Geochemical sampling of thermal and nonthermal waters in Nevada: Evaluation of geothermal resources for electrical power generation and direct-use applications

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Abstract

Nevada has extensive geothermal resources; approximately 216 MW (net) of geothermally generated electricity are produced and low to moderate temperature geothermal fluids are used for space heating and in vegetable dehydration. There is great potential for more use of geothermal resources in all the above categories as well as industrial processing and mineral extraction. There are more than 350 known geothermal systems in Nevada; at least 30% of these do not have modern, complete water analyses based on the data compilation by Garside (1994), and many of these have analyses from one spring in a group of springs, but it is not know from which spring in a group that the sample was taken or if it was the highest temperature spring in that group. Additional data are available from a previously digitized database containing all springs and wells on 7.5' quadrangles. From these digitized site locations, there are ≈1000 springs for which a location is known, but for which there are no available temperature (or chemical) measurements. Although many of these sites are within known geothermal areas and are located near springs for which temperature and/or geochemical data are available, many of these sites are not so located, and require evaluation before the geothermal potential of the area can be assessed.

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Introduction

There has been considerable research on the geochemical characteristics of various Nevada geothermal resources. Several power plants are currently operational in the state (see Fig. 1), as well as several direct use applications. Considerable hydrologic and geochemical data are available at these particular sites. However, there is an abundance of additional sites throughout the state that may have potential for utilization of geothermal resources, but for which insufficient information is publicly available to evaluate the individual resources.

Figure 1 illustrates the current information available for various thermal springs and wells throughout Nevada. The data used to construct this map were obtained from several sources: Trexler et al. (1983), GEOTHERM, WATSTORE, Southern Methodist University (SMU) web site, Garside (1994), and Shevenell et al. (2000). From this map and the work of Garside (1994), 208 of the depicted springs and 109 of the plotted wells have adequate chemical analyses from which preliminary evaluations of the geothermal resource potential can be made. Most of these sites have generally complete major and trace element analyses available, yet few have any stable isotope information, or chemical data from nearby cold waters from which mixing between deep-seated, high temperature thermal and shallower nonthermal waters can be evaluated. From the data compilation required to construct Figure 1, there are 88 areas for which there are no reliable chemical analyses available.

Additional springs and wells were digitized from 7.5' topographic maps when their names included "hot" or "warm," and these sites are also illustrated on Figure 1 as those that do not have temperature data. From these data, there are ≈1000 hot or warm springs for which there are neither geochemical data, nor even the most basic data of temperature. Therefore, we propose to conduct field evaluation and sampling of additional thermal sites in Nevada to determine the geothermal resource potential of sites within areas relatively close to towns or existing power transmission lines with sufficient capacity. The proposed study will expand and enhance the present knowledge of Nevada's geothermal resources by providing new water chemistry information on less-studied geothermal areas. These data will allow delineation of poorly characterized or understood geothermal areas in Nevada that may be developed for electrical power generation or direct-use applications.

In order to begin filling in gaps in the data on hot and warm springs in the state, ≈100 springs that have previously not been sampled will be visited, documented, and the fluids sampled for major and trace element chemistry, stable isotopes of water, and noble gas analyses (B. Mack Kennedy, LBNL will conduct the noble gas analyses under separate DOE funding, at no cost to this project). The results of this proposal will assist in exploration and identification of new geothermal resources in Nevada. As such, this proposal addresses the "Resource Assessment" part of this RFP.

Although there are numerous springs and wells in southern Nevada (Clark, southern Nye, and Lincoln Counties) that do not have adequate data to fully evaluate geothermal resource potential, these sites will not be sampled in the proposed work for several reasons. First, most of the sites met the criterion for inclusion on the map of being 10°C above average annual ambient temperature by only a few tenths to a few degrees Celsius, and hence, their potential as a geothermal resource is borderline. Second, although many of these sites in southern Nevada do not have temperature data, they are near wells and springs with complete temperature and chemical data available from which to evaluate the geothermal potential (e.g., southeast of Amargosa Valley, southern Nye County). Third, a geothermal resource assessment of this area was conducted by Flynn et al. (1995) and no significant resource

