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ASSESSMENT OF LOW – TO MODERATE –
TEMPERATURE GEOTHERMAL RESOURCES OF
NEVADA

Final Report for Period April 1978–June 1979

By
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Work Performed Under Contract No. ET-78-S-08-1556

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Nevada Bureau of Mines and Geology
Reno, Nevada

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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ASSESSMENT OF LOW- TO MODERATE-TEMPERATURE
GEOTHERMAL RESOURCES OF NEVADA

FINAL REPORT
FOR THE PERIOD

1 APRIL 1978 - 30 JUNE 1979

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U. S. DEPARTMENT OF ENERGY
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ABSTRACT

In April, 1978, the Nevada Geothermal Assessment Team (NGAT), which is composed of personnel from the Nevada Bureau of Mines and Geology (NBMG), began a one-year assessment of Nevada's geothermal resources. The assessment is part of the U. S. Department of Energy (DOE) sponsored geothermal State Coupled Program. The ultimate goal of the project was to produce a geothermal resource map of Nevada that provided detailed information on low- to moderate- temperature geothermal systems, and that also evaluated their potential for direct, non-electric utilization. The investigation consisted of these six tasks:

1. Edit and verify existing USGS GEOTHERM file for springs and wells in Nevada.
2. Supplement GEOTHERM file with NBMG data.
3. Digitize the location of springs and wells on 1:250,000 scale maps of Nevada.
4. Update water chemistry by sampling areas devoid of data.
5. Field check springs and wells designated as hot or warm, and
6. Prepare a 1:500,000 scale map of Nevada that evaluates geothermal resource areas of potential for direct use.

This report describes the completed tasks, delineates problems encountered, and presents additional miscellaneous information that augments the investigation.

The information shown on the accompanying map can be divided into two categories: spot data and regional assessment (or potential evaluation). Specific geochemical information, such as temperature, pH, and chemical species, is represented by approximately 300 circle and diamond-shaped symbols. Thirty-seven larger regions were evaluated for their potential for direct-use on the basis of a numerical technique, which is fully described in this report. An additional 15 sites were designated as areas that may provide a basis for investigations, but that lack sufficient data for a detailed potential evaluation at this time.

TABLE OF CONTENTS

	Page
ABSTRACT	i
STATEMENT OF WORK.	1
Task One: Editing and verifying GEOTHERM.	1
Task Two: Supplementing GEOTHERM data file.	1
Task Three: Digitization of geothermal springs and wells.	2
Task Four: Updating water chemistry file	4
Task Five: Field checking springs and wells.	4
Task Six: Map preparation	6
MISCELLANEOUS ACTIVITIES	12
1. Current and Planned Usage	12
2. Assessment and Exploration.	17
3. Liaison with Nevada Department of Energy.	18
4. Meetings.	20
EXPLANATION OF POTENTIAL EVALUATION NUMERICAL TECHNIQUE.	21
APPROACH-RATIONALE	21
APPLICATION OF THE SCHEME - AN EXAMPLE	30
REFERENCES	31

LIST OF FIGURES AND TABLES

	Page
FIGURE 1. GEOTHERM data for Nevada	3
FIGURE 2. Map of surveyed sites.	7
FIGURE 3. Temperature measuring technique.	9
FIGURE 4. Temperature reading at map site M-1.	9
FIGURE 5. Temperature measurement and pH buffer equilibration.	10
FIGURE 6. Temperature measurement, Trego Hot Springs	10
FIGURE 7. Measuring pH <u>in situ</u>	11
FIGURE 8. Calcareous tuffa mound, map site 31.	11
FIGURE 9. Food dehydration plant at Bradys Hot Springs	13
FIGURE 10. Temperature profiles of two wells, Caliente, Nevada.	15
FIGURE 11. Geothermal well test	16
FIGURE 12. Photographic sequence of erupting well	19
FIGURE 13. Weighting Factors and Their Limits for Industrial Process Heat Applications	24
FIGURE 14. Weighting Factors and Their Limits for Residential/Commercial Space Heating Applications.	27
TABLE 1. Chemical analyses of water from sampled sites.	8
TABLE 2a. Hypothetical Industrial Process Heat Example, Case A	29
TABLE 2b. Hypothetical Industrial Process Heat Example, Case B	29

STATEMENT OF WORK

Task One: Editing and verifying existing GEOTHERM¹ data file for Nevada springs and wells.

