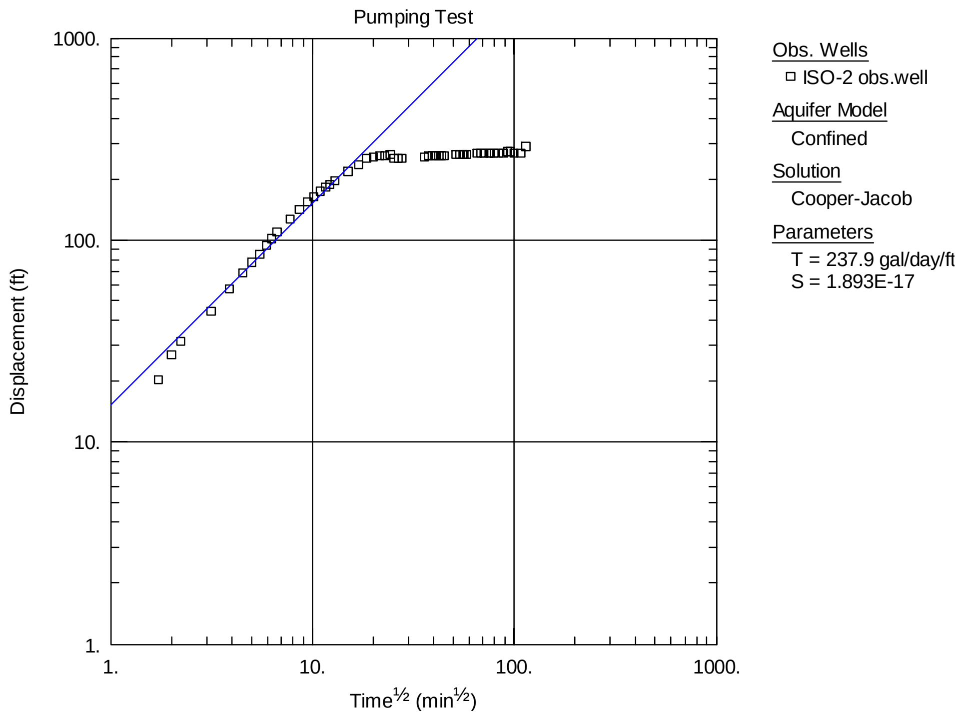
Compare ISO-1: T = 920 gpd/ft, assuming b = 200 ft, then K = 920/200 = 4.6 gpd/ft.



Well ISO-2, wellbore storage: not visible in these data



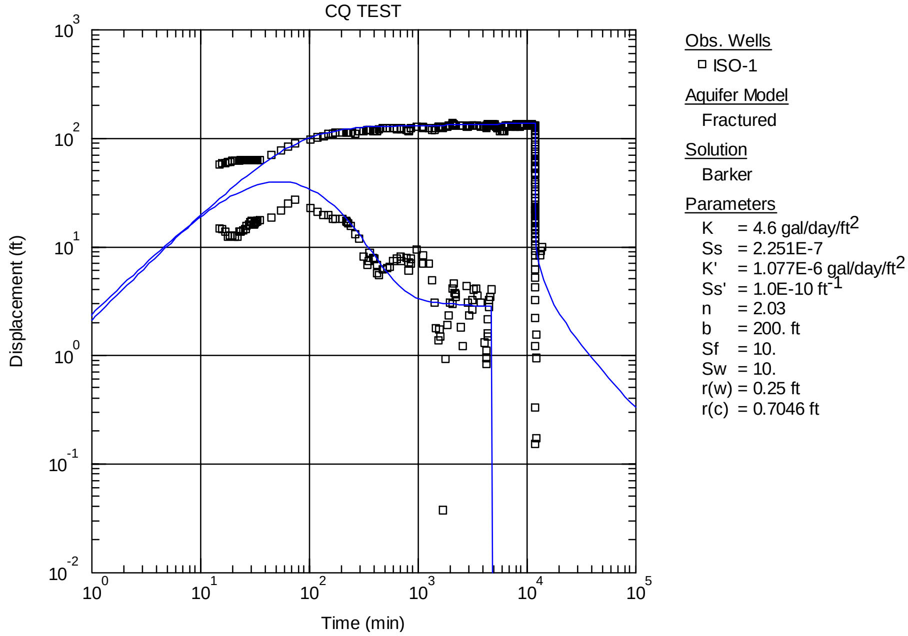
Well ISO-2, linear flow: maybe noticeable in the first ten minutes



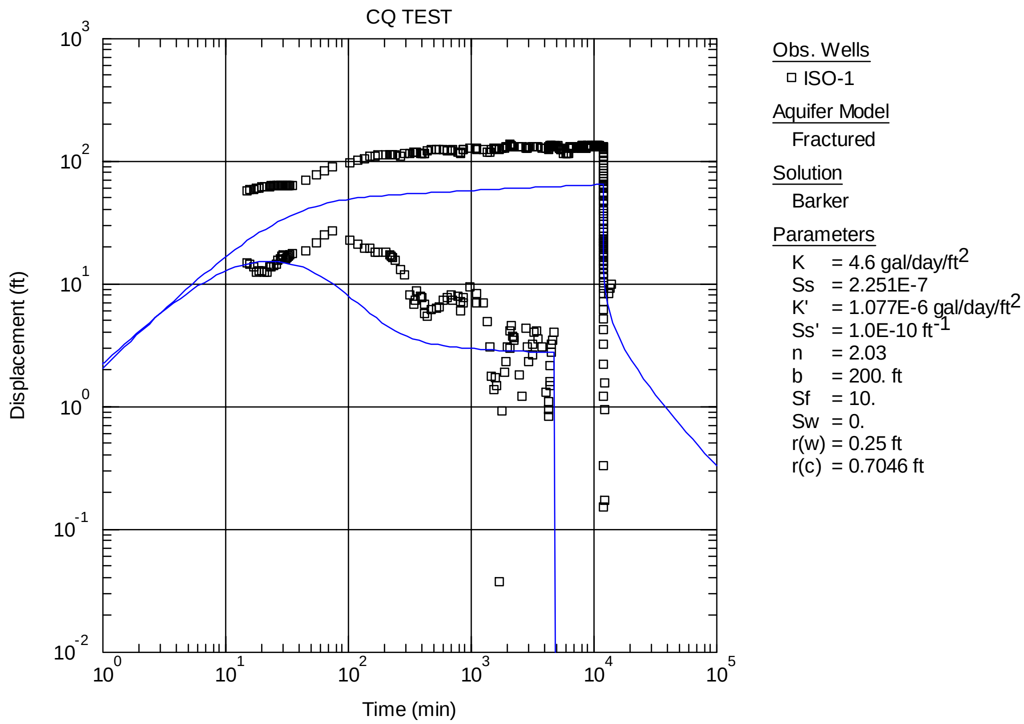
Attachment B: Type curve matches

Curve matches for ISO-1 test data, pumping 24 gpm:

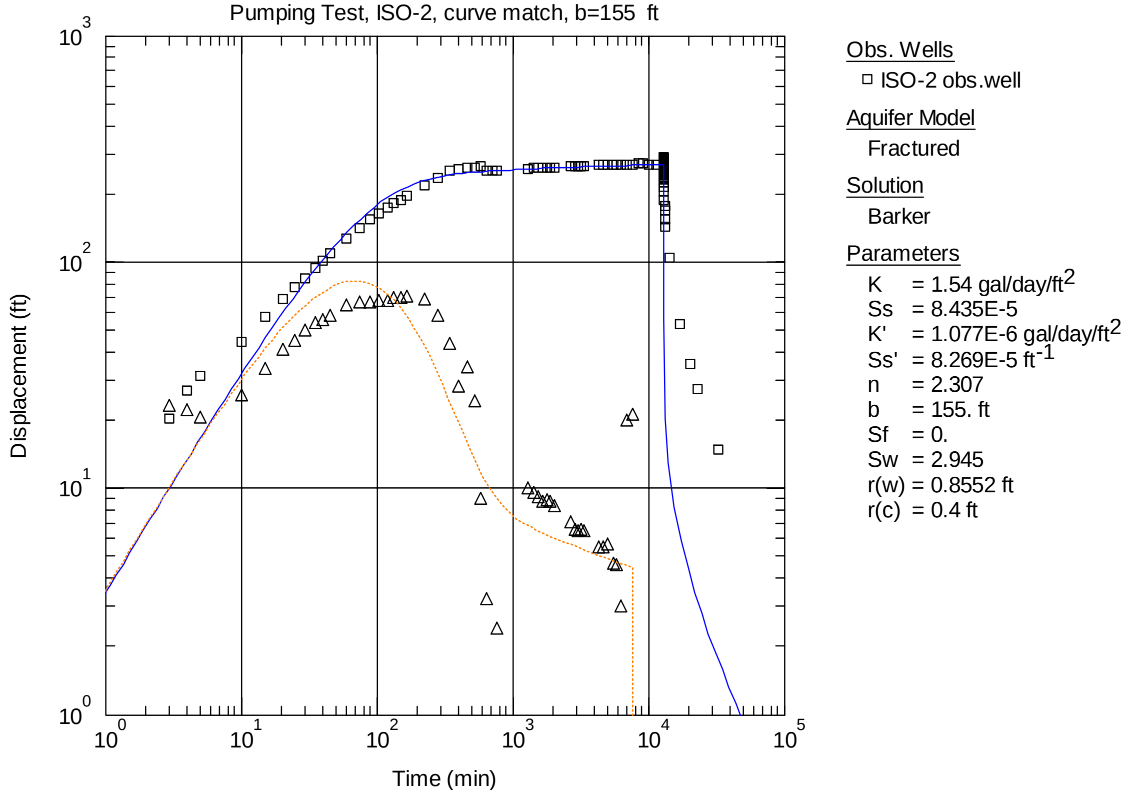
Data were preferentially matched for late time pumping data, since this is pertinent for long term prediction of well performance. The type curve fit implies well skin factor Sw = 10.



Curve match for ISO-1 data, assuming zero well skin, at 24 gpm, testing:

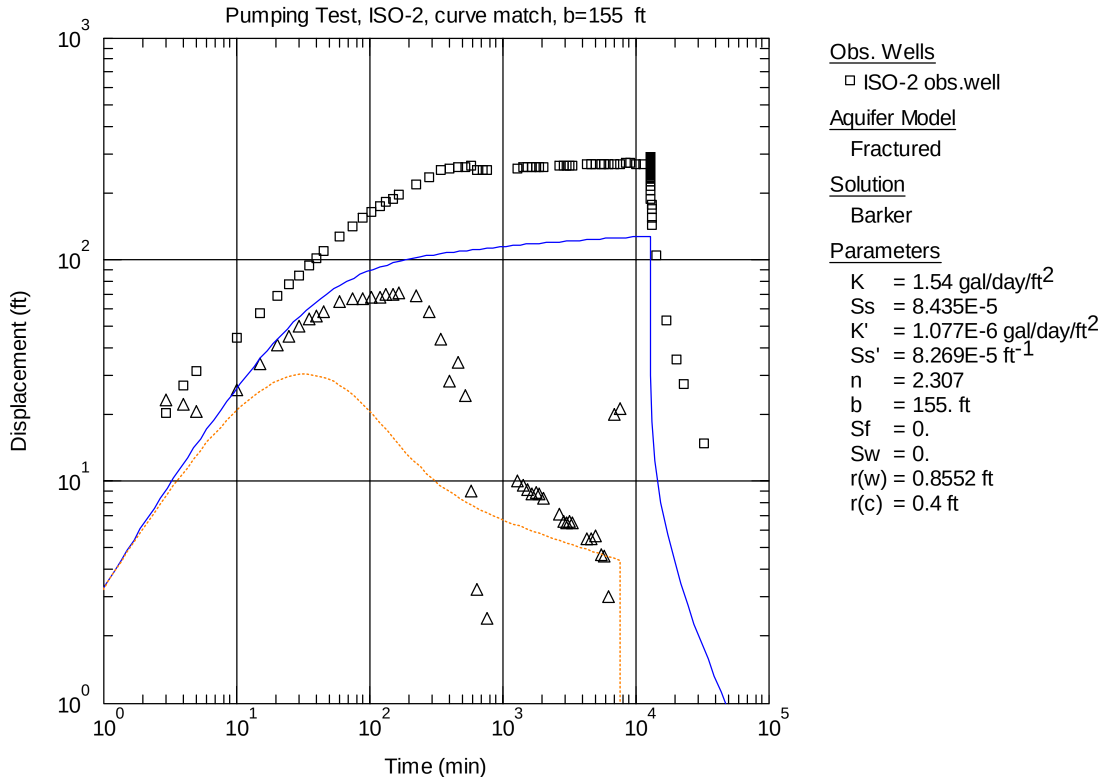


Curve matches for ISO-2 test data, pumping 13 gpm:

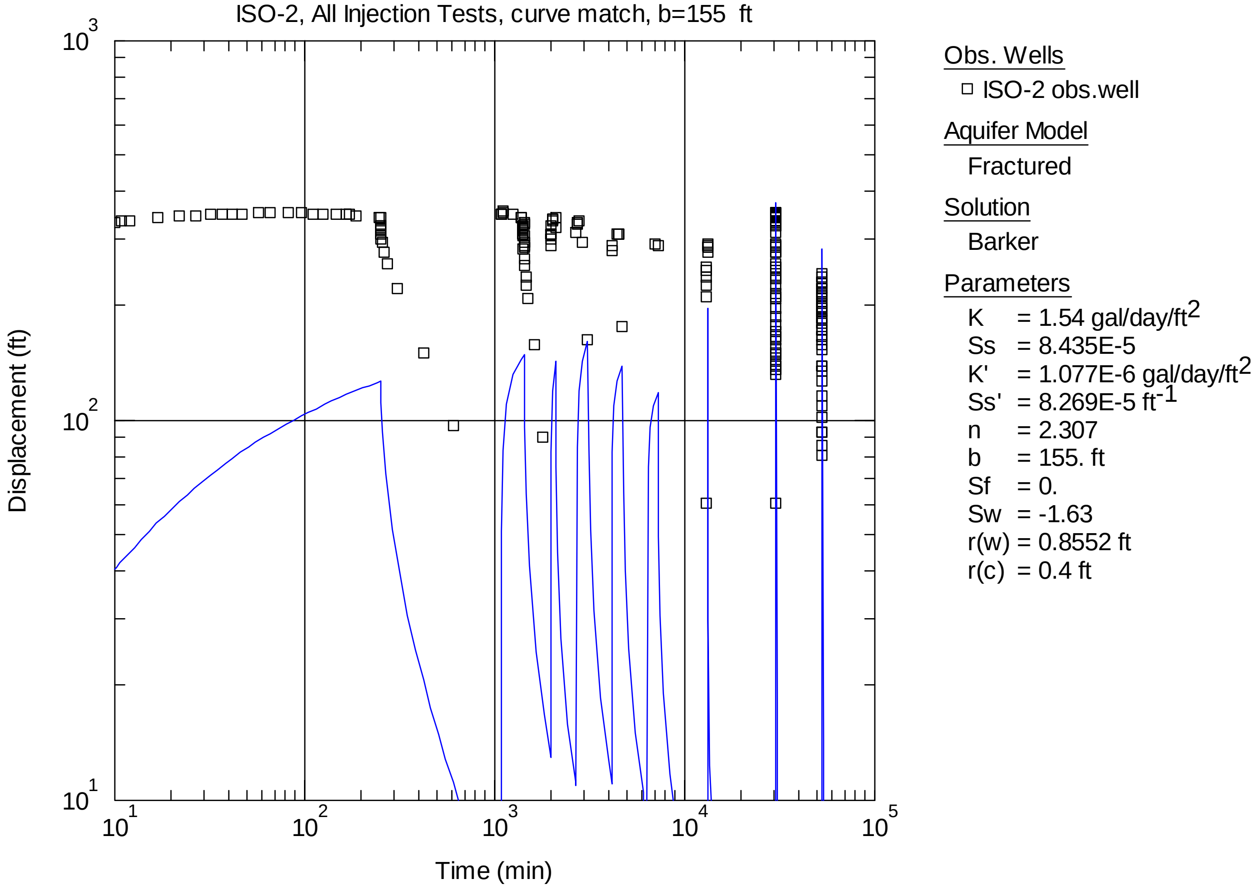


Well skin factor Sw = 2.945 indicates formation near wellbore is plugged.

Assuming zero well skin:



Attachment C: Injection tests

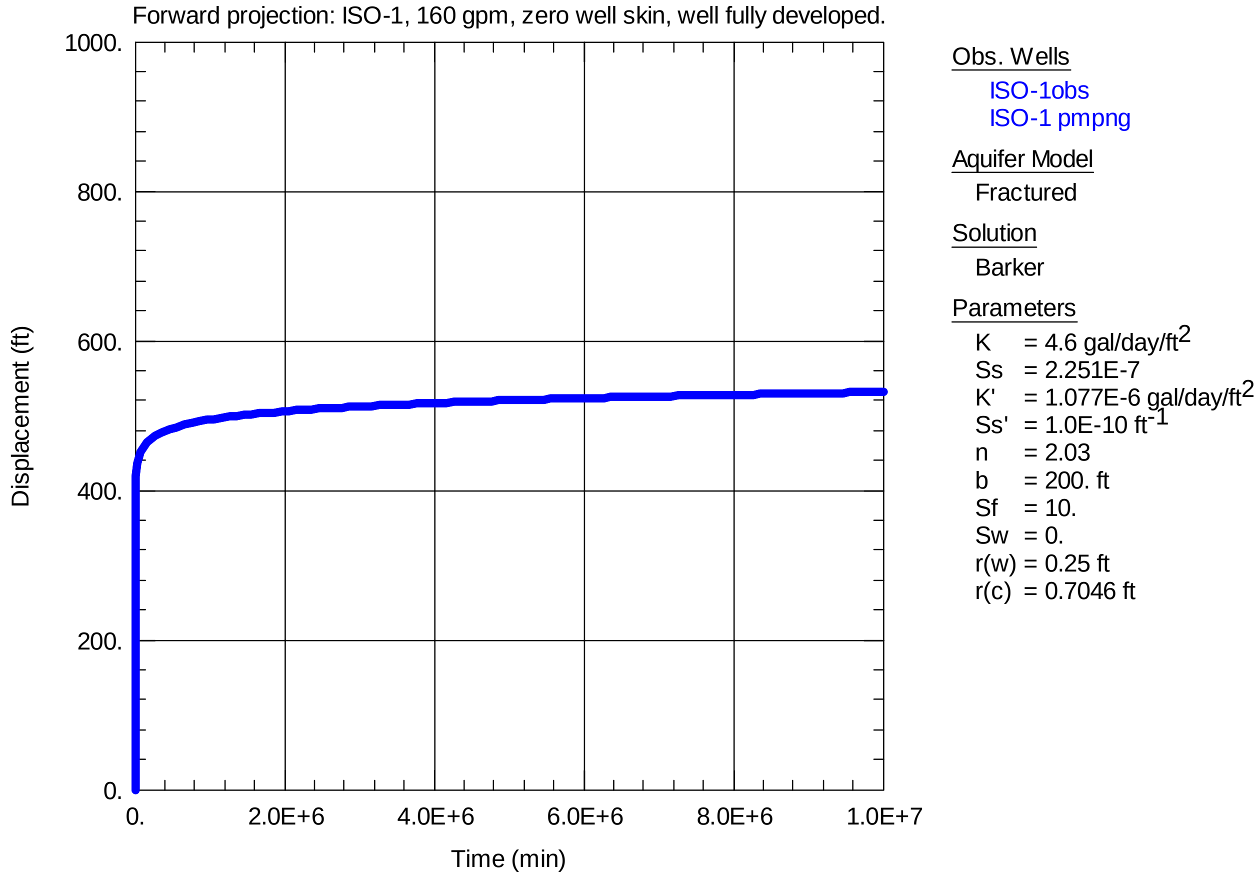


The type curve (blue) is a simulation of all injection pulses. Using the injection rates the pressure behavior was simulated, based on the aquifer parameters calculated from the preceding pumping test data.