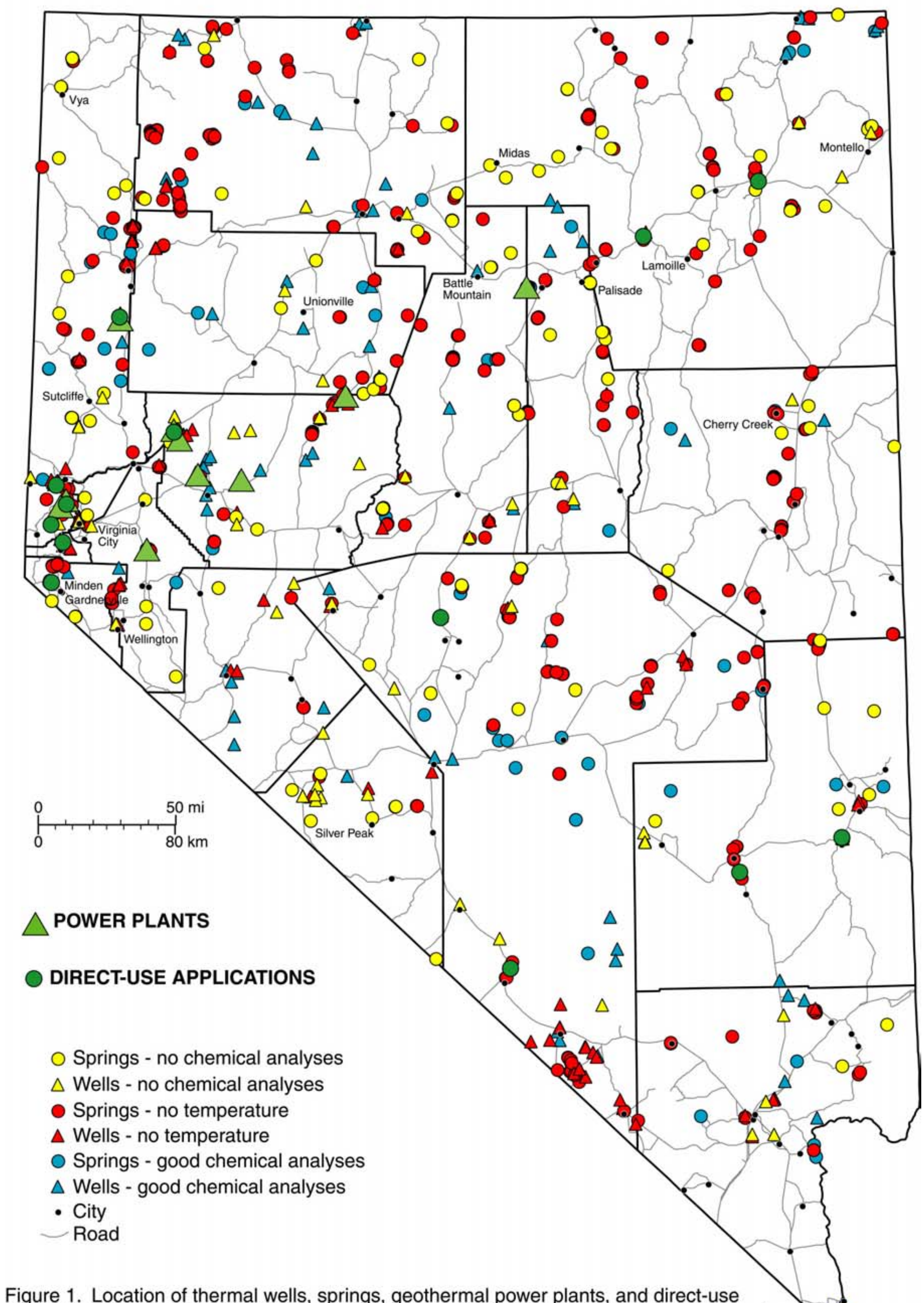

Figure 1. Location of thermal wells, springs, geothermal power plants, and direct-use applications in Nevada. Red and yellow sites have insufficient data from which to evaluate geothermal potential.

potential was identified in the region surrounding Yucca Mountain where most of these points are plotted on Figure 1.