The existing GEOTHERM file contained 544 separate entries for the State of Nevada. Of those, 340 were in the regular file and an additional 204 were in the USGS WATSTOR file. Because of the poor quality of the WATSTOR data, the inability on our part to trace the original references, and on the recommendation of J. Swanson, the WATSTOR file was eliminated from further consideration. The remaining 340 entries were edited and verified on the basis of a format suggested by GEOTHERM file supervisor Swanson. The editorial work consisted of corrections, additions, and deletions for the following items: source name; source location, including State, County, digitized latitude and longitude, Township, Range, and section; temperature (in degrees centigrade); flow rate; aqueous geochemistry; and miscellaneous information. All corrections, additions, and recommended deletions were forwarded to the GEOTHERM file supervisor in November, 1978.

Problems involving changes in location accounted for almost 70 percent of the total of 330 corrections. The remaining 30 percent involved changes in the literature reference, temperature, spelling, source name, maps, and scientific units.

Task Two: Supplementing the USGS data file GEOTHERM with NBMG data.

The NBMG compiles and collects data on geothermal springs and wells and has approximately 1100 individual data sheets on file. These sheets contain

-
- 1) GEOTHERM is the name of a U. S. Geological Survey computer file which contains data on physical, chemical, and geological aspects of geothermal springs and wells throughout the United States.
Mr. J. Swanson, USGS, Menlo Park, CA, is the GEOTHERM file supervisor.

location and temperature information and, in many cases, detailed geochemical analyses of the geothermal fluids. In addition, some of the sheets contain miscellaneous information including proximity to faults, associated mineral deposits, and case histories of prior use.

Using the format for data entry and the "short" coding forms provided by Mr. Swanson, NBMG personnel completed and submitted 439 records by mid-June, 1978. An additional 572 data sheets were completed using a new, more streamlined version of the shortform, and these forms were submitted in February, 1979. The GEOTHERM data file should now contain approximately 1400 valid entries. Both the amount of data and the nature of the records are represented in Figures 1a, 1b, and 1c. The following table lists the minimum requirements for the classification of GEOTHERM records:

Total Chemistry	SiO ₂ , Na, K, Ca, Mg, HCO ₃ , CO ₂ , SO ₄ , Cl, pH. (in addition, may contain minor and trace element analyses as well as stable light isotope analyses)
Partial Chemistry	Contains some, but not all, of the analyses listed under Total Chemistry. (in addition, may contain minor and trace element analyses as well as stable light isotope analyses)
No Chemistry	These records list only location and temperature and generally consist of shallow depth, low-temperature water wells.

Task Three: Digitization of 1:250,000 AMS sheets that have identified geothermal springs and wells.

This task was completed in two stages. In the first stage, 439 springs and wells with temperatures greater than 35°C were plotted on the AMS sheets and the latitude and longitude of each was digitized by hand using the

Figure 1a. $T > 35^{\circ}\text{C}$, 794 Records

Figure 1b. $20^{\circ} < T < 35^{\circ}$,
608 Records

Figure 1c. Total Existing

GEO THERM File (Sum of
1a and 1b), 1402 Records

sliding-grid method. In the second stage, the locations of the remaining springs and wells, those with temperatures between 20°C and 35°C, were digitized with the help of a PDP-11/34 computer and a peripheral digitizing tablet. The accuracy of this technique is very good; known latitude and longitude coordinates could be located within four seconds and six seconds respectively, which is equivalent to approximately 135 meters in a north-south direction and 200 meters in an east-west direction.

Task Four: Updating water chemistry file by collecting water samples for chemical analysis in areas devoid of chemistry data, and

Task Five: Field checking springs and wells designated hot or warm.

These two tasks are discussed together in this report because the field work involved was coordinated to accommodate sample collection, resolving uncertain location problems, and acquiring in situ temperature, conductivity, and other physical data.