The curve was fitted to the last three injection pulses, i.e. Tests 8 through 10 by “tweaking” (decreasing) the well skin factor Sw. Thereby the buildup in the first test is greater than predicted by the model. In other words, although in the first test the well performed less than predicted, significant development occurred during the following tests.

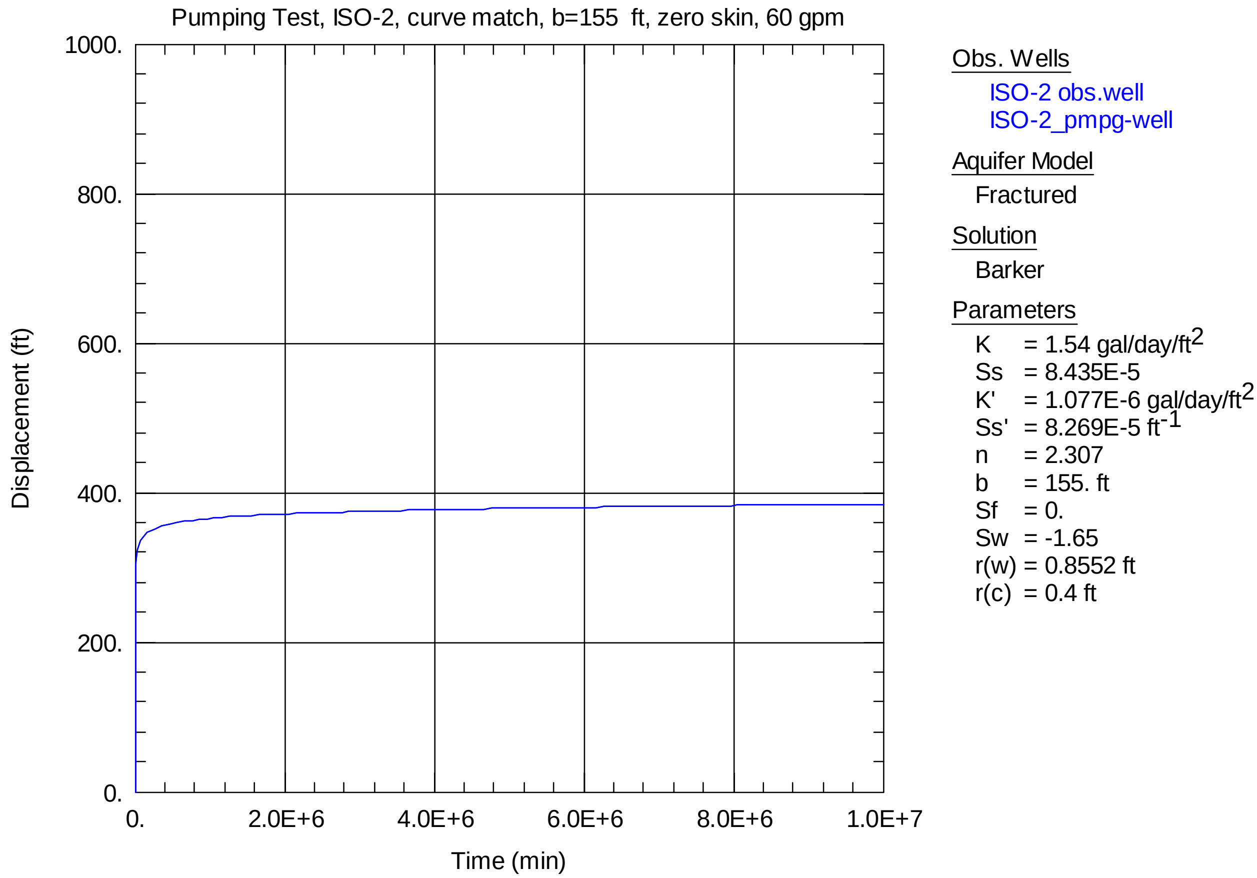
Attachment D: Well productivity estimates

Well ISO-1



Forward projection, Well ISO-1 pumping 160 gpm, assuming no well skin. Long term estimated drawdown is about 520 ft. Correspondingly under an injection scenario of 160 gpm the long term estimated wellhead pressure would be about 70 psi.

Well ISO-2:



Forward projection, Well ISO-2 pumping 60 gpm, assuming no well skin. Long term estimated drawdown is about 380 ft. Correspondingly under an injection scenario of 60 gpm the long term estimated wellhead pressure would be about 165 psi.

Attachment E: ISO-2 Pumping Test Data Table, 2 pages

CanbyGeo, LLC

Geothermal Well Pump Test, ISO-2

Pump Test Data Form

Well Number: ISO-2, SWL=19 ft, average pumping rate 12.7 gpm

Pump Level: 300 feet

Total Depth: 3852 feet

Casing Diameter: 13-3/8" inch x 9-5/8"

Pump test performed by Don Deardorff and Dale Merrick

Date	Time	time number	t (minutes)	t/t'	h (feet)	s (feet)	Q (gpm)	Total Gallons Pumped	Totalizer Reading	temperature, F	Comments
10/6/2012	9:15:00	41188.39	0.0		**31.9**	12.9	0	0			start
10/6/2012	9:18:00	41188.39	3.0		39.3	20.3					
10/6/2012	9:19:00	41188.39	4.0		46.0	27.0				89.3	
10/6/2012	9:20:00	41188.39	5.0		50.6	31.6		0			
10/6/2012	9:25:00	41188.39	10.0		63.6	44.6	0	0			
10/6/2012	9:30:00	41188.40	15.0		76.5	57.5	0	0		91.0	
10/6/2012	9:35:35	41188.40	20.6		87.8	68.8	0	0			
10/6/2012	9:40:00	41188.40	25.0		96.1	77.1	0	0		92.6	
10/6/2012	9:45:00	41188.41	30.0		104.1	85.1	0	0		93.3	
10/6/2012	9:50:00	41188.41	35.0		112.3	93.3	0	0		94.1	
10/6/2012	9:55:00	41188.41	40.0		120.1	101.1	0	0		95.0	
10/6/2012	10:00:00	41188.42	45.0		127.4	108.4	0	0		96.0	
10/6/2012	10:15:00	41188.43	60.0		145.6	126.6	0	0			
10/6/2012	10:30:00	41188.44	75.0		159.0	140.0	0	0		101.0	
10/6/2012	10:45:00	41188.45	90.0		173.1	154.1	0	0		104.0	
10/6/2012	11:00:00	41188.46	105.0		183.4	164.4	0	0		106.3	
10/6/2012	11:15:00	41188.47	120.0		192.7	173.7	0	0		108.8	
10/6/2012	11:30:00	41188.48	135.0		200.6	181.6	0	0		111.2	
10/6/2012	11:45:00	41188.49	150.0		207.4	188.4	0	0		113.4	
10/6/2012	12:00:00	41188.50	165.0		214.8	195.8	0	0		115.3	
10/6/2012	13:00:00	41188.54	225.0		235.3	216.3	0	0		124.5	
10/6/2012	14:00:00	41188.58	285.0		253.9	234.9	0	0		131.2	
10/6/2012	15:00:00	41188.63	345.0		272.0	253.0	0	0		137.4	
10/6/2012	16:00:00	41188.67	405.0		276.1	257.1	0	0		142.2	
10/6/2012	17:00:00	41188.71	465.0		278.6	259.6	-	15,856	15,856	145.4	
10/6/2012	18:00:00	41188.75	525.0		280.4	261.4	21.73	17,160	17,160	147.5	
10/6/2012	19:00:00	41188.79	585.0		282.1	263.1	11.08	17,825	17,825	149.5	
10/6/2012	20:00:00	41188.83	645.0		271.9	252.9	17.75	18,890	18,890	150.0	
10/6/2012	21:00:00	41188.88	705.0		270.4	251.4	17.33	19,930	19,930	150.0	
10/6/2012	22:00:00	41188.92	765.0		270.9	251.9	16.33	20,910	20,910	151.5	
10/7/2012	7:01:00	41189.29	1,306.0		276.9	257.9	21.33	29,892	29,892	154.0	
10/7/2012	9:00:00	41189.38	1,425.0		277.9	258.9	16.05	31,818	31,818	154.6	
10/7/2012	11:00:00	41189.46	1,545.0		278.7	259.7	15.53	33,681	33,681	155.8	
10/7/2012	13:00:00	41189.54	1,665.0		279.5	260.5	15.07	35,489	35,489	156.0	
10/7/2012	15:00:00	41189.63	1,785.0		279.9	260.9	14.78	37,263	37,263	156.5	
10/7/2012	17:00:00	41189.71	1,905.0		280.4	261.4	14.57	39,011	39,011	157.0	
10/7/2012	19:00:00	41189.79	2,025.0		280.9	261.9	14.52	40,753	40,753	157.0	
10/8/2012	6:00:00	41190.25	2,685.0		282.9	263.9	13.62	49,745	49,745	157.3	
10/8/2012	9:00:00	41190.38	2,865.0		283.4	264.4	13.81	52,230	52,230	157.8	
10/8/2012	12:00:00	41190.50	3,045.0		284.1	265.1	14.44	54,830	54,830	158.4	
10/8/2012	15:00:00	41190.63	3,225.0		284.5	265.5	14.59	57,457	57,457	158.5	
10/8/2012	18:00:00	41190.75	3,405.0		284.7	265.7	14.49	60,066	60,066	158.5	
10/9/2012	9:00:00	41191.38	4,305.0		286.3	267.3	12.63	71,429	71,429	159.0	
10/9/2012	15:00:00	41191.63	4,665.0		286.5	267.5	13.71	76,363	76,363	159.5	
10/9/2012	21:00:00	41191.88	5,025.0		286.7	267.7	12.56	80,132	80,132	159.6	
10/10/2012	6:00:00	41192.25	5,565.0		287.4	268.4	12.78	87,799	87,799	159.6	
10/10/2012	11:00:00	41192.46	5,865.0		287.8	268.8	11.33	91,198	91,198	160.0	
10/10/2012	19:00:00	41192.79	6,345.0		288.3	269.3	11.46	96,700	96,700	160.0	
10/11/2012	6:00:00	41193.25	7,005.0		288.8	269.8	13.30	104,677	104,677	160.0	
10/11/2012	18:00:00	41193.75	7,725.0		288.8	269.8	12.20	113,463	113,463	162.0	
10/12/2012	6:00:00	41194.25	8,445.0		289.8	270.8	11.41	121,675	121,675	162.0	
10/12/12	18:00:00	41194.75	9,165.0		*290.7*	271.7	11.78	130,155	130,155	160.0	
10/13/2012	9:00:00	41195.38	10,065.0		289.7	270.7	11.54	140,542	140,542	160.0	
10/14/2012	9:00:00	41196.38	11,505.0		288.5	269.5	10.73	155,998	155,998	160.8	
10/15/2012	9:00:00	41197.375	12,945.0		308.55	289.6	12.47	173,952	173,952	162.0	

Date	Time	time number	t (minutes)	t/t'	h (feet)	s (feet)	Q (gpm)	Total Gallons Pumped	Totalizer Reading	temperature, F	Comments
10/15/2012	9:00:30	41197.375	12,945.5	25,891.00	307.75	288.8					
10/15/2012	9:01:00	41197.376	12,946.0	12,946.00	306.70	287.7					
10/15/2012	9:01:30	41197.38	12,946.5	8,631.00	305.70	286.7					
10/15/2012	9:02:00	41197.38	12,947.0	6,473.50	304.70	285.7					
10/15/2012	9:02:30	41197.38	12,947.5	5,179.00	303.70	284.7					
10/15/2012	9:03:00	41197.38	12,948.0	4,316.00	302.70	283.7					
10/15/2012	9:03:30	41197.38	12,948.5	3,699.57	301.75	282.8					
10/15/2012	9:04:00	41197.38	12,949.0	3,237.25	300.90	281.9					
10/15/2012	9:04:30	41197.38	12,949.5	2,877.67	299.90	280.9					
10/15/2012	9:05:00	41197.38	12,950.0	2,590.00	299.00	280.0					
10/15/2012	9:05:30	41197.38	12,950.5	2,354.64	298.20	279.2					
10/15/2012	9:06:00	41197.38	12,951.0	2,158.50	297.30	278.3					
10/15/2012	9:06:30	41197.38	12,951.5	1,992.54	296.45	277.5					
10/15/2012	9:07:00	41197.38	12,952.0	1,850.29	295.60	276.6					
10/15/2012	9:07:30	41197.38	12,952.5	1,727.00	294.75	275.8					
10/15/2012	9:08:00	41197.38	12,953.0	1,619.13	293.95	275.0					
10/15/2012	9:08:30	41197.38	12,953.5	1,523.94	293.20	274.2					
10/15/2012	9:09:00	41197.38	12,954.0	1,439.33	292.35	273.4					
10/15/2012	9:09:30	41197.38	12,954.5	1,363.63	291.60	272.6					
10/15/2012	9:10:00	41197.38	12,955.0	1,295.50	290.85	271.9					
10/15/2012	9:11:00	41197.38	12,956.0	1,177.82	289.30	270.3					
10/15/2012	9:12:00	41197.38	12,957.0	1,079.75	287.90	268.9					
10/15/2012	9:13:00	41197.38	12,958.0	996.77	286.60	267.6					
10/15/2012	9:14:00	41197.38	12,959.0	925.64	285.25	266.3					
10/15/2012	9:15:00	41197.39	12,960.0	864.00	283.95	265.0					
10/15/2012	9:16:00	41197.39	12,961.0	810.06	282.70	263.7					
10/15/2012	9:17:00	41197.39	12,962.0	762.47	281.50	262.5					
10/15/2012	9:18:00	41197.39	12,963.0	720.17	280.30	261.3					
10/15/2012	9:19:00	41197.39	12,964.0	682.32	279.10	260.1					
10/15/2012	9:20:00	41197.39	12,965.0	648.25	278.00	259.0					
10/15/2012	9:22:00	41197.39	12,967.0	589.41	275.85	256.9					
10/15/2012	9:24:00	41197.39	12,969.0	540.38	273.85	254.9					
10/15/2012	9:26:00	41197.39	12,971.0	498.88	271.90	252.9					
10/15/2012	9:28:00	41197.39	12,973.0	463.32	270.05	251.1					
10/15/2012	9:30:00	41197.40	12,975.0	432.50	268.30	249.3					
10/15/2012	9:32:30	41197.40	12,977.5	399.31	266.20	247.2					
10/15/2012	9:35:00	41197.40	12,980.0	370.86	264.10	245.1					
10/15/2012	9:37:30	41197.40	12,982.5	346.20	262.20	243.2					
10/15/2012	9:40:00	41197.40	12,985.0	324.63	260.40	241.4					
10/15/2012	9:45:00	41197.41	12,990.0	288.67	257.00	238.0					
10/15/2012	9:50:00	41197.41	12,995.0	259.90	253.70	234.7					
10/15/2012	9:55:00	41197.41	13,000.0	236.36	250.30	231.3					
10/15/2012	10:00:00	41197.42	13,005.0	216.75	248.80	229.8					
10/15/2012	10:10:00	41197.42	13,015.0	185.93	242.60	223.6					
10/15/2012	10:30:00	41197.44	13,035.0	144.83	233.80	214.8					
10/15/2012	11:00:00	41197.46	13,065.0	108.88	223.30	204.3					
10/15/2012	12:00:00	41197.50	13,125.0	72.92	207.60	188.6					
10/15/2012	13:00:00	41197.54	13,185.0	54.94	196.10	177.1					
10/15/2012	14:00:00	41197.58	13,245.0	44.15	186.95	168.0					
10/15/2012	16:00:00	41197.67	13,365.0	31.82	172.80	153.8					
10/15/12	18:00:00	41197.75	13,485.0	24.97	162.15	143.2					
10/16/2012	6:00:00	41198.25	14,205.0	11.27	123.65	104.7					
10/18/2012	10:00:00	41200.42	17,325.0	3.96	72.18	53.2					
10/20/2012	17:00:00	41202.70833	20,625.0	2.69	54.40	35.4					
10/22/2012	13:30:00	41204.56	23,295.0	2.25	46.60	27.6					
10/29/2012	9:00:00	41211.38	33,105.0	1.64	33.90	14.9					

Attachment F: ISO-2 Injection Test Data Table, 6 pages

CanbyGeo, LLC
Geothermal Well Injection Test
Injection Test Data Form
Well Number: ISO-2

Total Depth: 3852 feet
Casing Diameter: 13-3/8" inch x 9-5/8"
Pump test performed by Don Deardorff, David Pacy and Dale Merrick