In evaluating Nevada Bureau of Mines and Geology Open File Report 94-2 (Garside, 1994) analyses at locations north of 40° latitude, we identified ≈90 that should be sampled, if we avoid the carbonate aquifer terrain of eastern and southeastern Nevada. Many of the unsampled areas are obscure, poorly located, cooler, not flowing, or wells that may not be accessible. Therefore, not all of these localities will be sampled because some of the spring locations are obscure, they are not too warm, or there are only drill holes that may not be open in the area. Many of the selected areas are important because many of these are in the Battle Mountain Heat Flow High and could represent cooled or mixed outflow fluids from a concealed higher temperature resource. Some areas that require additional data collection include the following (in no particular order):
(1) Northern Washoe County and **(2)** Smoke Creek Desert (The hot springs are not very hot, but they are in area of high heat flow.); **(3)** Southeast Humboldt County. (There are several springs with poorly characterized chemistry.); **(4)** Soldier Meadows (Available water chemistry analysis is not reliable.); **(5)** Western Elko County (There are some obscure springs, within 50-60 km of Beowawe.); **(6)** Spring in Independence Mountains; **(7)** Spring near Deeth; **(8)** Possible spring south of Wells and 12-mile spring north of Wells (This system is probably not a very hot (100°F at Wells, but may be well mixed). Sampling in this area might help characterize the geothermal system along 15 miles of a fault zone and determine if there are any resources that are hot enough for moderate temperature uses.); **(9)** Some poorly known springs 30-50 km north of Bradys (there are higher temperature gradient wells in this area, and there could be concealed resources that these springs might reflect.); **(10)** Springs in Battle Mountain-Golconda area, including some near Humboldt River (These springs could have a large River component, but may indicate concealed resources.); **(11)** Cooler warm springs near Beowawe (Sampling would help understand mixing, etc.); **(12)** Northeast Elko County (Probably lower priority); **(13)** The Pyramid and Anahoe Island area (these would help understand the Needle Rocks geothermal area); **(14)** Eightmile Flat/ Carson Sink. Geothermal wells, and springs; **(15)** Fallon Naval Air Station (Data are probably available from the Navy.); **(16)** Spring near Silver Springs (only warm, but along a projection of the Walker Lane structural zone); **(17)** Several springs in SW Lander County; **(18)** Fish Lake Valley (There may be company analyses available.); **(19)** Warm springs and/or wells in Clayton Valley (Silver Peak); **(20)** Alkali hot spring north of Goldfield (only one sample; no isotope or trace element data); **(21)** Blue Mountain (Mining companies may release data on this area.); **(22)** Springs near Eureka (Interest has been expressed by Jon Hutchings, Eureka County Natural Resource Manager to develop geothermal resources, although insufficient information is currently available to assess any resources).

Typically, ≈7 springs will be selected from each area, with five thermal springs (including one from the hottest spring in the group) and two nonthermal springs being sampled, depending on availability at the individual sites or regions. Additional water samples may be collected from cold springs in other areas of the state where geochemical data currently are available for nearby hot waters (Garside, 1994).

Approach

Stable isotope data, tritium (^{3}H) and carbon-14 (^{14}C) data have not yet been collected from any of the springs identified previously. These data are required to determine the origins and possible ages of the nonthermal fluids and compare to the thermal fluids to be sampled. These data will assist in determining the degree and extent to which these aquifers may be hydrologically connected.

Data from previous work (Mariner et al., 1975; Garside, 1994) will be used as a starting point. The goals of the proposed work include: (1) identifying possible recharge waters/areas of the different geothermal systems; (2) estimating mean residence times of selected fluids; and (3) identifying similarities and differences among the waters to evaluate possible mixing relationships in different areas. These three goals will be accomplished by (1) collection and evaluation of stable isotope data, (2) evaluation and modeling of ^{3}H and ^{14}C data to distinguish fluid ages between the different subsystems, and (3) evaluation of major and trace element geochemical data in conjunction with (1) and (2).

Fluid samples will be collected from ≈100 springs in the areas selected from those noted above. Selected cold springs in the adjacent ranges will be sampled for stable isotopes of water to obtain a better record of variations in these isotopes with elevation. A preliminary evaluation of the recharge areas for the different thermal and nonthermal waters at the study sites will then be made.