After a thorough review of the NBMG files, approximately 200 separated data sheets were found to have inadequate information regarding either location, temperature, or water chemistry. One-hundred data sheets were eliminated from further consideration on the basis of duplication of existing data, lack of surface water (including capped and locked well bores), and inaccessibility (including abandoned and condemned mine shafts and wells drilled in the middle of playas). Approximately 100 individual springs and wells were subsequently selected on the basis of cost-effective criteria. Preference was given to those locations for which the density of existing geothermal data plotted on the 1:250,000 scale AMS sheets, was low. Additional criteria for selection included low reliability of either conflicting or uncertain data and those "border-line" cases that, alone, did not qualify but were within a reasonable driving distance

of an area that did require field work. Many of the location uncertainties resulted from using Waring (1965) data, which were compiled over a long period of time and include areas of Nevada that remain unsurveyed. Examination of the 1:250,000 scale AMS sheets failed to provide the locations of many of the springs cited by Waring (1965), some of which were reported only by township and range. On the other hand, AMS air photo stereo pairs and 7 1/2 and 15 minute quadrangle maps, when available, were often useful for determining the locations of the larger springs. Those springs that could not be accurately located by either air photo or map were grouped for field checking.

The approximate locations of the 100 selected springs and wells were plotted on a 1:1,000,000 scale topographic map of Nevada. Secondary roads leading to springs and wells were penciled in and the sites grouped by vehicular accessibility, rather than by geographic area. The areas visited included every part of the state with the exception of the Las Vegas area.

The field work for each site included the following tasks:

- A. Temperature Measurements: This included both surface and down-hole temperature measurements up to 100°C and to a depth of approximately 300 m (1000 ft). All temperature recording equipment was calibrated under laboratory conditions, with a mercury-in-glass thermometer, in boiling distilled, demineralized water.
- B. pH and Electrical Conductivity: These were measured in situ with portable field pH-conductivity meter.
- C. Bicarbonate/Carbonate Titration: This was performed within 12 hours of sample collection to insure accurate results.
- D. Sampling: Site-specific water samples were collected when necessary. Two samples were taken from each site, a diluted sample (1:10, sample:distilled water) for silica analyses, and a "raw" sample for anion and cation analysis.

E. Photographic record: Sampled sites and diagnostic features of hot springs were photographed in black and white, and color.

Arrangements were made with the Desert Research Institute/Center for Water Resources Research, University of Nevada, Reno, for major cation and anion chemical analysis. Their analysis consisted of the following: $\text{SO}_4^{=}$, Cl^- , SiO_2 , K^+ , Na^+ , Ca^{++} , Mg^{++} , and F^- .

Field investigations included approximately 81 sites. In situ measurements of physical and chemical parameters accompanied by sample collection were completed at 24 locations. The location of all surveyed sites is shown in Figure 2 and data presently available are given in Table 1. Factors that precluded measurements and/or sampling at the remaining sites included: 1) lack of sufficient surface water (4 sites); 2) water temperatures below 20°C (33 sites); 3) inaccessible, not found, and unable to sample (20 sites). Data from the sampled areas were coded and submitted to the U.S.G.S. file GEOTHERM in February, 1979.

Approximately 5000 miles of travel and 700 man-hours were required to complete the surveying-sampling program (see Figures 3 through 8).

Task Six: Preparation of a multi-colored map of Nevada ranking areas for potential direct utilization at a scale of 1:500,000.

The NGAT has prepared a map of Nevada that not only ranks areas for potential direct utilization of geothermal resources, but also provides detailed geochemical and physical data on those resources. The map is designed with both technical and non-technical users in mind and is accompanied by a legend and separate text which thoroughly describes its use and application.

The map contains symbols that provide data for specific springs and wells. These symbols incorporate the following: 1) temperature (°C); 2) location; 3) pH;

TABLE 1. Chemical analyses of water from sampled sites.