Date	Time	time#	t minutes	Totalizer Reading	Total Volume	gpm, calcul.	psi
Test #1							
2/16/2013	8:53:00	41321.37014	0.00	0	0		0
2/16/2013	9:00:00	41321.37500	7.00	96	96		
2/16/2013	9:03:00	41321.37708	10.00	361	361	88	143
2/16/2013	9:04:00	41321.37778	11.00	416	416	55	144
2/16/2013	9:05:00	41321.37847	12.00	459	459	43	145
2/16/2013	9:10:00	41321.38194	17.00	690	690	46	148
2/16/2013	9:15:00	41321.38542	22.00	907	907	43	149
2/16/2013	9:20:00	41321.38889	27.00	1,114	1,114	41	149.5
2/16/2013	9:25:00	41321.39236	32.00	1,318	1,318	41	150
2/16/2013	9:30:00	41321.39583	37.00	1,520	1,520	40	150
2/16/2013	9:35:00	41321.39931	42.00	1,718	1,718	40	150
2/16/2013	9:40:00	41321.40278	47.00	1,918	1,918	40	150
2/16/2013	9:51:00	41321.41042	58.00	2,335	2,335	38	152
2/16/2013	10:00:00	41321.41667	67.00	2,660	2,660	36	152.5
2/16/2013	10:15:00	41321.42708	82.00	3,200	3,200	36	152
2/16/2013	10:30:00	41321.43750	97.00	3,734	3,734	36	152
2/16/2013	10:45:00	41321.44792	112.00	4,255	4,255	35	151
2/16/2013	11:00:00	41321.45833	127.00	4,775	4,775	35	151
2/16/2013	11:20:00	41321.47222	147.00	5,470	5,470	35	151
2/16/2013	11:40:00	41321.48611	167.00	6,237	6,237	38	150
2/16/2013	11:46:00	41321.49028	173.00	6,525	6,525	48	150
2/16/2013	12:00:00	41321.50000	187.00	7,010	7,010	35	149
2/16/2013	13:00:00	41321.54167	247.00	9,280	9,280	38	148
2/16/2013	13:05:00	41321.54514	252.00	9,478	9,478	40	148
2/16/2013	13:05:10	41321.54525	252.17	9,478	9,478	0	140
2/16/2013	13:05:20	41321.54537	252.33	9,478	9,478	0	140
2/16/2013	13:05:30	41321.54549	252.50	9,478	9,478	0	139
2/16/2013	13:05:40	41321.54560	252.67	9,478	9,478	0	138
2/16/2013	13:05:50	41321.54572	252.83	9,478	9,478	0	137
2/16/2013	13:06:00	41321.54583	253.00	9,478	9,478	0	136
2/16/2013	13:07:00	41321.54653	254.00	9,478	9,478	0	133
2/16/2013	13:08:00	41321.54722	255.00	9,478	9,478	0	130
2/16/2013	13:10:00	41321.54861	257.00	9,478	9,478	0	127
2/16/2013	13:16:00	41321.55278	263.00	9,478	9,478	0	120
2/16/2013	13:30:00	41321.56250	277.00	9,478	9,478	0	111
2/16/2013	14:00:00	41321.58333	307.00	9,478	9,478	0	96
2/16/2013	16:00:00	41321.66667	427.00	9,478	9,478	0	65
2/16/2013	19:00:00	41321.79167	607.00	9,478	9,478	0	42
Test #2							
2/17/2013	3:00:00	41322.12500	0.00	9,478	0		-
2/17/2013	3:11:00	41322.13264	11.00	10,000	522	47	150
2/17/2013	3:16:00	41322.13611	16.00	10,190	712	38	150
2/17/2013	3:20:00	41322.13889	20.00	10,350	872	40	152
2/17/2013	3:30:00	41322.14583	30.00	10,744	1,266	39	153
2/17/2013	6:00:00	41322.25000	180.00	16,280	6,802	37	150
2/17/2013	8:04:00	41322.33611	304.00	22,095	12,617	47	148
2/17/2013	8:08:00	41322.33889	308.00	22,188	12,710	23	148
2/17/2013	8:20:00	41322.34722	320.00	22,466	12,988	23	133
2/17/2013	8:30:00	41322.35417	330.00	22,551	13,073	8	122
2/17/2013	8:31:00	41322.35486	331.00	22,600	13,122	49	132
2/17/2013	8:32:00	41322.35556	332.00	22,663	13,185	63	134
2/17/2013	8:33:00	41322.35625	333.00	22,729	13,251	66	136
2/17/2013	8:34:00	41322.35694	334.00	22,790	13,312	61	137

2/17/2013	8:35:00	41322.35764	335.00	22,853	13,375	63	137.5
2/17/2013	8:36:00	41322.35833	336.00	22,914	13,436	61	138
2/17/2013	8:37:00	41322.35903	337.00	22,971	13,493	57	139
2/17/2013	8:38:00	41322.35972	338.00	23,029	13,551	58	139.5
2/17/2013	8:39:00	41322.36042	339.00	23,086	13,608	57	140
2/17/2013	8:40:00	41322.36111	340.00	23,144	13,666	58	140
2/17/2013	8:45:00	41322.36458	345.00	23,420	13,942	55	141
2/17/2013	8:50:00	41322.36806	350.00	23,690	14,212	54	142
2/17/2013	8:55:00	41322.37153	355.00	23,955	14,477	53	143
2/17/2013	8:56:00	41322.37222	356.00	24,008	14,530	53	
2/17/2013	8:57:00	41322.37292	357.00				132
2/17/2013	8:58:00	41322.37361	358.00				127
2/17/2013	8:59:00	41322.37431	359.00				125
2/17/2013	9:00:00	41322.37500	360.00				123
2/17/2013	9:05:00	41322.37847	365.00				115
2/17/2013	9:10:00	41322.38194	370.00				110
2/17/2013	9:20:00	41322.38889	380.00				103
2/17/2013	9:30:00	41322.39583	390.00				98
2/17/2013	10:00:00	41322.41667	420.00				90
2/17/2013	12:00:00	41322.50000	540.00				68
2/17/2013	15:00:00	41322.62500	720.00				39
Test #3							
2/17/2013	18:00:00	41322.75000	0.00	24,008	0		124
2/17/2013	18:07:00	41322.75486	7.00	24,265	257	37	130
2/17/2013	18:08:00	41322.75556	8.00	24,336	328	71	132
2/17/2013	18:09:00	41322.75625	9.00	24,405	397	69	133
2/17/2013	18:10:00	41322.75694	10.00	24,467	459	62	134
2/17/2013	18:20:00	41322.76389	20.00	25,036	1,028	57	141
2/17/2013	18:30:00	41322.77083	30.00	25,495	1,487	46	144
2/17/2013	18:45:00	41322.78125	45.00	26,179	2,171	46	146
2/17/2013	19:00:00	41322.79167	60.00	26,878	2,870	47	146
2/17/2013	20:00:00	41322.83333	120.00	29,644	5,636	46	147
2/17/2013	20:10:00	41322.84028	130.00	29,863	5,855	22	139
Test #4							
2/18/2013	6:00:00	41323.25000	0.00	39,813	0		
2/18/2013	6:02:00	41323.25139	2.00	39,959	146	73	
2/18/2013	6:04:00	41323.25278	4.00	40,339	526	190	
2/18/2013	6:10:00	41323.25694	10.00	40,870	1,057	89	135
2/18/2013	6:20:00	41323.26389	20.00	41,387	1,574	52	142
2/18/2013	6:30:00	41323.27083	30.00	44,684	4,871	330	143
2/18/2013	7:40:00	41323.31944	100.00	48,194	8,381	50	145
2/18/2013	10:00:00	41323.41667	240.00	49,842	10,029	12	127
2/18/2013	13:00:00	41323.54167	420.00				70
Test #5							
2/19/2013	6:15:00	41324.26042	0.00	61,100	0		121
2/19/2013	6:30:00	41324.27083	15.00	61,472	372	25	125
2/19/2013	10:30:00	41324.43750	255.00	69,688	8,588	34	134
2/19/2013	12:30:00	41324.52083	375.00	73,901	12,801	35	133
2/19/2013	12:33:00	41324.52292	378.00	74,001	12,901	33	133
2/19/2013	16:15:00	41324.67708	600.00	-			76
Test #6							
2/20/2013	19:35:00	41325.81597	0.00	74,001	0		
2/21/2013	6:10:00	41326.25694	635.00	92,355	18,354	71	126
2/21/2013	10:45:30	41326.44826	910.50	98,962	24,961	24	125
Test #7							
2/25/2013	13:15:15	41330.55226	0.00	218,313	0		26
2/25/2013	13:16:00	41330.55278	0.75	218,475	162	216	91
2/25/2013	13:17:00	41330.55347	1.75	218,552	239	77	98
2/25/2013	13:18:00	41330.55417	2.75	218,643	330	91	103
2/25/2013	13:19:00	41330.55486	3.75	218,732	419	89	107
2/25/2013	13:20:00	41330.55556	4.75	218,819	506	87	109
2/25/2013	13:30:00	41330.56250	14.75	219,609	1,296	79	119
2/25/2013	13:45:00	41330.57292	29.75	220,681	2,368	71	123
2/25/2013	14:00:00	41330.58333	44.75	221,705	3,392	68	124
2/25/2013	15:00:00	41330.62500	104.75	225,610	7,297	65	126
Test #8							

3/9/2013	11:05:00	41342.46181	0.00	466,730	0		26
3/9/2013	11:06:00	41342.46250	1.00	466,820	90	90	91
3/9/2013	11:07:00	41342.46319	2.00	466,916	186	96	98
3/9/2013	11:08:00	41342.46389	3.00	467,092	362	176	103
3/9/2013	11:09:00	41342.46458	4.00	467,252	522	160	107
3/9/2013	11:10:00	41342.46528	5.00	467,399	669	147	109
3/9/2013	11:11:00	41342.46597	6.00	467,549	819	150	119
3/9/2013	11:12:00	41342.46667	7.00	467,709	979	160	123
3/9/2013	11:13:00	41342.46736	8.00	467,877	1,147	168	124
3/9/2013	11:14:00	41342.46806	9.00	468,005	1,275	128	126
3/9/2013	11:15:00	41342.46875	10.00	468,230	1,500	225	145
3/9/2013	11:16:00	41342.46944	11.00	468,404	1,674	174	145
3/9/2013	11:17:00	41342.47014	12.00	468,575	1,845	171	147
3/9/2013	11:18:00	41342.47083	13.00	468,741	2,011	166	147
3/9/2013	11:19:00	41342.47153	14.00	468,907	2,177	166	149
3/9/2013	11:20:00	41342.47222	15.00	469,070	2,340	163	149
3/9/2013	11:21:00	41342.47292	16.00	469,231	2,501	161	150
3/9/2013	11:22:00	41342.47361	17.00	469,389	2,659	158	150
3/9/2013	11:23:00	41342.47431	18.00	469,550	2,820	161	150
3/9/2013	11:24:00	41342.47500	19.00	469,708	2,978	158	150
3/9/2013	11:25:00	41342.47569	20.00	469,867	3,137	159	150
3/9/2013	11:26:00	41342.47639	21.00	470,023	3,293	156	152
3/9/2013	11:27:00	41342.47708	22.00	470,180	3,450	157	152
3/9/2013	11:28:00	41342.47778	23.00	470,280	3,550	100	120
3/9/2013	11:29:00	41342.47847	24.00			0	111
3/9/2013	11:30:00	41342.47917	25.00			0	102
3/9/2013	11:31:00	41342.47986	26.00			0	93
3/9/2013	11:32:00	41342.48056	27.00			0	90
3/9/2013	11:33:00	41342.48125	28.00			0	85
3/9/2013	11:34:00	41342.48194	29.00			0	81
3/9/2013	11:35:00	41342.48264	30.00			0	77
3/9/2013	11:36:00	41342.48333	31.00			0	74
3/9/2013	11:37:00	41342.48403	32.00			0	72
3/9/2013	11:38:00	41342.48472	33.00			0	70
3/9/2013	11:39:00	41342.48542	34.00			0	67
3/9/2013	11:40:00	41342.48611	35.00			0	65
3/9/2013	11:41:00	41342.48681	36.00			0	64
3/9/2013	11:42:00	41342.48750	37.00			0	62
3/9/2013	11:43:00	41342.48819	38.00			0	60
3/9/2013	11:44:00	41342.48889	39.00			0	59
3/9/2013	11:45:00	41342.48958	40.00			0	57
3/9/2013	11:46:00	41342.49028	41.00			0	
Test #9							
3/9/2013	11:47:00	41342.49097	0.00	470,280	0	0	
3/9/2013	11:48:00	41342.49167	1.00	470,435	155	155	
3/9/2013	11:49:00	41342.49236	2.00	470,625	345	190	135
3/9/2013	11:50:00	41342.49306	3.00	470,824	544	199	140
3/9/2013	11:51:00	41342.49375	4.00	471,010	730	186	142
3/9/2013	11:52:00	41342.49444	5.00	471,200	920	190	145
3/9/2013	11:53:00	41342.49514	6.00	471,375	1,095	175	145
3/9/2013	11:54:00	41342.49583	7.00	471,555	1,275	180	
3/9/2013	11:56:00	41342.49722	9.00	471,890	1,610	168	149
3/9/2013	11:57:00	41342.49792	10.00	472,063	1,783	173	149
3/9/2013	11:59:00	41342.49931	12.00	472,395	2,115	166	149
3/9/2013	12:00:00	41342.50000	13.00	472,558	2,278	163	149
3/9/2013	12:05:00	41342.50347	18.00	473,359	3,079	160	151
3/9/2013	12:10:00	41342.50694	23.00	473,935	3,655	115	151
Test #10							
3/25/2013	10:00:00	41358.41667	0.00	779,590	0		40
3/25/2013	10:01:00	41358.41736	1.00	779,728	138	138	60
3/25/2013	10:02:00	41358.41806	2.00	779,852	262	124	70
3/25/2013	10:03:00	41358.41875	3.00	779,959	369	107	75
3/25/2013	10:04:00	41358.41944	4.00	780,062	472	103	78
3/25/2013	10:05:00	41358.42014	5.00	780,167	577	105	80
3/25/2013	10:06:00	41358.42083	6.00	780,274	684	107	83
3/25/2013	10:08:00	41358.42222	8.00	780,468	878	97	86
3/25/2013	10:10:00	41358.42361	10.00	780,667	1,077	100	88
3/25/2013	10:15:00	41358.42708	15.00	781,144	1,554	95	91
3/25/2013	10:22:00	41358.43194	22.00	781,795	2,205	93	94

3/25/2013	10:30:00	41358.43750	30.00	782,525	2,935	91	96
3/25/2013	10:45:00	41358.44792	45.00	783,870	4,280	90	99
3/25/2013	11:00:00	41358.45833	60.00	785,191	5,601	88	100
3/25/2013	11:25:00	41358.47569	85.00	787,350	7,760	86	103
3/25/2013	12:00:00	41358.50000	120.00	790,306	10,716	84	105
3/25/2013	12:00:00	41358.50000	120.00			0	105
3/25/2013	12:00:30	41358.50035	120.50			0	96
3/25/2013	12:01:00	41358.50069	121.00			0	92
3/25/2013	12:02:00	41358.50139	122.00			0	89
3/25/2013	12:03:00	41358.50208	123.00			0	85
3/25/2013	12:04:00	41358.50278	124.00			0	83
3/25/2013	12:05:00	41358.50347	125.00			0	80
3/25/2013	12:06:00	41358.50417	126.00			0	79
3/25/2013	12:08:00	41358.50556	128.00			0	75
3/25/2013	12:10:00	41358.50694	130.00			0	72
3/25/2013	12:12:00	41358.50833	132.00			0	68
3/25/2013	12:15:00	41358.51042	135.00			0	66
3/25/2013	12:20:00	41358.51389	140.00			0	60
3/25/2013	12:25:00	41358.51736	145.00			0	58
3/25/2013	12:30:00	41358.52083	150.00			0	55
3/25/2013	12:35:00	41358.52431	155.00			0	50
3/25/2013	12:40:00	41358.52778	160.00			0	47
3/25/2013	12:45:00	41358.53125	165.00			0	44
3/25/2013	12:50:00	41358.53472	170.00			0	40
3/25/2013	12:55:00	41358.53819	175.00			0	37
3/25/2013	13:00:00	41358.54167	180.00			0	35

March 29, 2013

To: Dale Merrick, Canby Geothermal

From: Ben Barker

Re: Indications of ISO-2 Capacity

I've considered the data from ISO-2 in light of the question you posed: can ISO-2 reasonably be expected to produce enough to support 50kW electric generation when operated with ISO-1? Specifically, is ISO-2 likely to provide at least 70 gpm with a drawdown no more than 500 ft? I believe we can answer that question affirmatively if we consider each of the tests in proper context. Attached to this note are two figures to which I will refer in my discussion.

I analyzed the data you sent from well ISO-2, in Canby, Modoc County, including (a) the drill rig test on September 14, 2011, (b) the production pump test a year later in October 2012 and (c) a series of short injection tests in 2013. I also examined the drilling daily reports and reports from consulting engineers, hydrologists and geologists. The geologic reports and logs indicate ISO-2 is completed in a thick, heterogeneous sequence of sedimentary rocks of volcanic origin. These layers are generally of low permeability, as evidenced by the lack of circulation losses during drilling.

This creates a situation in which the well test analyst treads carefully for two reasons. First, permeability development (or loss) in a small layer can greatly affect the overall performance of the well, making consistency of wellbore condition critical when comparing tests. Second, a single conductive streak or fracture in a largely impermeable formation creates the high permeability contrast situation that was studied by Tariq and Ramey (SPE 7453,1978). They found that type-curve matching in that situation is fraught with error in estimating wellbore storage and skin factors. Without down-hole flow meter data (e.g., tracer or spinner), we have no way of knowing that the same layers are producing or accepting water during the various tests. I believe that a holistic view of the data shows that we do not have such consistency.

The flow rates of the various tests vary by an order of magnitude and durations by three orders. I chose to transform the time scales for practical comparison by using wellbore volume units. For each wellhead pressure reading or water level drawdown measurement I calculated a surface injectivity or productivity index in gpm/psi. This is an expedient measure since we do not have time to run vertical flow models to get "sand face" values, as would be strictly proper. As a practical matter, all the fluid velocities are low and the temperatures vary in only a small range so I am confident the resulting errors are unimportant to answering your original question.

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Figure 1 shows the results of my calculations for each of the individual tests, displaying the injectivity or productivity index as a function of the fluid volume produced or injected. It is immediately apparent that there is little resemblance between the behavior between the well when rig tested in 2011, when production tested over a year later and when injection tested this year. This is not particularly surprising in light of the very limited opportunity for well development or cleanup. The fact that the well had almost no cleanup time when completed and then sat idle for a year makes it highly likely that old mud cake, swelling clays, unstable rocks and leprechauns had an opportunity to negatively affect the well before the 2012 production test. I believe this becomes clear if we look at the data in sequence, as I've shown in Figure 2.

To create a sequential data set I simply added the absolute value of produced volume to the prior step, disregarding the idle intervals between tests. This is not a rigorous analytical technique, just a convenient way to get a common sense look at the arc of the well's history. If the hypothesis were correct that formation damage and skin are affecting the well, we would expect to see gradual improvement as more flushing occurs in either direction. That is precisely what we do see in Figure 2. None of the individual injection periods in 2013 was enough to accomplish major improvement but their cumulative impact on the well is unmistakable.