Major and trace element samples will be filtered through 0.45 μm filter papers to be consistent with previous samplings of other geothermal waters reported (e.g., Garside, 1994). A 100 ml sample for cation analyses (acidified with ultra-pure HNO_3 to pH<2), and a 250 ml sample for anion analyses will be collected and analyzed at the University of Nevada, Reno, Mackay School of Mines (MSM) analytical laboratories that include Micromass Platform inductively coupled plasma-mass spectrometer with Hexapole collision cell and Merchantek UV laser ablation microprobe. Unfiltered water for δD and $\delta^{18}O$ (60 ml sample) and ^{3}H (500 ml sample) will collected. Stable isotopes will be analyzed at the MSM isotope lab, ^{3}H will be analyzed at the University of Miami, and ^{14}C will be analyzed by Betadyne. Due to the high cost of ^{3}H and ^{14}C analyses, only a subset of the springs will be selected for analysis, distributed among the areas selected. Sample volumes for ^{34}S, ^{13}C and ^{14}C will vary depending on the total SO_4 and HCO_3 (measured in the field) present in the particular water sample. Samples for ^{34}S will be filtered through 0.45 μm filters and the pH will be lowered to ≈4 with dilute HCl. In order to precipitate $BaCO_3$, $BaCl_2{\bullet}2H_2O$ will be added and the precipitate allowed to settle. $^{13}C_{DIC}$ will be preserved with NaN_2 to prevent biological activity. Both will be analyzed at the MSM isotope laboratory. Samples for ^{14}C will also be preserved in the field through addition of NaN_2, and will be analyzed using accelerator mass spectrometry in order to minimize sample volumes and the more involved sampling procedures and concomitant exposure to air of the larger samples needed for conventional dating.

These samples will be collected in collaboration with B. Mack Kennedy (LBNL) who is currently funded to sample and analyze geothermal waters in Nevada for noble gases and selected isotopes. All sampling and analyses will be coordinated through Kennedy in order to maximize the benefits of each sampling and evaluation program and avoid duplication of efforts.

Results

The study will expand and enhance the present knowledge of Nevada's geothermal resources by providing new water chemistry information on known geothermal areas for which there is currently little or no information that is publicly available. These data will allow delineation of new, or poorly understood, geothermal areas in Nevada that may be developed for electrical power generation or direct use applications. Geochemical indicators of fluid flow paths and results from the ^{13}C, $\delta^{18}O$, δD, ^{34}S will all be used as natural tracers in the individual groundwaters. These data will allow us to begin to identify distinct and different origins and evolutions of the various waters when used in conjunction with the evaluation of the inorganic chemical variations in the systems. Results from the ^{3}H and ^{14}C will allow evaluation of differences in mean residence times of the various fluids at selected sites. From the $\delta^{18}O$, δD and radiogenic isotope results, an initial assessment of the timing and location of recharge to selected aquifer systems will be gleaned.

The newly acquired geochemical data will be used in conjunction with the currently available geochemical data (e.g., Garside, 1994) to evaluate geothermal resources at selected sites throughout the state of Nevada. Due to interest by Elko County Commissioners (Warren Russell) and Eureka County (Jon Hutchings), one site near each town will be selected for these more detailed evaluations.

A suite of geothermometers will be computed and evaluated. In conjunction with estimated geothermometer temperatures, possible mixing relationships will be computed using stable isotope data and selected major and trace element data (e.g., B., Cl, Li, Br) for each site or region to provide a preliminary assessment of likely reservoir temperatures from which the mixed spring waters originated. The results of the geochemical analysis and evaluation will be used to assess the hydrologic relationships between the thermal and the nonthermal waters, and relationships relative to fault locations will be illustrated on maps constructed with the use of GIS techniques.

Simple computations will be used to estimate possible depths to the reservoirs using information such as known heat flow, thermal gradients (SMU, 2000), boiling point to depth curves, and an empirical trend identified for Nevada (Flynn and Schochet, 2001). The results of the proposed work will expand our current knowledge of the distribution and characteristics of geothermal resources in Nevada. Present knowledge of resource potential in Nevada will be enhanced by providing an evaluation of selected known resources in the state that are near population centers, and noting likely temperature and depth of the resource, and whether the resource might be used for electrical power generation or direct use applications. Trace elements deleterious to aquaculture will also be analyzed and reported. The results of the proposed work will be publicly available and can be used by others to move to the next step in the exploration process to verify the resource These tasks will be accomplished in year 1, and additional sites added in subsequent years if funding becomes available.

Deliverables

Principal investigators will present results at professional conferences, including the 2002 Geothermal Resources Council meeting where preliminary results of a summer sampling campaign will be presented. At least one journal article will be published in a refereed journal such as the Geothermics, or Journal of Volcanology and Geothermal Research,. There will be no restrictions on the distribution and use of the acquired data and associated evaluation of the geothermal potential of the sites throughout Nevada. All data will be publicly available for free on an NBMG web page, and individual operators in Nevada will be notified of the existence of the data.