Sample Number	Location Twn/Rng/Sec	T °C	pH	Specific Conductance Micromohs	HCO ₃ ⁻ ppm	Cl ⁻ ppm	SO ₄ ⁻ ppm	F ⁻ ppm	Na ppm	K ppm	Ca ppm	Mg ppm	SiO ₂ ppm	Anion/Cation (Equivalents)
M-1	18N/20E/28	94	8.5	3600	188	885	150		710	78	5.9	0.11	295	.992
56	15N/20E/16	24	8.8	570	48	21	148		82	2	13.5	0.33	33.4	1.033
67S	17N/39E/25	46	8.3	763	253	25	112	9.3	163	8.05	1.17	0.14	128	.999
67N	17N/39E/25	92	7.7	733	243	24	108	8.8	156	8.0	6.2	0.14	116	1.009
73/A	14N/43E/34	25	6.7	2630	1519	52	82		575	40.5	39.3	2.25	96	.996
73/B	14N/43E/34	82	7.2	2400	1385	48	76		555	40.5	11.3	2.46	92.5	.988
82S	13N/44E/32	32	7.5	480	202	12	38	4.0	73.5	12.5	23.2	0.95	94	.967
69	17N/45E/13	58	6.5	1180	673	22	51		201	35.0	44.4	3.10	80	1.048
1	44N/20E/18	28	8.9	318	106	23	23		57.5	3.9	5.8	0.34	41	.995
7	45N/33E/21	27	7.3	250	94	15	14		27.5	6.3	14.2	2.76	53	.983
8	44N/27E/12	40	7.7	175	68	7	13		31.5	6.3	1.4	0.10	67	.986
45	33N/25E/3	83	7.9	2350	150	505	182	3.8	445	9.6	12.5	0.15	82	1.022
18	43N/51E/19	51	7.0	875	476	17	37		146	19	39	5.8	41	.978
22	47N/65E/11	35	8.0	400	190	2.3	19		19.2	6.65	35.2	10.5	21	.988
24	38N/59E/14	36	8.0	1990	1149	30.5	2	21	450	35.5	3.10	0.45	151	1.008
27	38N/59E/11	30	7.7	1600	959	25	1.8		358	32.5	6.5	0.8	132	.992
31	39N/59E/15	52	6.7	1450	867	20	10		236	43	40.7	13.8	38	1.030
36	33N/53E/8	64	6.9	1130	690	10	25		231	26.5	15.4	5.9	52	1.01
M-2	6N/36E	40	7.6	510	239	1.0	41.2	0.31	55	4.8	25.5	13.2	28	.989
40	35N/45E/10	31	7.1	410	136.5	25	35.9	1.9	37.5	5.6	33	4.1	51	1.006
43	34N/41E/13	34	7.0	1085	533	33.5	84.4	1.65	157	14.5	57.5	15.5	43.8	1.016
81	13N/36E/28	54	8.7	820	68	33	238	10.6	160	2.7	7.0	0.25	62.8	1.024
85	1N/38E/6	25	8.4	4400	56	625	1120	5.6	875	2.5	71	2.0	48.3	1.003
M-3	4S/67E/4	67	7.2	400	200	8	30	1.4	39.2	14.3	34	4.8	106	1.010

Figure 3. Temperature measuring technique at blowing well, map site M-1 (fig. 2).

Figure 4. Thermometer at site M-1 (above) reads 95°C (fig. 2).

Figure 5. Temperature measurement and pH buffer equilibration at map site 67 (fig. 2).

Figure 6. Temperature measurement at Trego Hot Springs, map site 45 (fig. 2).

Figure 7. Measuring pH in situ, map site 56 (fig. 2).

Figure 8. Calcareous tuffa mound, map site 31 (fig. 2).

4) flow rate; 5) dominant chemical species; and 6) total dissolved solids.

In addition, a number of larger areas have been ranked according to a numerical technique, formulated by the NGAT (see pg.21), that integrates several of the more important geothermal parameters including nature of dissolved species, pH, land vehicle accessibility, total dissolved solids, depth, and temperature. This technique yields a semi-quantitative probability function, the value of which may be used to determine resource development favorability for either industrial process heating, residential and commercial space heating, or both. A detailed description of the use and application of this technique is included in a following section of this text (pg.21).

MISCELLANEOUS ACTIVITIES

In addition to the tasks outlined in the statement of work, the NGAT has been investigating several other areas of geothermal energy potential that augment this study. Some of the more important areas are discussed below.