Your original question about ISO-2 productivity is essentially, "will ISO-2 have a productivity index greater than 0.32 gpm/psi?" I believe we can answer "yes" with reasonable confidence, since Figure 2 shows that the entirely of the last four injection tests have taken place with an injectivity index > 0.5, and there may well be a convergence on the value of 1 gpm/psi measured in the rig test. For comparison, ISO-1 has an index of about 0.7 gpm/psi. This is hardly an exact science, but as a business proposition I would recommend to management that the probability of ISO-2 having an index > 0.5 gpm/psi is better than 75%, or better than 3:1 odds.

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Figure 1
Permeability In ISO-2 as a Function of Volume Flow Measured by Individual Tests

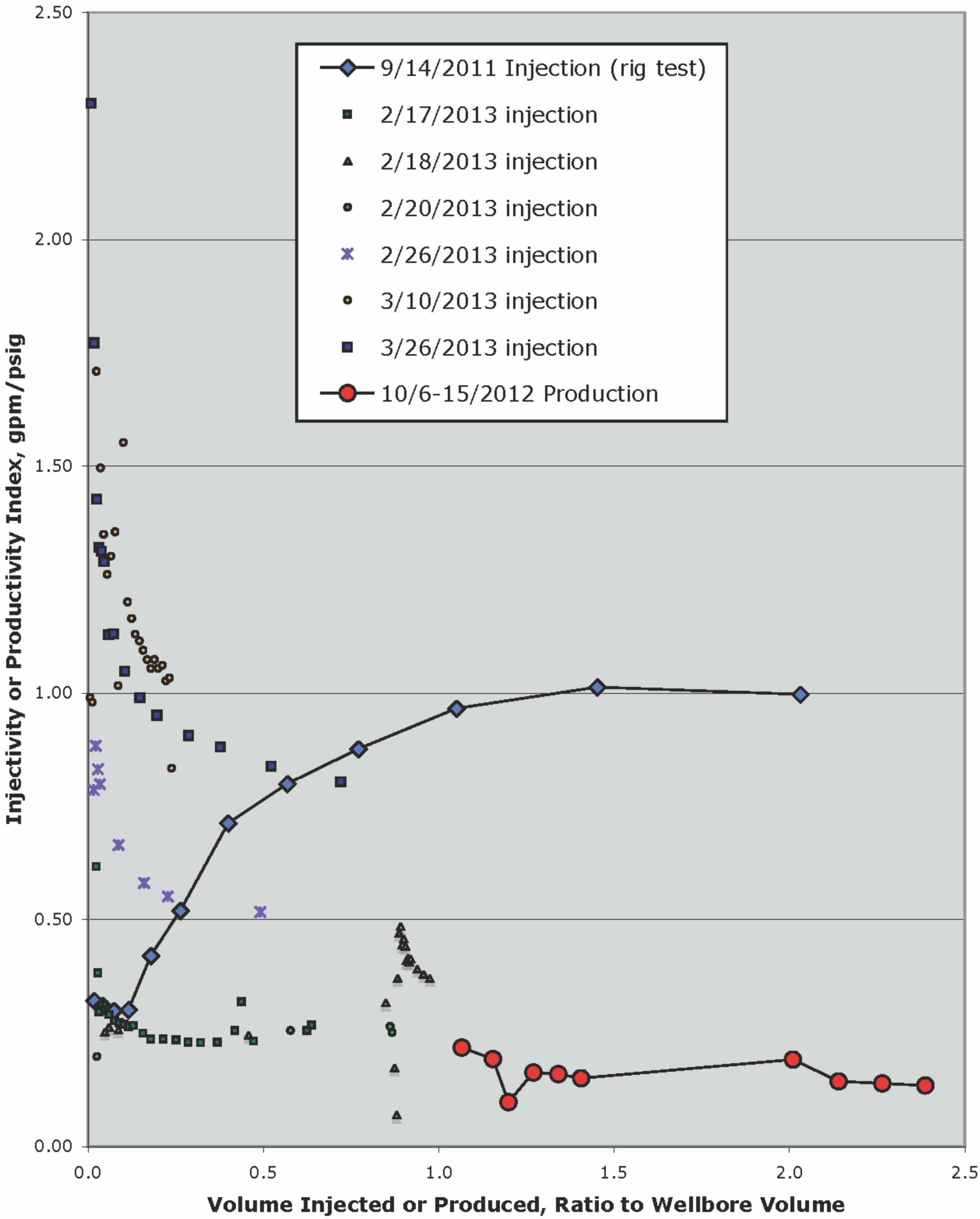

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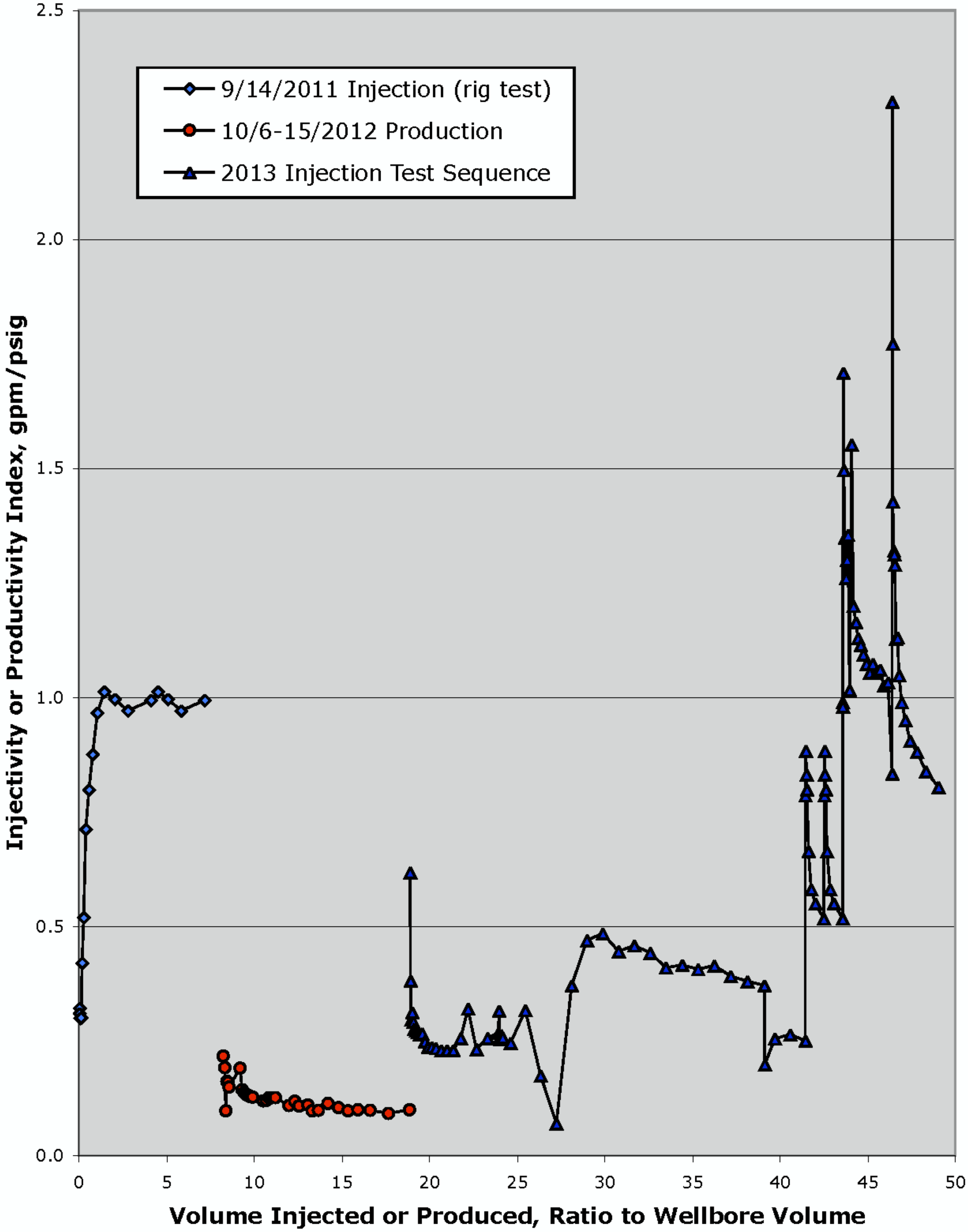
Figure 2
Permeability Variation in ISO-2
as a Function of Fluid Flow Volume



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Project Financial Projection

Aquaponic Tomato Harvest.

Canby Geothermal Heat & Power Project, Nominal 50 kW

4/2/2013

SCHEDULE & MILESTONES ASSUMPTION

Feasibility Study & Drill ISO-2 Well	1	Feb-11	Jun-13
Complete Engineering and Permitting	2	Jun-13	Aug-13
Order Equipment & Initiate Construction	2	Aug-13	Sep-13
Complete Construction and Startup	3	Mar-14	May-14
	SUBTOTAL, $000		

FEASIBILITY STUDY & DEVELOPMENT COSTS

Feasibility Study-Environmental	1	52.0	
Feasibility Study-Engineering	1	47.1	
Feasibility Study-Transmission & PPA	1	43.0	
Feasibility Study-Geology	1	42.0	
Feasibility Study-Reservoir Engineer	1	4.0	
Feasibility Study-Drilling Engineer	1	3.0	
Feasibility Study-Project Management	1	67.2	
Feasibility Study-Travel		1.5	
USDOE Budget Period 1:	1		258.3

CAPITAL COST ESTIMATES

	Phase		
Personnel / Project Mgmnt, Travel	2	163.0	163.0
ProductionWell Pumping Equipment	2	50.0	
Power Generation Equipment	2	375.0	
Elecrical interconnection System	2	152.0	
3,650 Foot Pipeline System		275.0	
Heat Transfer Equip./Cascaded Uses	2	120.0	
Equipment Subtotal:			972.0
Site civil work	2	5.0	
Engineering (civil, electrical & mech.)	2	55.0	
Drilling Costs, ISO-3	2	750.0	
Procure, Install & Commission Equip	2	163.0	
Contractual Subtotal:	2		973.0
USDOE Budget Period 2:	2		2,108.0
Personnel / Project Mgmnt, Travel	3	9.8	
Optns & Maint. Training & Mobilization	3	21.0	
USDOE Budget Period 3:			30.8
USDOE GRANT BUDGET:			2,397.1

PREVIOUS INVESTMENT & CONSTRUCTION

Drilling & Pump Costs, ISO-2	1,300.0	
Drilling & Pump Costs, ISO-1	550.0	
Existing thermal loop & infrastructure	1,500.0	
Subtotal:		3,350.0
TOTAL FUNDS REQUIRED:		5,747.1

SOURCES OF FUNDS

CEC, NREL, DOE, ISOT		1,200.0
USDOE Geothermal Grant:		2,000.0
CEC Grant (2011)		1,300.0
Project Debt	0.0	0.0
Canby Geothermal Equity		1,247.1
TOTAL FUNDS SUPPLIED:		5,747.1

OPERATING PLAN

	2014 $	2015 $	2016$
One Green Energy Machine	Year 1	Year 2	Year3>
Gross Power Generation (kW):	50	50	50
Cooling System Load (kW):	-3	-3	-3
Geothermal Well Pump Load (kW):	-15	-15	-15
Net Plant Output, Avg. (kW):	32.0	32.0	32.0
Capacity Factor:	58.0%	88.0%	94.0%
Annual power production, MWh:	163	247	264

REVENUE

	1	2	3
Retail power rate ($/MWh):	$70.00	$72.10	$74.26
Less Transmission Cost:	$0.00	$0.00	$0.00
Value of Renewable Energy Credits:	$3.00	$3.00	$3.00
Total Rate:	$73.00	$75.10	$77.26
Total Annual Power Revenue:	$11,869	$18,526	$20,359
Thermal Energy Rev, District Heat:	$100,000	$103,000	$106,090
Thermal Energy Rev, Fish Farm:	$0	$100,000	$103,000
Thermal Energy Rev., Greenhouse:	$14,000	$50,000	$51,500
Total Annual Power Revenue:	$125,869	$271,526	$280,949

OPERATING EXPENSE

FIXED O&M:	7 Months		
Salaries & OH-Operations:	7,000	12,360	12,731
Salaries & OH-Mgmt	1,750	3,090	3,183
Routine Repairs & Maint	1,200	2,119	2,182
Major Maintence Reserve	1,750	3,090	3,183
Remote Monitoring	300	530	546
Meter Testing	75	132	136
	$12,075	$21,321	$21,961
VARIABLE O&M:			
Supplies/consumables	2,333	4,120	4,244
Cooling Water Supply/Pump Power	0	0	0
	$2,333	$4,120	$4,244
GENERAL & ADMINISTRATIVE COSTS:			
Prof Svcs: Legal, Audit & Engineering	1,000	1,030	1,061
Property Tax	30,000	30,900	31,827
Insurance	1,675	1,725	1,777
In-House Administrative Costs:	600	618	637
Total, General & Administrative Costs:	$33,275	$34,273	$35,301
TOTAL O&M and G&A:	$47,683	$59,714	$61,506
OPERATING INCOME:	$78,185	$211,812	$219,443

	SVEC Transmission	Pwer Sales Whsl	General Inflation
Inflation/Escallation Assumptions:	1.00%	3.00%	3.00%

RESULTS

f		i			y
Project Financial Performance					
	yr 1	yr 5	yr 10	yr 15	
Revenue	11.9	20.9	24.9	28.7	
Fixed O&M	-12.1	-22.6	-26.9	-31.2	
Variable O&M	-2.3	-4.4	-5.2	-6.1	
Admin. Exp.	-33.3	-36.4	-43.4	-50.3	
Tot. Expenses	-47.7	-63.3	-75.6	-87.6	
Oper Income	212.8	226.1	269.8	312.6	
Debt Svc:					
Cash flow					

	j	o	t	y	ad
Sensitivity	5 yr NPV	10 yr NPV	15 yr NPV	20 yr NPV	25 yr NPV
Pwr Gen Eqip	-7.1%	11.0%	15.5%	17.1%	17.7%
$300	-5.4%	12.3%	16.6%	18.1%	18.7%
$350	-6.6%	11.4%	15.9%	17.4%	18.0%
$400	-7.6%	10.6%	15.1%	16.8%	17.4%
$450	-8.7%	9.8%	14.5%	16.1%	16.8%
Major Maint	-7.1%	11.0%	15.5%	17.1%	17.7%
$1,000	-6.9%	11.1%	15.6%	17.2%	17.8%
$1,500	-7.0%	11.0%	15.5%	17.1%	17.8%
$2,000	-7.2%	11.0%	15.5%	17.0%	17.7%
$2,500	-7.3%	10.9%	15.4%	17.0%	17.6%
Gross Output	-7.1%	11.0%	15.5%	17.1%	17.7%
45	-7.5%	10.7%	15.2%	16.8%	17.5%
48	-7.3%	10.9%	15.4%	17.0%	17.6%
53	-6.9%	11.2%	15.7%	17.2%	17.9%
Cap. Fact	-7.1%	11.0%	15.5%	17.1%	17.7%
85.0%	-7.3%	10.9%	15.4%	17.0%	17.6%
90.0%	-7.2%	10.9%	15.4%	17.0%	17.7%
97.0%	-7.0%	11.1%	15.5%	17.1%	17.8%
Pwr. Rate	-7.1%	11.0%	15.5%	17.1%	17.7%
50.00	-7.8%	10.4%	15.0%	16.6%	17.3%
55.00	-7.6%	10.6%	15.2%	16.8%	17.4%
65.00	-7.3%	10.9%	15.4%	17.0%	17.6%
70.00	-7.1%	11.0%	15.5%	17.1%	17.7%
PPA Esc	-7.1%	11.0%	15.5%	17.1%	17.7%
2.0%	-7.6%	10.1%	14.5%	16.0%	16.6%
4.0%	-6.6%	11.9%	16.5%	18.1%	18.8%

Canby Geothermal Heat & Power Project, Nominal 50 kW — 0 ,000 Debt Assumption — 4/2/13 9:03