Estimated Budget:

Year 1: $113,723 (sample and analyze 100 springs; assess ≈15 sites; produce report on web page including a site ranking for geothermal potential of the 15 sites)

Year 2: $120,000 (continue sampling additional sites, analyze waters, assess additional sites; produce report on web page)

Year 3: $ 40,000 (finalize reports, journal articles and databases and present results at professional meetings)

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Professional Preparation

New Mexico Institute of Mining and Technology	Geology	B.S. 1984
University of Nevada, Reno	Hydrogeology	Ph.D. 1990

Areas of Expertise

Groundwater hydrology, isotope hydrology, geothermal systems, aqueous geochemistry

Research Grants

Twenty-two (six geothermal) funded research projects for a total of $1,212,000 since 1994.

Appointments

Associate Director, Great Basin Center for Geothermal Energy, UNR, 2001 – present
Associate Research Hydrogeologist, Nevada Bureau of Mines and Geology, 1993 –present
Research Associate, Oak Ridge National Laboratory, 1990-1993.
Research Assistant, Desert Research Institute, Reno, Nevada 1987-1990.
Research Assistant, Los Alamos National Laboratory, 1984-1987.

Selected Publications (of 27 refereed journal articles, 22 peer reviewed publications, 10 symposium papers, 10 other articles, 66 abstracts, and 32 contract reports)

Skalbeck, J.D., L. **Shevenell**, and M. Widmer, 2002, Mixing of thermal and non-thermal waters in the Steamboat Hills area, Nevada. Geothermics, *v.* 31(1): 69-90.

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Professional Assignments

Steering committee member for the Acid Drainage Technology Initiative (ADTI), Metal Mining Sector (MMS), 2000-2002.

Chair, Committee on Pit Lakes, ADTI-MMS, 2000-2002.

NIWR-USGS National Competitive Grants Program Review Panel, 2000-2002.

Steering committee member for the Western State Pit Lake Conference, 1999–00.

Member of the Interagency Abandoned Mine Lands Environmental Task Force, 1999-02.

Member of the Mining Life-Cycle Center Council, 2000-2002.

Co-organizer/convener of the Nevada Pit Lakes Working Group, 1997–98

Member, UCCSN Regents committee for DRI presidential search 1997–98.

Member and Chair of numerous UNR internal committees.

Current Support

Department of Energy - Idaho Operations Office ($933,000): Expanding Geothermal Resource Utilization in Nevada through Directed Research and Public Outreach (Shevenell, Taranik) 1/1/02-2/28/03.

Nevada State Energy Office (DOE, Geothermal Division pass-through) ($74,728) Nevada Geothermal Resources Database and Web Site (Shevenell, Garside) 9/1/01-8/31/03.

U.S. Geological Survey, ($34,245) Construction of an Electronic Database of Geothermal and Mineral Water and Gas Samples Collected by the USGS in the Western U.S. (Shevenell) 6/1/01-8/31/02

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EDUCATION

B.S. Geology, Iowa State University, 1965

M.S. Geology, University of Nevada, Reno, 1968

AREAS OF EXPERTISE

Geologic mapping, volcanic geology, energy resources geology, hydrothermal mineral deposits, isotopic dating of igneous rocks and mineralization.

RESEARCH GRANTS

Twenty-seven funded research projects, as principal and co-principal investigator, for a total of approximately $2,800,000.

PROFESSIONAL WORK EXPERIENCE

A. Research Geologist (Rank I - IV), Nevada Bureau of Mines and Geology,
University of Nevada, Reno (1968-present).

B. Research Assistant, Nevada Bureau of mines and Geology,
University of Nevada, Reno, Mackay School of Mines
(1965-1968)

SELECTED PUBLICATIONS (of more than 120 citations on Nevada geology)

Related Publications (Geothermal)

Shevenell, L., L. **Garside**, and R. Hess, 2000. Nevada geothermal resources. Nevada Bureau of Mines and Geology, Map 126.

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CURRENT SUPPORT

Nevada State Energy Office (DOE, Geothermal Division pass-through) ($74,728) Nevada Geothermal Resources Database and Web Site (Shevenell, Garside) 9/1/01-8/31/03.

U.S. Geological Survey (STATEMAP) ($20,008 plus $29,264 cost share) Geologic map of the north half of the Virginia City Quadrangle, Nevada (Garside, Castor) 5/1/01-4/30/02.

U.S. Geological Survey (STATEMAP) ($14,000 cost share only) Geologic map of the Minden Quadrangle, Nevada (Ramelli, dePolo) 5/1/01-4/30/02.

U.S. Geological Survey (STATEMAP) ($7,440 cost share only) Geologic map of the Sutcliff Quadrangle, Nevada (Faulds, dePolo, Henry) 5/1/01-4/30/02.