1. Current and Planned Usage

One of the most promising areas in Nevada for geothermal exploration and development is the Brady-Hazen KGRA. Bradys Hot Springs is the site of the world's first commercial food dehydration plant to be operated with geothermal energy (fig. 9). The plant was opened in the Fall of 1978.

The plant design includes a process that extracts both heat and potable water from saline fluids. The main product of this operation is dried onions, but the plant will also produce dried carrots and celery as these vegetables become available.

During the course of gathering field data, NGAT representatives made contact with many current and prospective users of geothermal energy. Such contacts provided investigators the opportunity to introduce prospective users to the DOE

Figure 9. Geothermally operated food dehydration plant at Bradys Hot Springs.

State Coupled Program, the available DOE funding programs, and to physical and chemical information regarding the resource.

In Caliente, Mr. Fergus Wallis operates the Aqua Caliente Trailer Park. The park is unique because many of the residents are using geothermal energy for space heating. Hot water is pumped from nearby shallow wells and the water (60°C) is delivered at a rate of up to 1000 GPM.

In addition to the obvious benefits of the geothermal heat, the residents are promoting the use of geothermal energy by demonstrating a do-it-yourself attitude and have customized their heating systems to fit their needs. One of the pioneering residents uses an automobile radiator as a heat exchanger and a simple electric fan for a blower. His monthly heating bill was reduced from 80 dollars to approximately 5 dollars.

Mr. Wallis has received a grant to drill more wells for residential space heating and his success has attracted the attention of the Caliente City Council which is considering using geothermal energy to heat the local public buildings. The NGAT has also benefited from Mr. Wallis' success. Field work in the Caliente area included temperature profiles of two well bores (fig. 10) as well as sampling for water chemistry.

In the Crescent Valley area, the Hot Springs Point KGRA has become the focus of a very ambitious and well integrated plan that, if enacted, would capitalize on available water, agricultural, and geothermal resources. Mr. Kent Whitney has access to 49,000 deeded acres and 212,000 leased acres in Crescent Valley. He plans to use geothermal energy directly as a heat source for an industrial park designed to process agricultural products. Mr. Whitney is presently working with EG&G Idaho and has also received some assistance from the NGAT.

In the Moana area, a subdivision two miles south of Reno, some residents have been using moderate-temperature geothermal resources for space heating since the early 1960's. A down-hole heat exchanger provides energy for both space heating

Figure 10. Temperature profiles of two wells at the Aqua Caliente Trailer Park, Caliente, Nevada.

Figure 11. Testing a Geothermal Well near the Rye Patch Reservoir. (Courtesy of Phillips Petroleum Corp.)

and domestic hot water. The geothermal fluids are somewhat high in dissolved solids and are not used directly. The depth to the resource is generally between 250 and 300 feet, which makes it economical for single family units. The NGAT conducted an informal survey of some Moana residents in August, 1978 to determine the economics of the geothermal space heating system. Of the 20 residents contacted, none required the use of a backup heating system since the geothermal system was installed. In September, 1978, the NGAT initiated another survey to quantify the savings realized by these residents. The survey involved a comparison of utility bills of users and non-users for both heating and non-heating seasons. A credible baseline has not been established for this analysis, however, because the non-heating related electrical demands for each house are extremely variable. The problem is still under consideration.

2. Assessment and Exploration

Sixty miles north of the Bradys Hot Springs area, the Phillips Petroleum Corp. drilled 1800 feet and penetrated what appears to be a substantial geothermal reservoir. Shortly after the drilling was completed, the NGAT was invited to the drill site (fig. 11) to witness pressure, temperature, and flow rate tests. Subsequent to these tests, Phillips released some of the physical and chemical data associated with this well and those data have been incorporated into the State resource assessment map.

A geothermal exploration technique formulated by the NGAT, is currently being tested. The method consists of low altitude color photo-coverage of suspected thermal areas. Hot Springs, in the temperature range 40°-70°C, should be easy to recognize because of the presence of the distinctly red and green colored cyanophytes algae. Thermophyllic algae are widespread throughout the hot springs in the Basin and Range, and, during the course of field work, often provided a quick estimation of the spring temperatures from a distance of several tens of meters.

An area with both hot and cold springs has been targeted for photo coverage, and the results will be compared with other airphoto techniques.