Year Number:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Year:		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Annual power production, MWh:		163	247	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264
Retail power rate ($/MWh):		70.0	72.1	74.3	76.5	78.8	81.1	83.6	86.1	88.7	91.3	94.1	96.9	99.8	102.8	105.9	109.1	112.3	115.7	119.2	122.7	126.4	130.2	134.1	138.2	142.3
Less Transmission Cost:		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Value of Renewable Energy Credits:		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Total Rate:		73.0	75.1	77.3	79.5	81.8	84.1	86.6	89.1	91.7	94.3	97.1	99.9	102.8	105.8	108.9	112.1	115.3	118.7	122.2	125.7	129.4	133.2	137.1	141.2	145.3
REVENUE ($ 000's except otherwise noted)																										
Power Sales Revenue:		11.9	18.5	20.4	20.9	21.6	22.2	22.8	23.5	24.2	24.9	25.6	26.3	27.1	27.9	28.7	29.5	30.4	31.3	32.2	33.1	34.1	35.1	36.1	37.2	38.3
Thermal Energy Rev, District Heat:		100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	138.4	142.6	146.9	151.3	155.8	160.5	165.3	170.2	175.4	180.6	186.0	191.6	197.4	203.3
Thermal Energy Rev, Fish Farm:		0.0	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	138.4	142.6	146.9	151.3	155.8	160.5	165.3	170.2	175.4	180.6	186.0	191.6	197.4
Thermal Energy Rev., Greenhouse:		14.0	50.0	51.5	53.0	54.6	56.3	58.0	59.7	61.5	63.3	65.2	67.2	69.2	71.3	73.4	75.6	77.9	80.2	82.6	85.1	87.7	90.3	93.0	95.8	98.7
Total Revenue:		125.9	271.5	280.9	289.4	298.0	306.9	316.1	325.6	335.3	345.3	355.7	366.3	377.3	388.6	400.2	412.2	424.6	437.3	450.4	463.8	477.7	492.0	506.8	522.0	537.6
OPERATING EXPENSE																										
FIXED O&M:																										
Salaries & OH-Operations:		7.0	12.4	12.7	13.1	13.5	13.9	14.3	14.8	15.2	15.7	16.1	16.6	17.1	17.6	18.2	18.7	19.3	19.8	20.4	21.0	21.7	22.3	23.0	23.7	24.4
Salaries & OH-Mgmt		1.8	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	5.0	5.1	5.3	5.4	5.6	5.7	5.9	6.1
Routine Repairs & Maint		1.2	2.1	2.2	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1	4.2
Major Maintence Reserve		1.8	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	5.0	5.1	5.3	5.4	5.6	5.7	5.9	6.1
Remote Monitoring		0.3	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
Meter Testing		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Subtotal Fixed O&M:		12.1	21.3	21.9	22.6	23.2	23.9	24.6	25.4	26.1	26.9	27.7	28.6	29.4	30.3	31.2	32.2	33.1	34.1	35.1	36.2	37.3	38.4	39.6	40.7	42.0
VARIABLE O&M:																										
Supplies/consumables		2.3	4.1	4.2	4.4	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.1	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.7	7.9	8.1
Cooling Water Supply/Pump Power		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal Variable O&M:		2.3	4.1	4.2	4.4	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.1	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.7	7.9	8.1
GENERAL &ADMINISTRATIVE EXPENSES																										
Prof Svcs: Legal, Audit & Engineering		1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0
Property Tax		30.0	30.0	30.0	32.8	33.8	34.8	35.8	36.9	38.0	39.1	40.3	41.5	42.8	44.1	45.4	46.7	48.1	49.6	51.1	52.6	54.2	55.8	57.5	59.2	61.0
Insurance		1.7	1.7	1.7	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.9	2.9	3.0	3.1	3.2	3.3	3.4
In-House Administrative Costs:		0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2
Total, General & Administrative Costs:		33.3	33.3	33.3	36.4	37.5	38.6	39.7	40.9	42.2	43.4	44.7	46.1	47.4	48.9	50.3	51.8	53.4	55.0	56.6	58.3	60.1	61.9	63.8	65.7	67.6
TOTAL O&M and G&A:		47.7	58.7	59.4	63.3	65.2	67.1	69.2	71.2	73.4	75.6	77.8	80.2	82.6	85.1	87.6	90.2	92.9	95.7	98.6	101.6	104.6	107.7	111.0	114.3	117.7
Operating Cash Flow:	-1,247	78.2	212.8	221.5	226.1	232.8	239.8	247.0	254.3	261.9	269.8	277.9	286.2	294.7	303.5	312.6	322.0	331.6	341.5	351.8	362.3	373.1	384.3	395.8	407.7	419.9
IRR:			-55.4%	-31.3%	-16.6%	-7.1%	-0.8%	3.7%	6.9%	9.2%	11.0%	12.4%	13.4%	14.3%	15.0%	15.5%	16.0%	16.3%	16.6%	16.9%	17.1%	17.3%	17.4%	17.5%	17.6%	17.7%
NPV @10%:		-1,069.1	-909.2	-757.9	-617.5	-486.1	-363.1	-247.9	-140.0	-39.0	55.6	144.1	227.0	304.6	377.3	445.3	509.0	568.6	624.5	676.8	725.7	771.6	814.5	854.7	892.3	927.5
NPV @8%:		-1,087.7	-918.7	-755.9	-602.1	-455.3	-315.4	-182.0	-54.8	66.6	182.3	292.6	397.8	498.2	593.9	685.1	772.1	855.1	934.3	1,009.7	1,081.7	1,150.3	1,215.8	1,278.2	1,337.7	1,394.5
Operating Cash Flow:		78	213	222	226	233	240	247	254	262	270	278	286	295	304	313	322	332	342	352	362	373	384	396	408	420
Less Interest Charges:		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Less Depreciation:	3,747	-749	-1,199	-719	-432	-432	-216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taxable Income:		-671	-986	-498	-206	-199	24	247	254	262	270	278	286	295	304	313	322	332	342	352	362	373	384	396	408	420
Less Taxes, Plus Tax Credit:	38%	630	375	189	78	76	-9	-94	-97	-100	-103	-106	-109	-112	-115	-119	-122	-126	-130	-134	-138	-142	-146	-150	-155	-160
Net Income:		-41	-611	-309	-127	-123	15	153	158	162	167	172	177	183	188	194	200	206	212	218	225	231	238	245	253	260
Add Back Depreciation:		749	1,199	719	432	432	216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Less Principal Payments:		-12	-13	-14	-16	-17	-19	-21	-23	-25	-28	-30	-33	0	0	0	0	0	0	0	0	0	0	0	0	0
After Tax Cash Flow:	-1,247	696	575	397	289	291	212	132	135	137	140	142	144	183	188	194	200	206	212	218	225	231	238	245	253	260
IRR:		-44.2%	1.3%	17.8%	24.9%	29.4%	31.5%	32.4%	33.1%	33.6%	33.9%	34.2%	34.4%	34.5%	34.7%	34.8%	34.8%	34.9%	34.9%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%

Additional Information

Conceptual model of project area.

Hydro
resources

AQUIFER IMAGING GROUP

MT4 Geophysical Aquifer-Imaging Survey

for

Canby Geothermal Project

IRRIGATION PROJECT

Canby, CA

April
2012

Hydro
--*Aquifer Imaging Group*

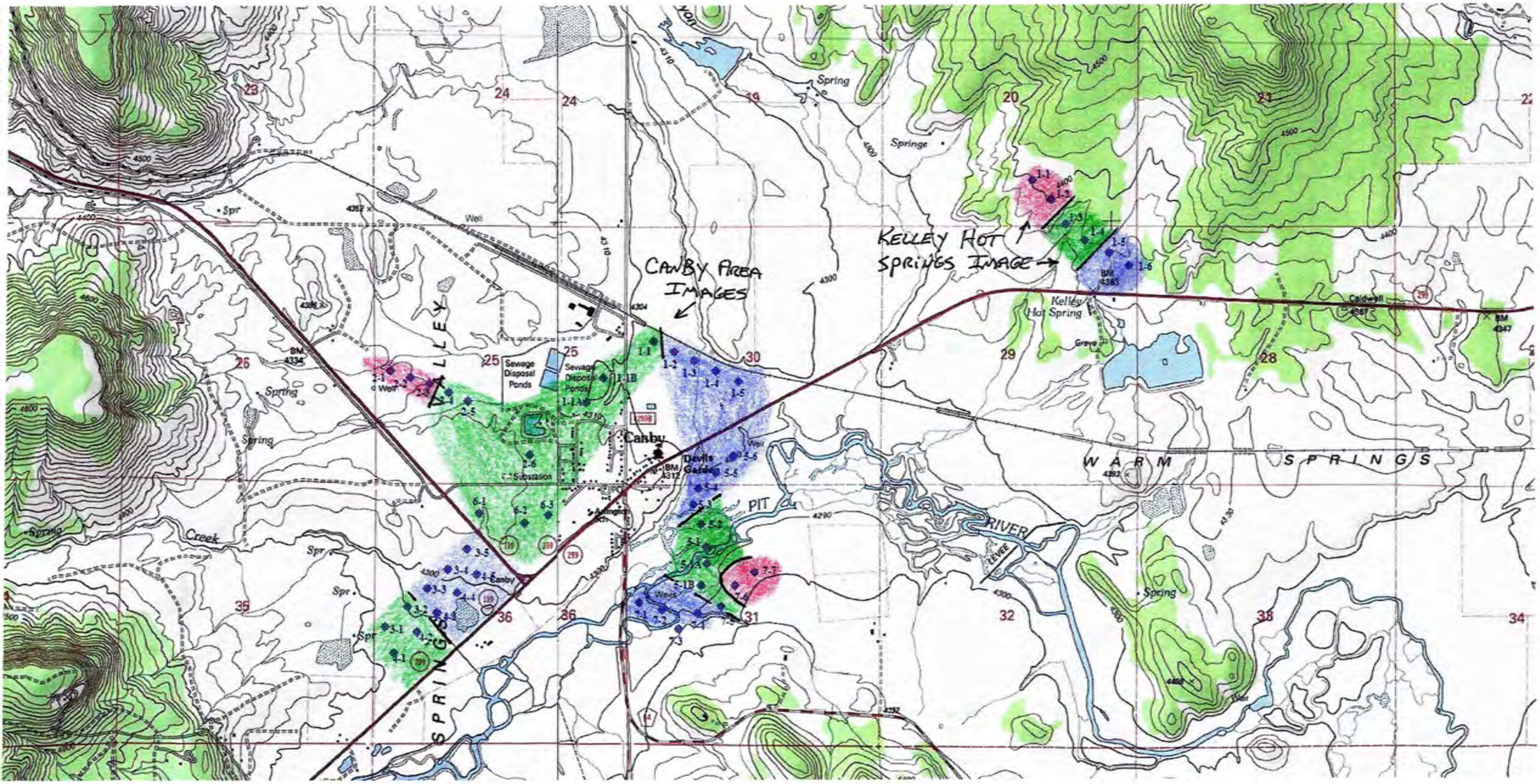
MT4-ED GEOPHYSICAL SUMMARY

To better understand the geological framework of the subsurface in the Pit River Valley in Canby, California, we have conducted numerous MT geophysical surveys with our MT4-ED system. Seven image transects were acquired in the Canby area, and one image was acquired in the vicinity of the Kelly Hot Springs to give us a better understanding how the deeper geothermal source bed relates to the hot spring at the surface. The final objective of the understanding of the geothermal system in the Canby area is to identify areas which may be optimal for drilling one or more geothermal wells with maximum hot water yields. Finding good permeability is accomplished by finding the uppermost lithified tuff which has fracture porosity caused by faulting. Two geothermal wells have been drilled here to date. Although capable of higher production levels, the ISO-1 has an average utilized production of 17 gpm, and the ISO-2 well is currently awaiting further evaluation to determine productive potential. It is known that the ISO-1 well experienced higher temperatures at the geothermal source bed than was found at the ISO-2 well, indicating that the ISO-1 well is more proximal to the geothermal temperature maximum.

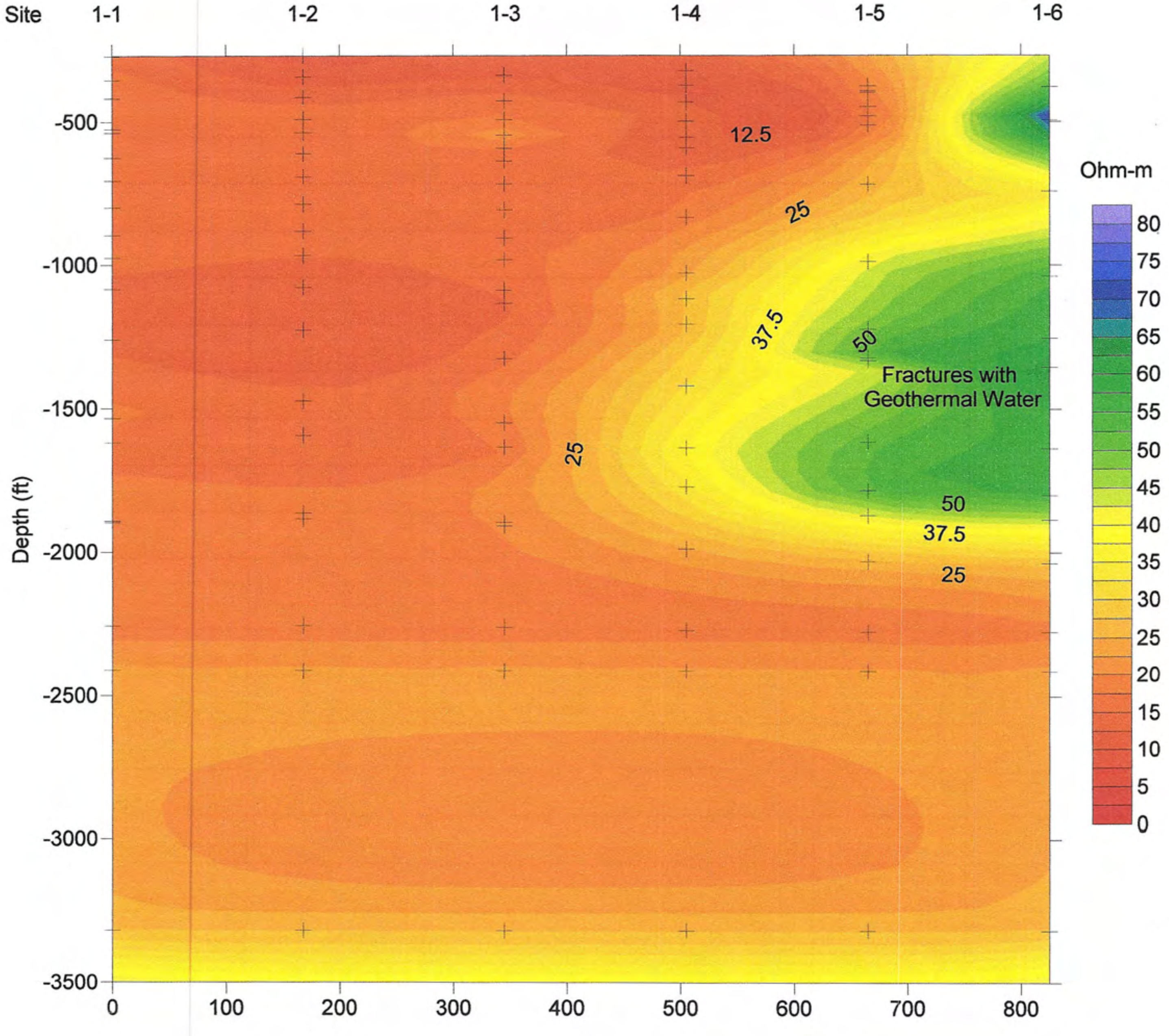
Although we can look at the MT data in both scaler and tensor formats, the scaler data provides the clearest subsurface view of the two formats. As such, the scaler images are enclosed with this preliminary summary for review. The Kelly Hot Springs (KHS) image line is the exception. Although the scaler and tensor images are very similar, the tensor image provides even better detail of the geoelectrical properties of the geothermal source bed and source-bed overburden.

Kelley Hot Springs MT4-ED Image Transect

The Kelley Hot Spring image line shows some fairly remarkable variance which gives a good understanding of how the deeper geothermal source bed may be affecting the overburden to allow the hot water to flow to the surface. Because the geothermal water within this locality is fairly fresh, it is identified as a resistive area on the image. In general, the higher resistivity values which are identified in the overburden and the Geothermal Source Bed (GSB) indicate more interconnected fresh water within the fractures and joints in those areas. Sites 1-1 and 1-2 show very little indication of high resistivity which is indicative of the geothermal water. Site 1-3 shows the beginning of an increase of the overburden resistivity as the image moves closer to the hot spring. The increase is seen primarily in the area just above 2,000 feet in depth. Sites 1-4, 1-5, and 1-6 show a continued increase in resistivity in the overburden above 2,000 feet. At site 1-6, there is high resistivity present on the image from the 2,000-feet deep level to very near the top of the ground. This data suggests that there could be an excessively fractured and permeable area of the GSB which provides high volumes of hot water upward. The hot water preferentially moved upward through planes of weakness in the smectite clays, lavas, and non-lithified tuffs. Once the hot water found the pathway to the surface, the area of invasion by the hot water expanded outward, affecting a larger area of the overburden around the hot spring. With an average production of 650 gpm, this geothermal source bed provides significant subsurface erosional ability which widens the areas of permeability by dissolution and particle transport.


CANBY AREA IMAGES
KELLEY HOT SPRINGS IMAGE
Canby
Devils Garden
Kelley Hot Spring
Sewage Disposal Ponds
PIT RIVER
WARM SPRINGS
Creek

Kelly Hot Spring
RON1
Surfer Image



2-D Resistivity Image
Hydro Resources
Imaging Division

GPS COORDINATES

KELLEY HOT SPRING FISH

CANBY,CALIFORNIA 96015 MODOC COUNTY

5/7/2012

Line 1

RO 1-1	41°	27'	38.2"	N	120°	50'	25.3"	W
RO 1-2	41°	27'	34.3"	N	120°	50'	20.3"	W
RO 1-3	41°	27'	29.4"	N	120°	50'	16.4"	W
RO 1-4	41°	27'	26.0"	N	120°	50'	11.1"	W
RO 1-5	41°	27'	23.5"	N	120°	50'	04.6"	W
RO 1-6	41°	27'	20.9"	N	120°	49'	59.2"	W

Dir Name: RON

File Name: ron,dat

rons,dat

Notes: No wells

With the KHS model as our case study for exploration, it appears that finding a resistive overburden may be the evidence which shows us the area which has been eroded or fracture-enhanced by geothermal water emanating from the geothermal source bed near 2,000 feet. These conditions are expected to indicate the areas of highest-volume geothermal water potential.

Canby MT4-ED Image Summaries

When viewing Line One, it is readily apparent that several key geological conditions are identified which were found when drilling the wells. Note that site ISO 1-1A has a lacustrine sand, a thin lava flow, and a top of permeable fractures shown. These geophysical anomalies match very well with the lacustrine sand found between 630 and 680 feet, the lava flow found near 900 feet, and geothermal water (permeability) found in the ISO-1 well between 2048 feet and 2100 feet (total depth). Also, the area on Line One marked as "Geothermal Source Bed" matches very well with the temperature anomaly found in the ISO-2 well where potential permeability may be found. As mentioned above, this geothermal system has fresh water in the springs and geothermal well production areas, so the resistive bed between 2000 and 2400 on this survey identify the objective horizon for targeting.

Site (ISO)1-1 shows a possible displacement in the deep, resistive marker bed near 2400 feet. This potential displacement could be the desired identifying characteristic marking the location of a large potential fault noted on the surface with satellite radar imagery shown on page 7 of the ISO-2 report summary. There could even be an argument for numerous faults, one just to the west of the 1-1 site, one to the east of site 1-1, and another near site 1-4 (shallower displacement at 1300 feet). If so, then the area marked "Geothermal Source Bed" likely represents a zone of permeability and geothermal water potential. There is also an increased-resistivity affect at sites 1-2 to 1-5 between the depths of 500 and 2,000 feet which suggests that the deeper GSB fracturing may have been significant enough to affect the overburden, creating permeability above the source bed, but not quite to the surface in the survey area. For example, should a well be drilled at site 1-5, the well may encounter hot water as shallow as 500 feet. It may be slightly cooler than the water at 2,400 feet because there is an expected cooling effect as the water moves upward and away from the GSB. With the evidence that we have in hand, it appears that sites 1-4 and 1-5 may be areas with good potential for geothermal exploration on Line One.

When we view Line Two, we can see the GSB with a base near 2,000/2,100 feet. Sites 2-1 through 2-5 have a fairly continuous conductive layer between 600 and 1800 feet. The image in these locations do not have the increased resistivity over the GSB which we identified at the Kelly Hot Springs MT line, so we are interpreting that, although the source bed is present, there may not be significant fracturing for production. There could be some fracturing at sites 2-4 to 2-5, but the fracturing appears to go downward from the source bed to nearly 2600 feet. This could suggest deeper sourcing at sites 2-4 and 2-5, making these two sites anomalous to the rest of the imaged areas. Site 2-6 has a greater possibility of upward-fracturing because we can see increased resistivities between the surface and 2,100 feet as compared to the rest of this image line. We would view this as a "fair" MT response for fracturing, but not as significant as seen in the KHS area. We would expect permeability which is somewhat better than found at the ISO-1 well due to the increased proximity to the Pit River Fault (mentioned later in this report) and increased resistivity values in the MT4-ED image.

Lines Three and Four are two parallel image lines which both show resistivity characteristics which are somewhat similar to the KHS image line. We do not expect quite the level of fracturing here as was seen at the KSH when the images are compared to each other. Sites 3-3 through 3-5, and sites 4-3 to 4-5, have several resistivity anomalies in the overburden above the GSB. It is especially noteworthy that the resistivity begins to increase on both lines near a depth of 1000 feet. The area of greatest resistivity anomaly coincides with an observed southeast-to-northwest surface lineament which was interpreted as a potential fault.

On the east side of the road, Line Six provided correlative information to Line Three and Line Four at several levels. The GSB is easily identified with a base at 2100 feet on Line Six, and there is also an area of increasing resistivity which begins near 1200 feet at site 6-1, and closer to 1300 feet at sites 6-2 and 6-3. The total resistivity anomaly above the GSB is not as pronounced as what we see on Lines Three and Four, so we do not expect Line Six to be quite as fractured as the eastern portion of Lines Three and Four. Again, this matches very well with the projected fault trace.

Lines Five and Six show us the complexity of the geology along the Pit River. This river was interpreted as overlying a fault or fault complex. Projected northeastward, the fault lineament can be traced to the Kelley Hot Spring. Line Seven is a very important line because it shows us a very distinct increase in the resistivity above the GSB. The image very closely parallels the image at the KHS. Sites 7-1 to 7-5, in particular, show a very regular increase in the resistivity anomaly to site 7-5, where it reaches a maximum. The GSB is identified with a base near 2000 feet at sites 7-1 to 7-3, but the zone becomes increasingly difficult to identify from sites 7-4 to 7-6. There may be a second GSB at the 2600 level, which means that a deeper zone may be sourcing the 2000/2200-feet deep horizon. There is also evidence of a slightly higher resistivity level at sites 7-1 to 7-4 between the GSB and 2600 feet. Additional geothermal sourcing from a deeper source bed near 2600 feet here, or the main GSB could be sourcing water downward into a fractured area below the GSB. In any event, the behavior of the resistivity variances that we see on this line coincides extremely well with the intersection of two potential faults in the survey area, the Pit River Fault and another fault which trends to the north-northwest toward our site ISO1-1. There is a possibility that the GSB could be sourcing hot water directly into the Pit River in this area. Our interpretation of this line is that sites 7-1 through 7-3 would be optimal sites for drilling geothermal wells which could produce very high water volumes from the GSB and possibly below the GSB down to 2600 feet.

Line Five appears to show significant dip, or possible faulting/fracturing at a resistive formation between 1000 and 1600 feet which overlies the GSB. This zone could be a lava layer and is likely fractured due to the faulting in the Pit River fault/fault complex. This area is near the mapped intersection of two faults, but may be significantly-affected by the NNW-SSE trending fault. There is a very pronounced increase in the resistivity of the overburden between sites between sites 5-2 and 5-6 which compares somewhat favorably with Line Seven and KHS images. There is also a possibility that the geothermal water could be very close to the surface at sites 5-4 and 5-5. Although we can only see minor resistivity increases at the GSB from sites 5-1B to site 5-6, we expect that the area between sites 5-3 and 5-6 would have significant potential for geothermal exploration, particularly at site 5-5.

To summarize, the MT4-ED appears to be an excellent geophysical technique for modeling the geological conditions between the target depths of 600 and 3500 feet in this area. Areas of potential fracturing and fault offset are apparent on all of the images. The fresh water in this geothermal system allows us to visualize the migration of the geothermal water from the GSB upward as the source bed creates surface hot springs. The KHS image line shows us an excellent example of how the resistivity changes as the image line approaches the hot spring. Because the hot spring represents a very high water volume flow, we can use this as a model for targeting potential high-volume, highly-fractured geothermal water sources.

The coincidence of the MT anomalies with the mapped fault/fracture lines has provided the information needed to target areas with the highest potential. Line Seven, Line Five, and Line One show areas with good geothermal potential due to the altered resistive overburdens and probable displacements seen on the images. We have provided a map with the most promising areas for geothermal exploration colored as blue ("good"). The areas identified as green are considered "fair" for exploration. Note that the two ISO wells would be expected as being "fair" locations on the map although we do not have MT data directly at the wells. The red areas are those which appear to have the least potential for exploration, either due to a lack of fracturing or the lack of visibility of the GSB.

Priority Project Area

Our recommended location for the drilling of the ISO-3 geothermal well is at site 2-6 on Line Two. This location is the optimal area to drill on this property due to an increased resistivity in the GSB and increases in the resistivity of the overburden. We recommend a minimum total depth of 2200 feet for the ISO-3, but there is additional potential to 2800 feet due to a second area of elevated resistivity identified on the MT4-ED image between 2500 and 2800 which may have some fracture porosity and permeability.

Future Project Areas

Because there are several areas in the survey area which have close MT4-ED image correlations to the KHS image, we also have recommendations for future exploration. Our top recommended area for a very high-volume geothermal water potential would be the area between **7-1 and 7-3** on Line Seven. In this area, we would recommend a minimum depth of 2100 feet for total depth, and a maximum depth of 2750 feet. These locations appear to be along an apparent fracture strike, and thus any of these three locations would be positive for drilling. Site **7-1 or 7-2** would likely be the lowest risk sites for drilling of the three sites on Line Seven.

The second area of focus for a geothermal well would be site **5-5**. The recommended total depth for this location is 2400 feet.

The final area recommended for future exploration would be site **1-5**. The recommended total depth for this location is 2500 feet.

Hydro Resources-Midcontinent
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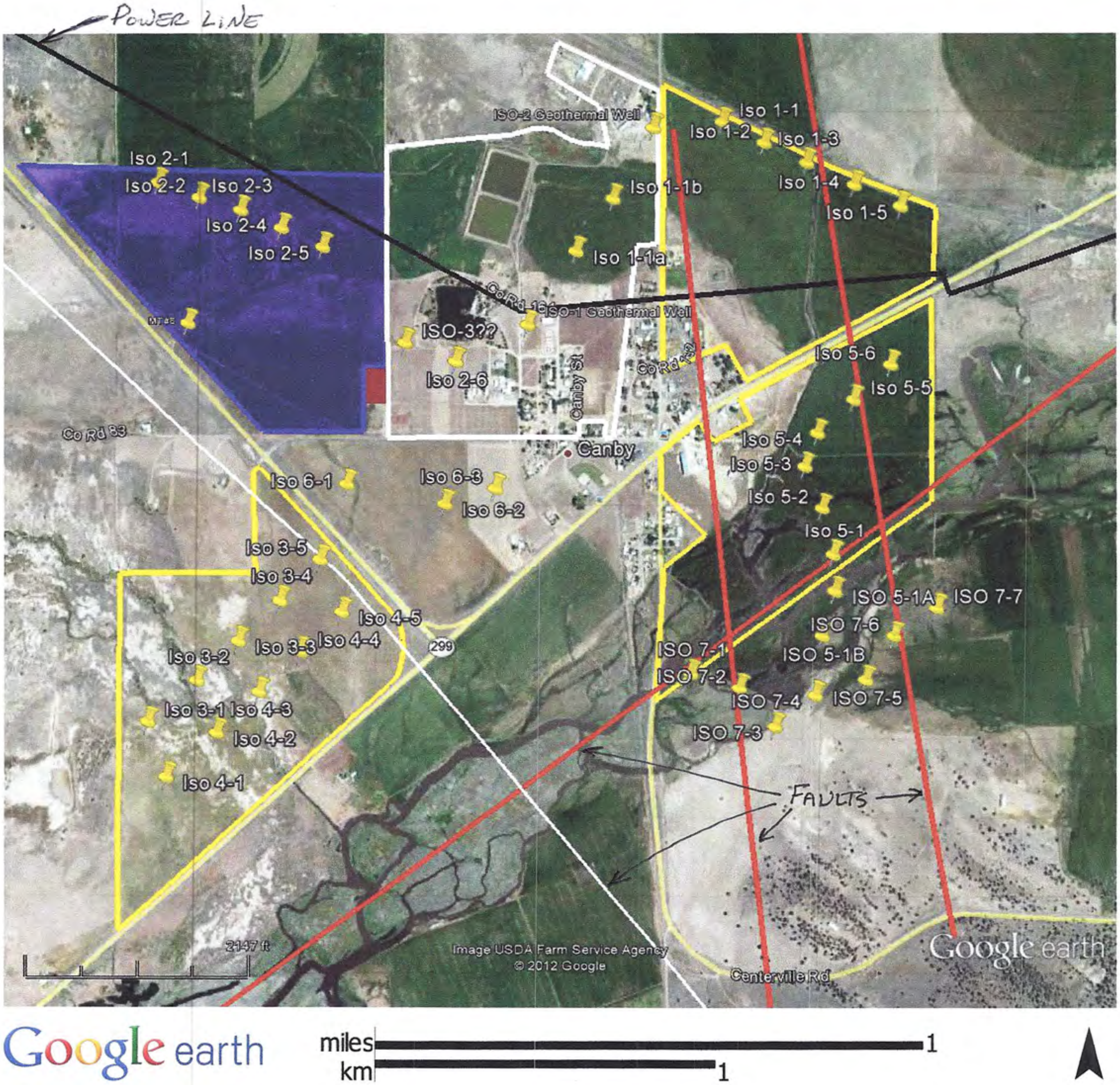
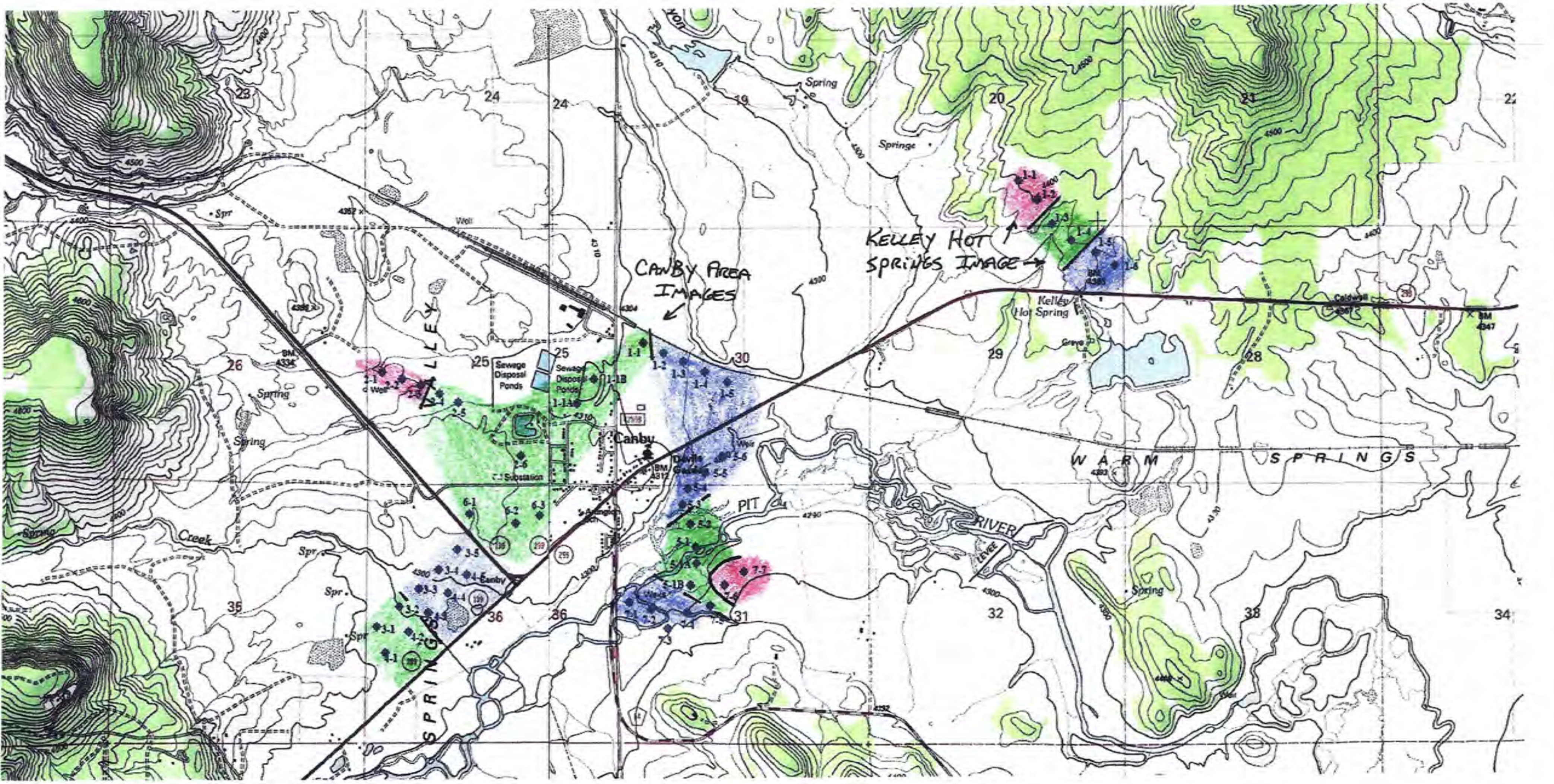
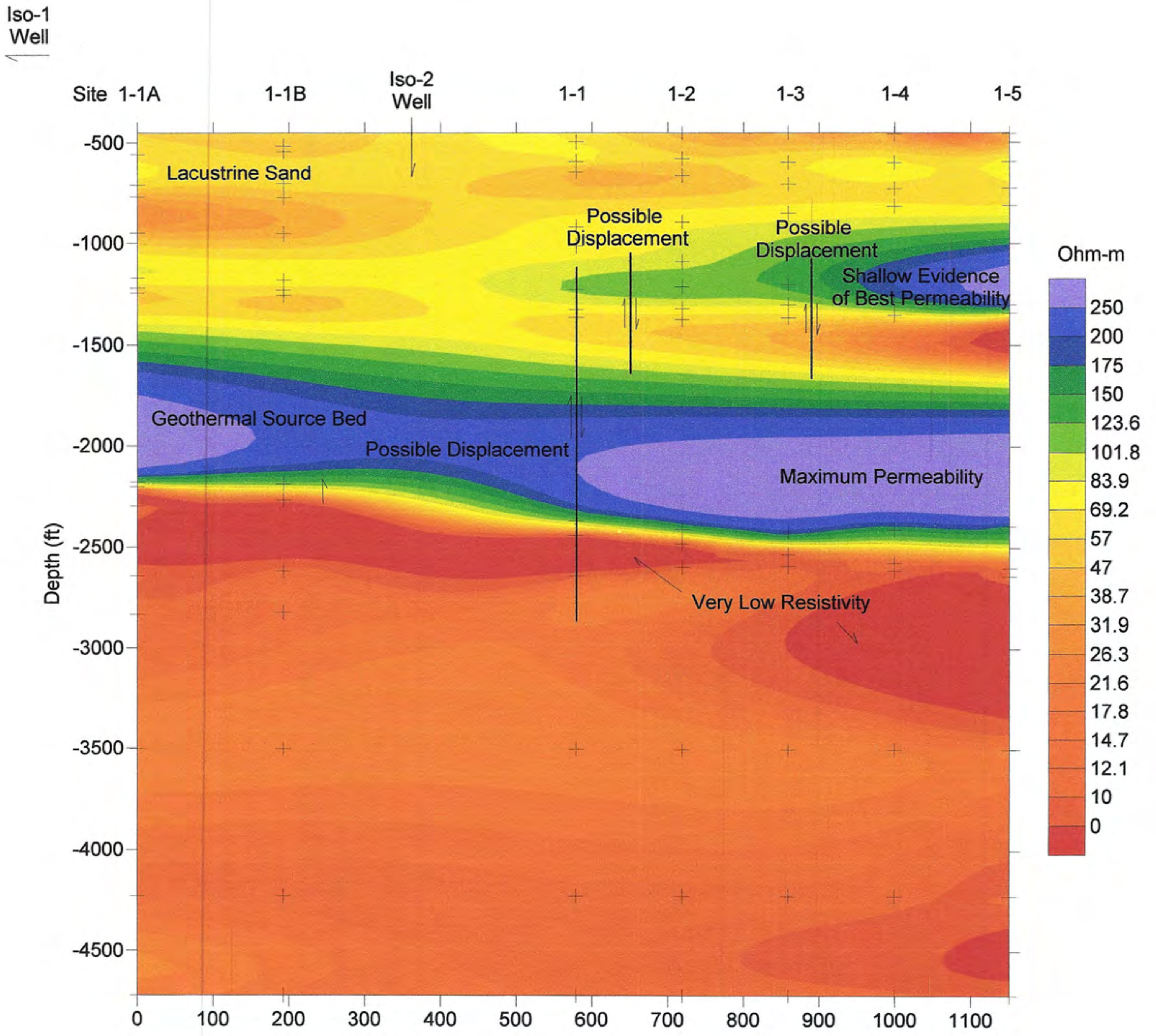
krigsby@hydroresources.com