This aerial-survey technique may provide a quick, cost-effective reconnaissance of thermal areas and its successful application should overcome the inaccessibility of certain areas within the Basin and Range Province.

In October 1978, NGAT personnel responded to a request to investigate a geysering steam well in the vicinity of the Steamboat Hot Springs. A nearby resident noticed that the well began to erupt at regular 70-minute intervals shortly after a small earthquake had shaken the area earlier that month.

The resident maintained that some geysering had occurred prior to the earthquake, but that intensity increased after the shock. White, (1968) describes this, and several other geysering wells in the area.

Preliminary reports indicated a magnitude 2.4 earthquake at a shallow (1.6 km) depth of focus and, at the request of the NGAT, a University of Nevada, Reno seismic team was dispatched to the geysering well in mid-October to monitor seismicity. The team was, unfortunately, unable to detect any additional seismic activity. A sequence of photographs that recorded the eruption is shown in Figure 12.

3. Liaison with Nevada Department of Energy

The NGAT has also maintained a close working relationship with the Nevada Department of Energy (NDOE), which is directing the Outreach Program for Nevada. In March, 1979, a member of the NGAT accepted an invitation and appeared on a local television station with the Deputy Director of the NDOE, and one of the principal investigators of the Dixie Valley Industry Coupled Program. The purpose of the television program was to introduce the public to some of the geological, engineering, and economic aspects of geothermal energy. The thirty-minute program consisted of discussion and color slides, which were used to illustrate some of the more interesting concepts.

3:20 PM

3:21 PM

3:22 PM

3:23 PM

3:24 PM

3:25 PM

Figure 12. Photographic sequence of erupting well near Steamboat Hot Springs.

4. Meetings

In connection with geothermal research, NGAT personnel were present at the following meetings:

Date	Meeting
May, 1978	D. Foley (UURI) and J. Swanson (USGS), to discuss GEOTHERM input strategy
June, 1978	At Salt Lake City, to discuss Rocky Mountain/Basin and Range Regional Hydrothermal Commercialization Plan
July, 1978	D. Foley, E. Sammel (USGS) and F. Olmsted (USGS), to discuss data input for USGS Circular 790
July, 1978	Geothermal Resources Council Meeting at Hilo, Hawaii
September, 1978	First Conference on the Cerro Prieto Geothermal Field, Mexico; at San Diego, California
November, 1978	Heat Transport Processes within the Earth, a Penrose Conference at Vail, Colorado
December, 1978	American Geophysical Union, San Francisco Meeting
January, 1979	Geothermal Operations Research Workshop, sponsored by EG&G and DOE at Pocatello, Idaho
January, 1979	D. Foley and Debra Struhsacker (UURI), State Coupled planning and coordination
February, 1979	State Coupled Program Regional Meeting, Status reports and coordination, at Salt Lake City
February, 1979	Special Nevada State Legislative Session on Energy in Nevada, Senator T. Wilson, Chairman
March, 1979	Round table discussion with NDOE, State, Federal, and Financial officials regarding K. Whitney's plan for Crescent Valley Geothermal Industrial Park
April, 1979	Cordilleran Section of the Geological Society of America, San Jose, California
May 1979	R. Sasek (NDOE) and R. Ganzel (UNR) to discuss Geothermal Outreach Program in Nevada

EXPLANATION OF POTENTIAL EVALUATION NUMERICAL TECHNIQUE

The major problem that must be addressed in any attempt to define the potential for direct utilization of Nevada's geothermal resources is the diversity of the resources in both areal distribution and character. While some resources are closely spaced and can be easily grouped, others cannot be readily associated.

Many geothermal occurrences, for instance, are inaccessible by land vehicles. Temperatures may vary from 20°C to over 200°C, and resources may discharge at the surface or be confined to a reservoir at a depth of 2 km or more. In addition, geothermal fluids range in total dissolved solids (TDS) from 150 ppm (drinking water quality) to over 6000 ppm (saline solution).