PROJECTED FAULTS FROM
SATELLITE IMAGERY

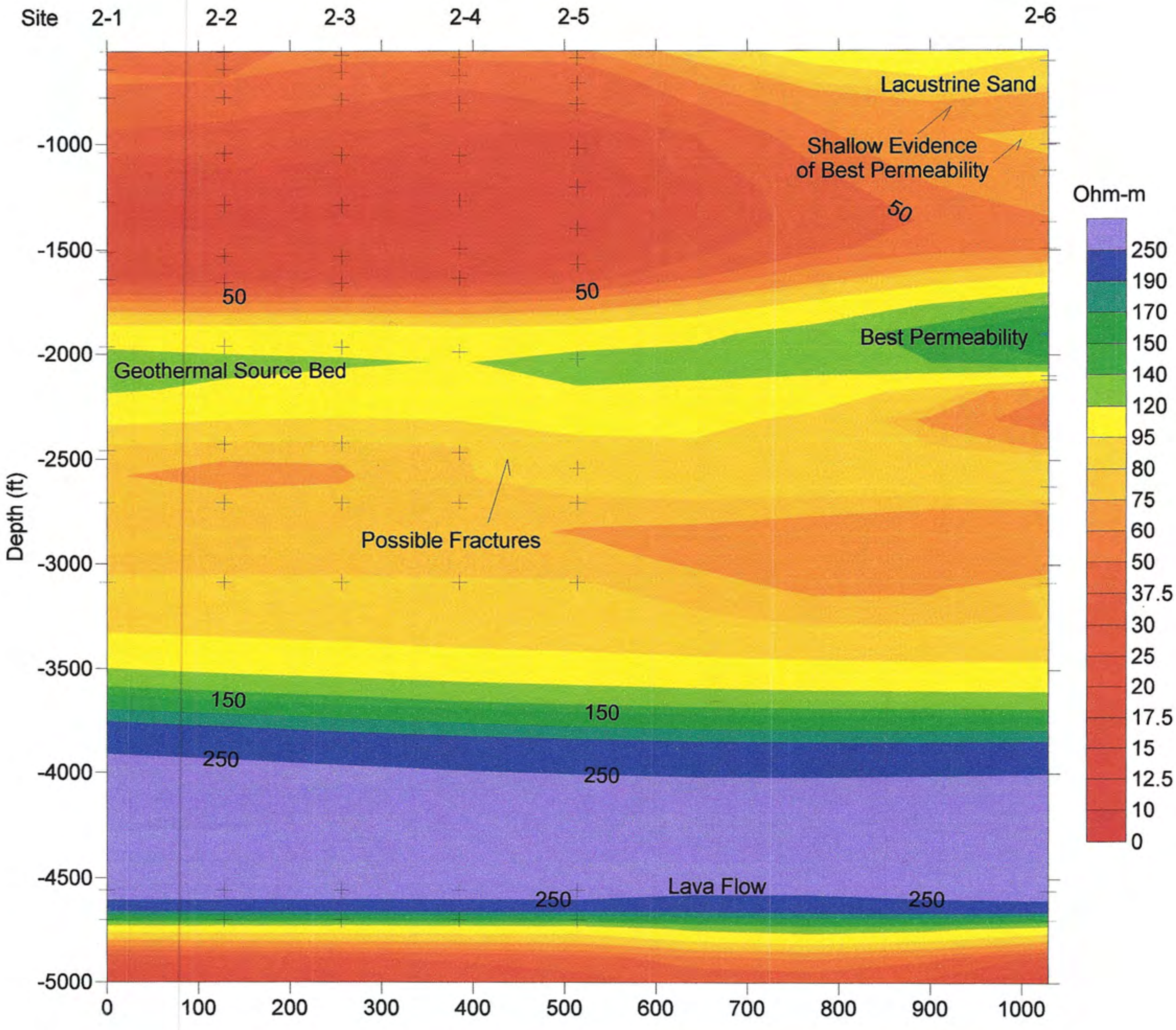

CANBY AREA IMAGES
KELLEY HOT SPRINGS IMAGE
Kelley Hot Spring
Canby
Sewage Disposal Ponds
Substation
Devils Garden
PIT RIVER
WARM SPRINGS
SPRINGS
VALLEY
Creek
LEVEE
Spring
Caldwell

CANBY ED1SCALER
Surfer Image



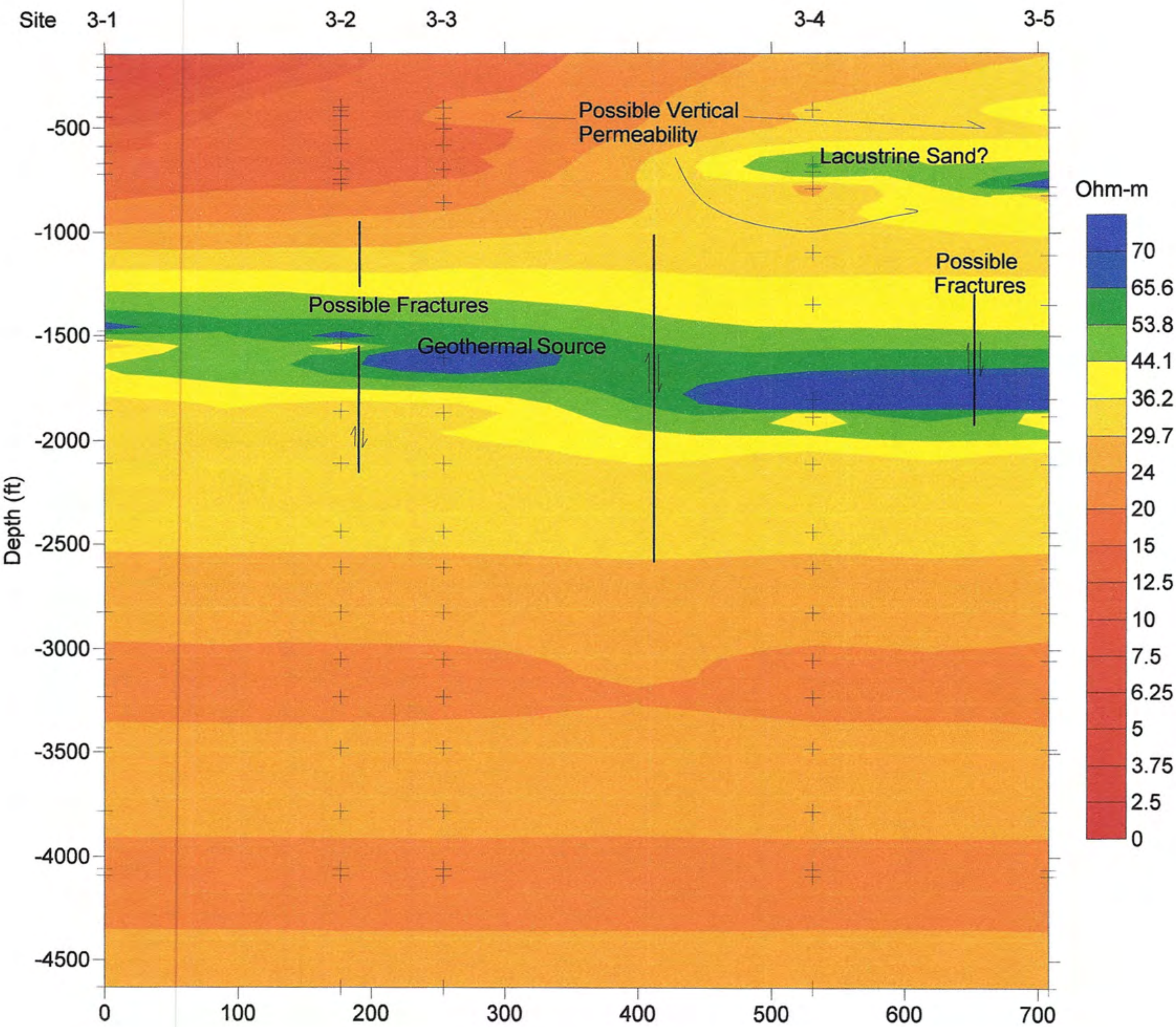
2-D Resistivity Image
Hydro Resources
Imaging Division

CANBY ED2SCALER
Surfer Image



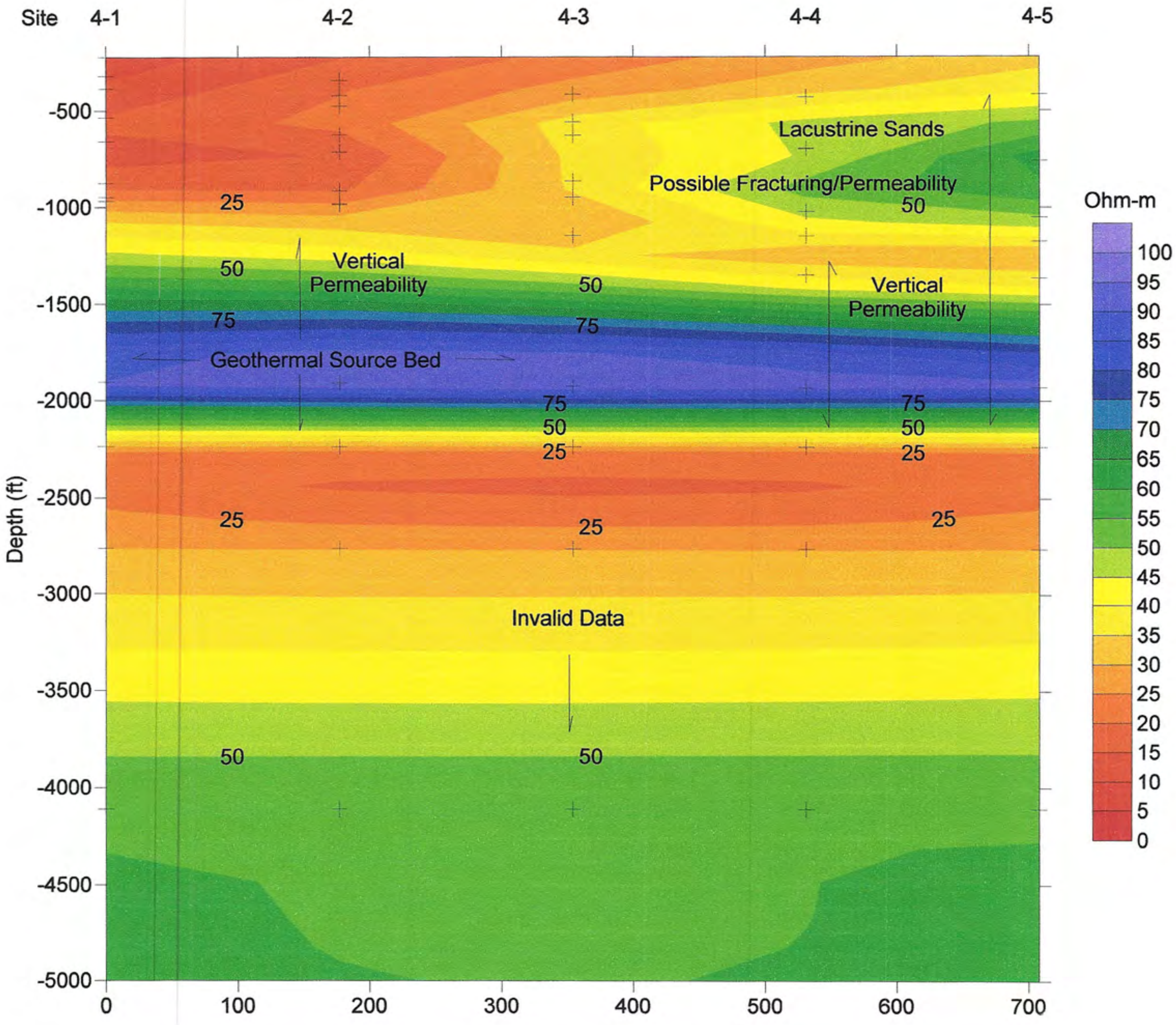
2-D Resistivity Image
Hydro Resources
Imaging Division

CANBY ED3SCALER
Surfer Image



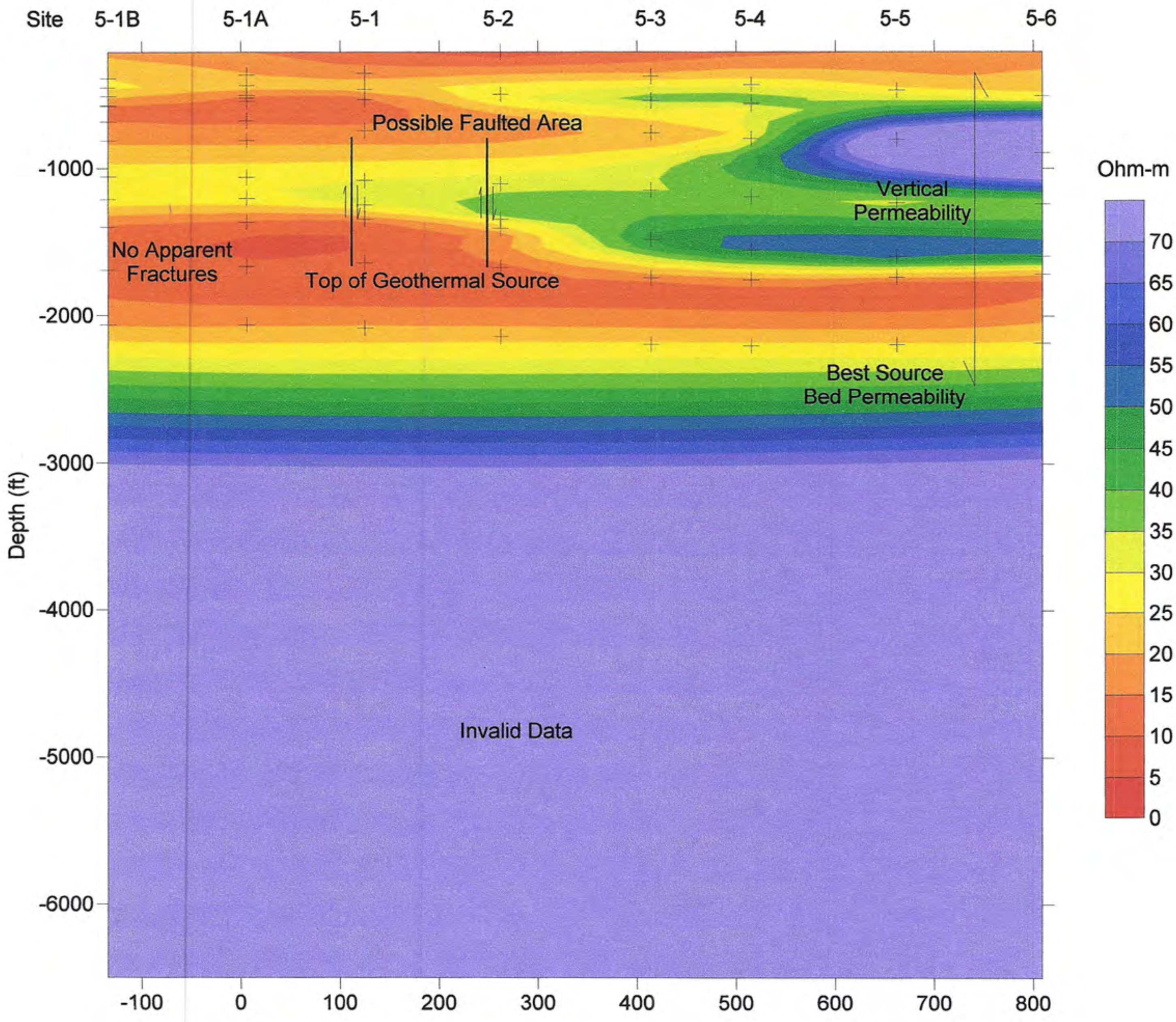
2-D Resistivity Image
Hydro Resources
Imaging Division

CANBY ED4SCALER
Surfer Image



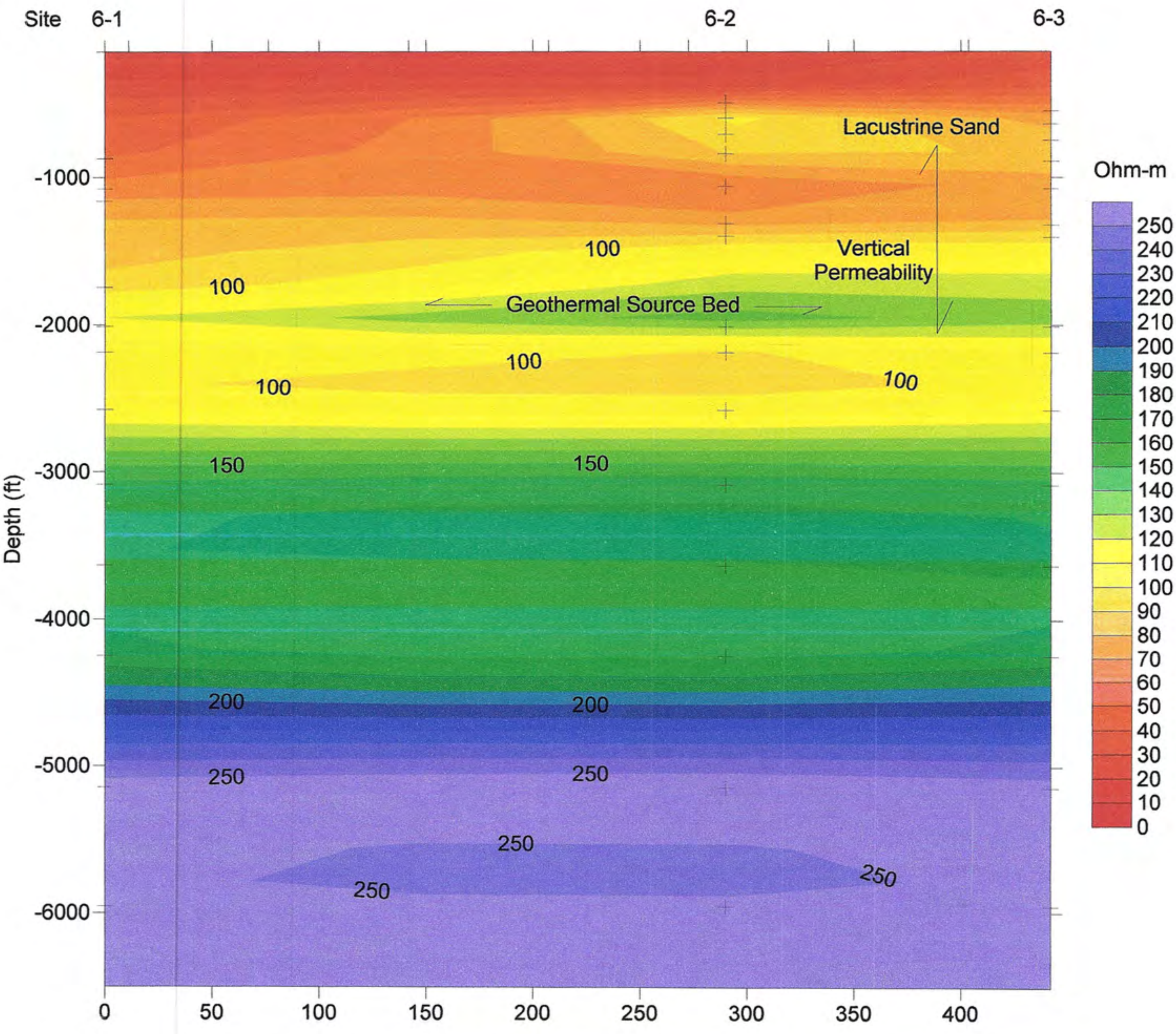
2-D Resistivity Image
Hydro Resources
Imaging Division

CANBY ED5SCALER
Extension
Surfer Image



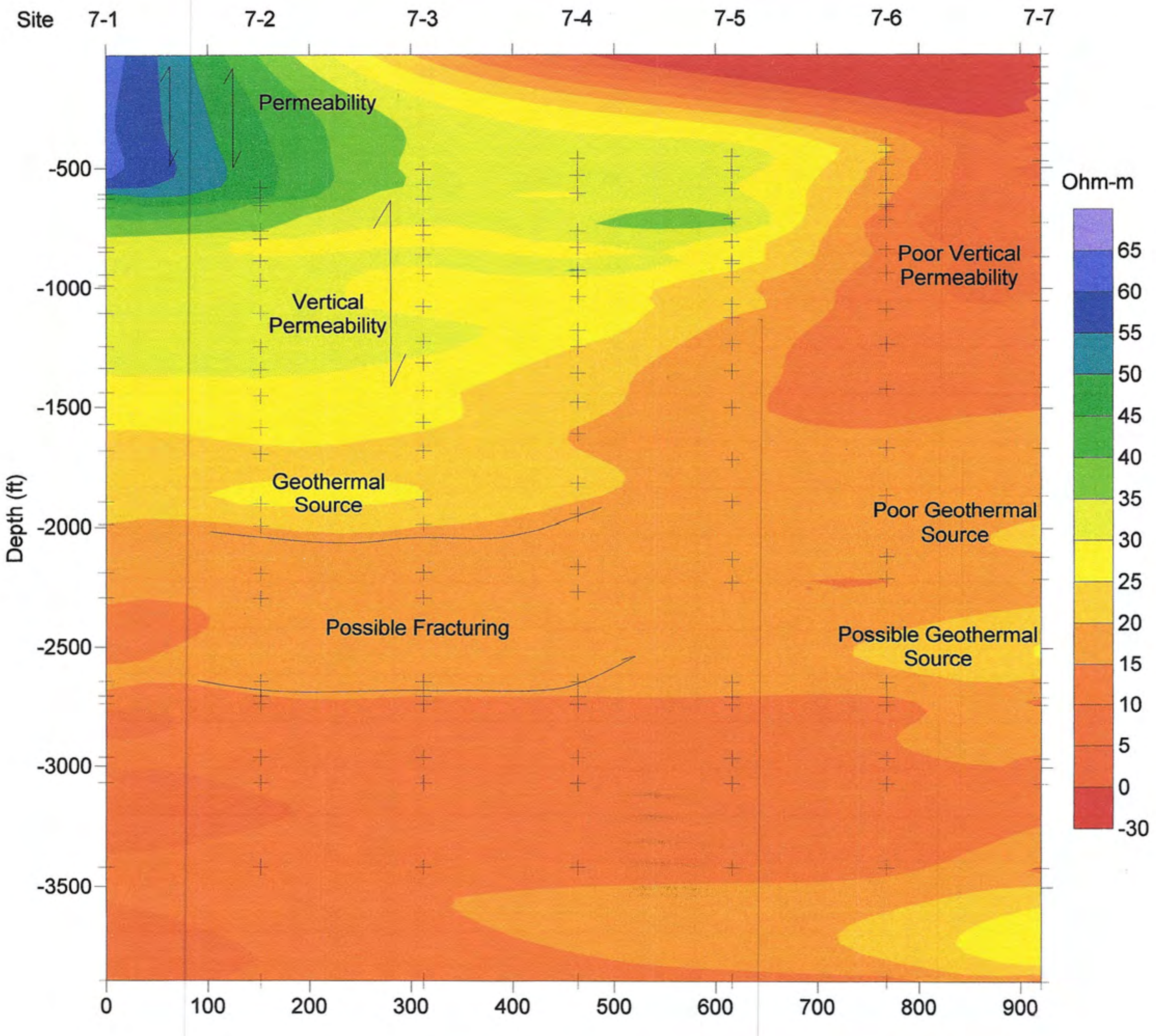
2-D Resistivity Image
Hydro Resources
Imaging Division

CANBY ED6SCALER
Surfer Image



2-D Resistivity Image
Hydro Resources
Imaging Division

CANBY ED7SCALER
Surfer Image



2-D Resistivity Image
Hydro Resources
Imaging Division

GPS COORDINATES

Canby Geothermal Project

Dale Merrick

Canby, Ca

			Line 1					
Iso 1-1a	41°	26'	53.4"	N	120°	52'	26.5"	W
Iso 1-1b	41°	26'	58.4"	N	120°	52'	21.8"	W
Iso 1-1	41°	27'	05.7"	N	120°	52'	07.9"	W
Iso 1-2	41°	27'	03.7"	N	120°	52'	02.6"	W
Iso 1-3	41°	27'	01.8"	N	120°	51'	57.2"	W
Iso 1-4	41°	26'	59.7"	N	120°	51'	51.2"	W
Iso 1-5	41°	26'	57.7"	N	120°	51'	45.3"	W
			Line 2					
Iso 2-1	41°	26'	59.9"	N	120°	53'	19.4"	W
Iso 2-2	41°	26'	58.5"	N	120°	53'	14.2"	W
Iso 2-3	41°	26'	57.3"	N	120°	53'	09.0"	W
Iso 2-4	41°	26'	55.6"	N	120°	53'	03.8"	W
Iso 2-5	41°	26'	53.8"	N	120°	52'	58.6"	W
Iso 2-6	41°	26'	42.8"	N	120°	52'	41.8"	W
			Line 3					
Iso 3-1	41°	26'	08.2"	N	120°	53'	20.9"	W
Iso 3-2	41°	26'	12.2"	N	120°	53'	14.7"	W
Iso 3-3	41°	26'	16.0"	N	120°	53'	09.4"	W
Iso 3-4	41°	26'	19.9"	N	120°	53'	04.1"	W
Iso 3-5	41°	26'	23.8"	N	120°	52'	59.0"	W
			Line 4					
Iso 4-1	41°	26'	02.9"	N	120°	53'	18.6"	W
Iso 4-2	41°	26'	07.1"	N	120°	53'	12.2"	W
Iso 4-3	41°	26'	11.1"	N	120°	53'	06.8"	W
Iso 4-4	41°	26'	15.0"	N	120°	53'	01.5"	W
Iso 4-5	41°	26'	18.8"	N	120°	52'	56.3"	W

			Line 5					
Iso 5-1A	41°	26'	20.8"	N	120°	51'	53.7"	W
Iso 5-1B	41°	26'	16.5"	N	120°	51'	55.3"	W
Iso 5-1	41°	26'	24.3"	N	120°	51'	53.9"	W
Iso 5-2	41°	26'	28.8"	N	120°	51'	55.3"	W
Iso 5-3	41°	26'	32.8"	N	120°	51'	57.5"	W
Iso 5-4	41°	26'	36.0"	N	120°	51'	55.9"	W
Iso 5-5	41°	26'	39.2"	N	120°	51'	51.3"	W
Iso 5-6	41°	26'	42.5"	N	120°	51'	46.6"	W
			Line 6					
Iso 6-1	41°	26'	31.1"	N	120°	52'	55.6"	W
Iso 6-2	41°	26'	29.2"	N	120°	52'	43.2"	W
Iso 6-3	41°	26'	30.7"	N	120°	52'	36.8"	W
			Line 7					
Iso 7-1	41°	26'	12.9"	N	12O°	52'	12.0"	W
Iso 7-2	41°	26'	11.5"	N	12O°	52'	05.8"	W
Iso 7-3	41°	26'	07.7"	N	12O°	52'	01.3"	W
Iso 7-4	41°	26'	10.8"	N	12O°	51'	56.2"	W
Iso 7-5	41°	26'	12.3"	N	12O°	51'	49.8"	W
Iso 7-6	41°	26'	16.5"	N	12O°	51'	46.2"	W
Iso 7-7	41°	26'	19.2"	N	12O°	51'	40.8"	W

Dir Name: ISO

File Name: CanbyED1.dat
CanbyED2.dat
CanbyED3.dat
CanbyED4.dat
CanbyED5.dat
CanbyED6.dat
CanbyED7.dat

Notes: Added two points to line 5.

STATEMENT OF PROJECT OBJECTIVES

Modoc Contracting Company Canby Cascaded Geothermal Development Project

NOTE: This Statement of Project Objectives includes all Phases of the Project Period; however, only Phase 1 is approved by this action. Phases 2/3 will be approved subsequent to the Competitive Down Select process, depending on the results of Department of Energy (DOE) review.

A. PROJECT OBJECTIVES

The Canby Project objectives are to fulfill its plan to expand its reliance on geothermal resources by producing more hot water, and using it to produce power as well as thermal energy. These objectives are more thoroughly described as follows:

Phase 1, Feasibility Study

The feasibility studies will incorporate a comprehensive economic analysis including factors of estimated capital cost; estimated cost of capital; revenue from power sales; revenue from thermal energy sales; routine operating costs; routine maintenance costs; planned major maintenance intervals and costs; property taxes; insurance costs; and administrative and management costs.

The goal of this phase is to complete a preliminary design for a cascaded geothermal system from wellhead to power plant and then to several direct-use applications. Canby is uniquely situated to create a number of new jobs as a result of the thermal energy that could be made available. It could also provide leadership to other communities in the vicinity who could also implement co-located energy facilities with geothermal resources for job creation and domestic use.

Phase 2, Construction

Procure, install, and commission a complete geothermal power plant with cascaded thermal applications. The system is to have an estimated capacity of about 250 kilowatts (kW) of power generation, integrating smaller, modular generation units. The project will use the power plant and waste heat to support several direct-use applications including a growing 67,000 square foot geothermal district heating system, a potential greenhouse operation, aquaculture operation and domestic wells.

The goal of this objective is to create a sustainable system that (A) generates green power for the local community; (B) provides thermal energy to support a greenhouse and aquaculture operation; (C) provides sustainable thermal energy for residential, commercial and agricultural units; and (D) eliminate the geothermal discharge to a local river.

Phase 3, Long Term Operations and Maintenance of the Facility

Operate Canby's geothermal energy facility for the term of the power purchase agreement, and provide data to the DOE, reporting on the economic, technical performance, and operating characteristics of the facility.

B. PROJECT SCOPE

The Canby Project started in 2000 with project partner I'SOT, Inc. for drilling of a geothermal production well (ISO-1) and installation of a district heating system for local residences, a greenhouse and Laundromat. The existing ISO-1 geothermal well was to be used as a limited injection well until a future injection well could be drilled.

This current funding opportunity offers an engineered solution for an entire cascaded geothermal system from production well to power plant then several direct-use thermal applications. Power purchase agreements and transmission options have been explored to determine the financial feasibility of the proposed project, but due to less than 1 Megawatt (MW) of power generation and the current low cost of natural gas, a power purchase agreement is not feasible.

Phase 2 funding would allow the power production systems to be installed, thereby initiating power production and expanding direct-use thermal distribution activities.

C. TASKS TO BE PERFORMED

As required by the Funding Opportunity Announcement for this Financial Assistance award, the Recipient must provide data to the DOE Geothermal Data Repository (DOE-GDR). The Recipient must provide data to the DOE-GDR as it is generated, but no later than the end of each reporting quarter in which the data is generated. The data will be submitted to DOE-GDR at https://gdr.openei.org. The data will be made publicly available via the National Geothermal Data System (NGDS) once it has been submitted and accepted into the DOE-GDR system. If the data is protected or subject to a moratorium, it will not be made publicly available until the moratorium has expired, and it will be held in a secure section of the DOE-GDR. Protected Data will be treated according to the Intellectual Property Provisions. Please refer to the Provision entitled “DOE Geothermal Data Repository (DOE-GDR) Instructions for Recipients” in the award Special Terms and Conditions for specific data submission instructions.

Project Management and Reporting

All non-proprietary data collected during the project will be made available to the public through the National Geothermal Data System (NGDS). Reports and other deliverables will be provided in accordance with the Federal Assistance Reporting Checklist following the instructions included therein. The contents of each technical report will conform to DOE requirements. The results will be shared with the geothermal community through papers.

PHASE 1, Budget Period 1 – Feasibility Study

Task 1.0 Conduct Environmental Review and Obtain Permits

An environmental assessment for the project will be performed to clear the way for Phase 2 development. The review is expected to be completed within the Phase 1 timeframe. An environmental and biological assessment was performed in 2003 on the previous geothermal district heating project so much information has already been gathered. The concurrent National Environmental Policy Act (NEPA)/California Environmental Policy Act (CEQA) review will begin immediately, with an expected finding of No Significant Impact/Mitigated Negative Declaration.

The Project manager will work to obtain permits concurrent with the environmental review and a DOGGR (Division of Oil, Gas, and Geothermal Resources) permit for injection well activities. Consultation and permits with the CARWQCB (California Regional Water Quality Control Board) will result in a discharge permit. The intention of the Canby Project is to have all permits ready to go for early Phase 2 implementation.

Task 2.0 Engineer Cascaded Geothermal Power and Thermal System

Design a scalable cascaded geothermal system, based on power plant modules. The design work will plan the use of discharge geothermal water through several direct-use applications. The design should include controls to integrate the system as a whole so that the energy from the new well is directed to where the need is most important. The design will include specifications and cost for all components and equipment.

Power generation equipment will be designed to operate in parallel with the local utility to offset retail power purchase or to operate a stand-alone microgrid in parallel with a propane-fired standby generator. The extent of the microgrid will depend on power generation capacity versus load. Priority for inclusion in the microgrid will be based on relative importance of the electrical load to sustainable operation of critical community services in extended off-utility operation. Operation priorities would include:

- Geothermal district heating and power generation
- Domestic water wells
- Food storage freezers
- Heat and power to greenhouses and aquaculture operations adequate to prevent crop loss
- Heat and power to community buildings

Subtask 2.1 Select Generator Module; Obtain Power Plant Specifications
Determine the most cost effective power plant option and select. Design/engineer the cascaded system in specified increments in order to quickly implement the resource found in the drilling of the new well. Criteria for selection of the power generation modules will include, but is not limited to:

- Power plant efficiency and economics at the available resource temperature
- Ease of operation and maintenance
- Compatibility with cascaded energy uses
- Compatibility with microgrid operation
- Power cycle cooling technology
- Appropriate controls/data acquisition system

Subtask 2.2 Complete Preliminary Engineering & Design
Complete preliminary engineering design and specification of the system to include cooling tanks, pumps, piping, electrical (micro-grid), control system, refrigeration safety equipment, building plans and specifications.

Subtask 2.3 Prepare Construction Cost Estimate
Identify all major components of the proposed project and estimate the cost of labor, materials and detailed design for the project.

Subtask 2.4 Complete Performance Projection
Estimate the net power production expected from the proposed project, considering the gross output of the generator, and estimate the electrical loads associated with the geothermal water pump, the cooling tower fan, the circulating water pump and other parasitic loads.

Task 3.0 Injection Site Study
The project has identified an attractive site for drilling an injection well because of the convenience of the location. Further analysis is needed to confirm or adjust the location and develop a model to verify the drilling site. After completion of a flow test, the proposed well will be used for injection or production based on project needs.

Subtask 3.1 Select Injection Site
The project geologist and reservoir engineer will create a model for understanding Canby's geothermal resource and select a suitable site for disposal of geothermal fluids from the new well above.

Subtask 3.2 Submit Injection Site Report
The project geologist and reservoir engineer will execute a report on the findings of the new injection well study and submit to the DOE project manager.

Subtask 3.3 Prepare Drilling Plan and Injection Test Plan
The goal of this task is to submit a drilling and injection test plan for DOE review.

Task 4.0 Power Sales, Interconnection Study and Transmission Analysis
Canby has several power transmission options. Analysis will be done to determine the potential revenue that could be earned from power purchase agreements with various utilities, and to determine the least cost to transmit power to the most promising substation and power purchaser.

Subtask 4.1 Interconnect Study
Complete interconnect study applications with either power company and the local electric cooperative and submit a detailed cost estimate for construction, interconnection, power sales negotiations, permit application and compliance.

Subtask 4.2 Domestic Electrification Study
Explore options to supply power to a district heating system, greenhouse operation and fish farm if no interconnect with grid is feasible, and report the findings.

Subtask 4.3 Interconnect and Domestic Electrification Report

Task 5.0 Prepare Monthly Progress Reports and Final Feasibility Report
Prepare monthly progress reports, indicating the progress of all aspects of the feasibility study effort, as well as at the conclusion of the study which includes design documentation.

Go/No-Go Decision for Phase 2 - Based on the progress review upon the completion of Phase 1, the project will be evaluated for Phase 2. The expected criteria for evaluation are the results from the feasibility study, review of the cascaded geothermal system, analysis of the injection site report, and compilation of all appropriate permits. The Recipient shall not continue into Phase 2 activities without written authorization from the DOE. Should Phase II not be initiated, the Phase 1 Report and all review presentation materials shall serve as the final technical report for DOE purposes.

PHASE 2, Budget Period 2 – Construction
Task 1.0 Obtain All Remaining Permits
This task is for obtaining all remaining project permits from State and County agencies.

Subtask 1.1 Obtain Remaining County Permits
Obtain all County permits and submit to DOE manager.

Subtask 1.2 Obtain Remaining State Permits
Obtain all State permits and submit to DOE manager.

Task 2.0 Procure, Install and Commission Equipment
This task will implement the feasibility study recommendations with respect to power plant installation, and connecting pipeline between ISO-1 and the new injection well (connecting pipeline from new production well to ISO-1 will be funded from CEC and Modoc Contracting funds). Connecting pipelines and heat exchange equipment will also be installed to supply the heating loads of the district heating system, greenhouse operation and finally the aquaculture facility.

Subtask 2.1 Prepare Bid Documents
Prepare bid documents for procurement and construction of the power plant and heat supply to cascaded energy uses; issue to potential vendors.

Subtask 2.2 Procure Equipment
Enter into agreements for procurement and construction.

Subtask 2.3 Oversee Construction
Manage construction progress and completion quality.

Subtask 2.4 Install Data Acquisition System

Subtask 2. 5 Startup, Commissioning and Report

Task 3.0 Drill and Test Injection Well
The goal of this task is to drill and test the geothermal injection well. The drilling shall proceed in accordance with the drilling plan produced in Phase 1, Task 3.3.

Subtask 3.1 Select Driller
Select an appropriate driller to drill a geothermal well at a site selected by the project geologist.

Subtask 3.2 Construct Drilling Pad
Construct a drilling pad and a containment basin according to regulatory requirements.

Subtask 3.3 Drill and Test New Injection Well
Drill, case and test the geothermal injection well. Conduct well logging and injection test according to industry good practices for geothermal well logging.

Subtask 3.4 Analyze Injection Test and Report Results
Analyze the results of the injection test and submit report to the DOE.

Task 4.0 Implement Power Transmission Feasibility Study

Subtask 4.1 Secure Power Purchase Agreement
Secure power purchase agreements and install power transmission and interconnect equipment; or

Subtask 4.2 Implement Domestic Electrification
Implement power transmission to community, greenhouse and aquaculture operations.

Phase 3, Budget Period 2 – Long Term Operations and Maintenance of the Facility

Task 1.0 Facility Operation
Operate the facility under the terms of the policies of the operations and maintenance management procedures, which may be modified form time to time.

Task 2.0 Final Report
Complete the final report to the DOE summarizing the results of the plant operation after two years duration.

Project Area.