The facts that various direct-use applications place differing constraints on the nature of the required resource and that, in many specific geothermal resource areas, detailed data are not yet available, present additional problems to the question of resource assessment. Therefore, any method used to evaluate geothermal potential should be a) generally applicable, b) sufficiently flexible to allow for future data input or changing priorities in resource requirements, and c) be of limited complexity, yet produce a semiquantitative basis for area to area comparisons.

APPROACH-RATIONALE

To overcome the problems and meet the requirements discussed above, a numerical scheme was developed. The basis of the method is a simple function called the probability function (PF) defined as follows:

PROBABILITY FUNCTION

$$PF = \sum RiWFi$$

where

Ri = Rank i^{th} Parameter
(30-34)

WFi = Weighting Factor of i^{th} Parameter
(0,1,2)

Several parameters could be viewed as useful for defining potential, a partial list includes: temperature, land vehicle accessibility, rock type, rock age, depth to resource, population centers, geophysical data, fluid chemistry, areal extent, flow rate, permeability, recharge, economics, structure, and environmental considerations. Although the potential function could accommodate any number of parameters, the quantitative data necessary to establish limits for the weighting factors is unavailable in many instances. Such data are presently available for the following parameters: temperature, fluid chemistry, population centers, land vehicle accessibility, depth to resource, and areal extent. These parameters were selected for use with the function.

The direct-use applications selected for evaluation using the scheme are industrial process heat (IPH) and residential/commercial space heating (RSH). Potential for agriculture/aquaculture applications was not evaluated because the nature of the resource required and the method of exploitation are currently in a developmental stage. Having chosen the parameters to be used and the applications to be evaluated, the tasks remaining included establishing an order of importance for both IPH and RSH parameters and defining the limits to be associated with the weighting factor values.

Industrial process heat evaluation parameters, in their order of importance are:

INDUSTRIAL PROCESS HEAT (IPH)

<u>PARAMETER</u>	<u>RANK</u>
TEMPERATURE	81
WATER CHEMISTRY	27
ACCESSIBILITY	9
POPULATION CENTERS	3
DEPTH TO RESOURCE	1

where "accessibility" refers to land vehicle access to the resource. Note that the "rank" of the parameters is in terms of decreasing powers of 3. Use of powers of 3 preserves the established order of importance. This will be demonstrated in a later hypothetical application of the scheme. The weighting factors (WFi) associated with these parameters and the limits established for the factors are illustrated in Figure 13. A weighting factor of "2" indicates the most desirable range for a parameter, "1" intermediate, and "0" the least desirable range. When judging the value to be assigned to the "water chemistry" weighting factor, consideration was given collectively to pH, TDS, and the presence or lack of corrosives, scaling compounds, or toxins. For example, although a fluid might have a pH between 5 and 6.5 and a total dissolved solids value of 450 ppm, the solids may consist of three hundred ppm dissolved silica which could cause scaling problems and thus the weighting factor used is "0".

The parameters used for the residential/commercial space heating (RSH) potential evaluation are similar, but they assume a different order of importance. Additionally, the weighting factor ranges have been adjusted to values more appropriate to the application. Note that areal extent is now considered because this parameter would be important to the development of a residential area where individual wells are used at each residence (as is the case in Reno, NV, and Klamath Falls, OR). Accessibility is no longer used because it is assumed to be tacitly accounted for by the presence of a population center. A listing of the parameters in their order of importance follows:

SPACE HEATING (RSH)

<u>PARAMETER</u>	<u>RANK</u>
POPULATION CENTERS	81
DEPTH TO RESOURCE	27
TEMPERATURE	9
WATER CHEMISTRY	3
AREAL EXTENT	1

IPH

81 TEMPERATURE

IPH

27 WATER CHEMISTRY

IPH

9 ACCESSIBILITY

FIGURE 13. Weighting Factors and Their Limits for Industrial Process Heat Applications

IPH

3 POPULATION CENTERS

IPH

1 DEPTH OF RESOURCE

FIGURE 13. (continued)

Ranges and limits used in weighting factor evaluations are given in Figure 14. Arrows on the horizontal bars indicate that certain factors (for example TDS) have ranges that extend beyond those used in evaluating the weighting factor. However, once the established limit is exceeded the weighting factor value does not change.

Numerical values, derived by summing the products of the rank-weighting factor pairs, range from a low of 0 to a high of 242, thus defining the limits of the probability function. This range was divided into three equal parts to obtain the "low", "moderate", and "high" categories of the probability function rating, and are:

PROBABILITY FUNCTION RATING PF VALUE	
HIGH	(+) 216-242
	(±) 188-215
	(-) 162-187
MODERATE	(+) 136-161
	(±) 109-135
	(-) 81-108
LOW	(+) 55-80
	(±) 28-54
	(-) 0-27

Each category is further divided into thirds and this is represented by the "-", "±", and "+" symbols.

The usefulness of powers of 3 in preserving the selected order of parameter importance can be illustrated by a pair of hypothetical industrial process heat examples (Table 2). Case A receives a non-zero weighting factor only for the temperature parameter, thus its probability function value is 162 and its probability function rating (PFR) is "HIGH(-)" (Table 2A). In case B, all weighting factor values are 2 except temperature, which receives a 1 because it is less

SH

81 POPULATION CENTERS

SH

27 DEPTH TO RESOURCE

SH

9 TEMPERATURE

FIGURE 14. Weighting Factors and Their Limits for Residential/Commercial Space Heating Applications

FIGURE 14. (continued)

TABLE 2a. Hypothetical IPH Example, Case A

	<u>Weighting Factor</u>	<u>Rank</u>	<u>Product</u>
110°C	2	81	162
TDS>2000 PPM pH>9 Corrosive	0	27	0
>15 Mi. from Major Road	0	9	0
<500 People	0	3	0
>2000 m	0	1	<u>0</u>
			TOTAL 162
PFR = HIGH(-)			

TABLE 2b. Hypothetical IPH Example, Case B

	<u>Weighting Factor</u>	<u>Rank</u>	<u>Product</u>
60°C	1	81	81
TDS <500 PPM pH 7.0 No Corrosives	2	27	54
<5 Mi. to Major Road	2	9	18
>5000 People	2	3	6
<1000 Meters	2	1	<u>2</u>
			TOTAL 161
PFR=MODERATE(+)			

than 100°C. Here the probability function value equals 161 and the PFR is "MODERATE(+)" (Table 2B). Thus, the importance of temperature above all other parameters in the evaluation scheme is demonstrated.

APPLICATION OF THE SCHEME - AN EXAMPLE

Application of the scheme to the region surrounding and containing Gabbs, Nevada provides a factual example of the probability function's use in evaluating the potential for direct utilization. Data from the geothermal occurrences in the area indicate an average temperature of 51°C, an average pH of 8.7, an average total dissolved solids of 582 ppm, an average depth to resource of 97 meters, an areal extent greater than 2 km², a population greater than 500 but less than 5000, and a distance of less than 8 km (5 mi) from an asphalt highway. Using these data the evaluation scheme applied to Gabbs is as follows:

Application	Parameter	Rank	Weighting Factor	Product
Industrial Process Heat	Temperature	81	1	81
	Chemistry	27	1	27
	Accessibility	9	2	18
	Population	3	1	3
	Depth to Resource	1	2	2
			TOTAL	131
Residential Space Heat	Population	81	1	81
	Depth to Resource	27	2	54
	Temperature	9	1	9
	Chemistry	3	1	3
	Areal Extent	1	2	2
			TOTAL	149

Probability function ratings are MODERATE ($\pm$) and MODERATE (+) respectively for industrial process heat and residential space heating applications.

COMMENTS

As discussed earlier, the evaluation scheme is flexible with respect to the number of parameters it can accommodate; however, modifications are not limited

to that aspect of its use. The ordering of parameters and the choice of limits for the weighting factors were based on the characteristics of Nevada and its geothermal resources. This ordering and choice of limits can be changed when using different parameters or a larger or smaller number of parameters to accommodate the data availability, geothermal resource characteristics, or application requirements of non-Nevada resources. It should be emphasized that the scheme is intended to be applied to regions of relatively similar resource characteristics. Geological, hydrological, and other pertinent sources of information should be used when bounding regions for potential evaluation.

REFERENCES

- Waring, G. A. (1965) Thermal springs of the United States and other countries of the world -- A summary: U. S. Geol. Survey Prof. Paper 492, 363 p.
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