**EXECUTIVE SUMMARIES OF REPORTS
LEADING TO THE CONSTRUCTION OF
THE BACA GEOTHERMAL DEMONSTRATION PROJECT**

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ABSTRACT

Executive summaries have been written for 61 reports and compilations of data which in part, have led to the construction of the Baca 50 MW Geothermal Demonstration Project (GDP). The reports and data include environmental research, reservoir and feasibility studies, the project proposal to DOE and the Final Environmental Impact Statement. These executive summaries are intended to give the reader a general overview of each report prior to requesting the report from the GDP Data Manager.

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REPORT NO. 1
EXECUTIVE SUMMARY

PRELIMINARY INVESTIGATION
HYDROGEN SULFIDE BACKGROUND LEVELS
BACA LOCATION NO. 1, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
ENVIRONMENTAL SCIENCES DIVISION
STEARNS-ROGER INCORPORATED
PROJECT C-15474
NOVEMBER 1974

Summary Prepared By
WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

A preliminary investigation to determine background hydrogen sulfide concentrations within the Baca Location No. 1 proposed project area and to provide recommendations for further detailed and specific studies was undertaken. This preliminary study began on September 7, 1974 with the installation of a 50-site semi-quantitative hydrogen sulfide monitoring network in and about the proposed project area. For the next 50 days, each detector was read daily, recorded, and changed, as necessary. As the investigation progressed, special short-term studies were made at those locations with the highest H_2S concentrations. The field data logs of H_2S measurements for the 50-day study are attached at the end of the complete report. Conclusions were drawn based on this preliminary investigation of background ambient level hydrogen sulfide concentrations within the proposed geothermal project area. Recommendations for future studies included baseline meteorological and air quality studies, performing H_2S emission estimates from well venting, and carrying out detailed numerical H_2S impact dispersion modeling are included.

INTRODUCTION AND SCOPE

This report presents the first detailed technical investigation of the baseline levels of hydrogen sulfide (H_2S) in an around Baca Location No. 1, situated in the Jemez Mountains of north central New Mexico about 15 miles west of Los Alamos. The purpose of this preliminary study was to determine average ambient H_2S concentrations, to identify major sources and potential dispersion mechanisms and to provide recommendations for further detailed and specific studies.

Many constraints dictated that this survey be only semi-quantitative. Since exact locations of H_2S sources and magnitudes of background H_2S concentrations had not been identified, the monitoring method also required that it be operated without power, be easily serviced by one technician and yield a result that could be related to the New Mexico hourly H_2S standard of 3 ppb. The Colortec Hydrogen Sulfide Detector manufactured by Metronics Associates Incorporated was selected as a simple method of obtaining measurements of H_2S levels. The detector has a chemically treated pad which develops a brown stain when exposed to H_2S . The darkness of the stain is then proportional to the H_2S dosage. Color standards representative of known dosages of H_2S are printed around the treated pad and the stain can be compared visually with the standards for immediate evaluation. By regarding (and replacing as necessary) the Colortec sampler each day, an average daily H_2S concentration was determined. Although there is no direct correlation of the hourly state air quality standard to daily average concentrations, this method provided an excellent survey tool with which later studies were structured.

Areas selected for study were based on reports of odor occurrences determined by Union Oil Co. geologists familiar with the Baca area. Most of the sites in the 50-station H_2S network were concentrated along Redondo and Sulfur Creeks where H_2S odor had previously been noted. Three sensors were located near Jemez Springs and five sensors were deployed along State Highway 4 where it crosses Baca Location No. 1 to determine existing exposure levels in areas of public access. After several weeks, four detectors were redeployed from areas where no H_2S was ever measured to several other sites along State Highway 4.

The H_2S detector network became operational on September 7, 1974 and was operated until October 26 of the same year. Each detector site was visited daily, the stain intensity of each sampler were recorded in the sampling log, and detectors were changed when necessary.

In addition to the routine monitoring program covering a larger area of potential H_2S odor impact, a small scale diffusion study was carried out at a venting well (Baca Well No. 4) for three days during the larger-scale monitoring program. Fifteen detectors were used surrounding the well on a downwind arc to measure dispersion factors of emissions from a single point source.

SUMMARY AND CONCLUSIONS

Because of very localized sources of H_2S , the ambient concentrations of H_2S showed considerable spatial variability. Within the Redondo Creek drainage, concentrations averaged over all 50 monitoring days were generally less than 3 ppb (except at one site), with measurable H_2S levels extending from a point 2.1 miles from the State Highway 4 turnoff to the area called Upper and Lower Forks. The maximum 50 day average concentration in Redondo Creek was 3.2 ppb near a known natural seep between Baca Wells No. 6 and No. 11. Within the Sulfur Creek drainage, H_2S concentrations were much higher. Fifty-day average concentrations near Sulfur Springs were over 100 ppb with considerable dead plantlife on the hillside where the maximum concentration was observed. All monitoring sites along State Highway 4 except one location near Battleship Rock showed zero concentrations. Dispersion of H_2S emissions from natural sources and from isolated leaking or venting wells appeared to be sufficient in areas of public access, to avoid exceedances of the standard with the exception of areas very close to any direct H_2S sources.

Monitoring activities around well areas in Redondo Creek showed little difference in H_2S levels when compared to nearby areas of natural seepage except during periods of continuous atmospheric venting of the wells. During the direct venting of Baca Well No. 4, 15 H_2S detectors were deployed around the well site. Short period analysis of the detector color stains suggested a dilution factor of 100 within 5 feet of the source and a factor of 16,000 within 25 feet of the source. The preparers of this report concluded that "the atmosphere is an excellent dispersive medium for H_2S ."

The H_2S data also showed a strong negative correlation with rainfall, particularly in areas of natural seepage. Periods of rain corresponded to low ambient H_2S levels. The authors concluded that "the rain is either purging the H_2S from the air or the increased soil moisture content is preventing H_2S seepage."

The overall conclusions from this preliminary monitoring program, as stated by Stearns-Roger Environmental Sciences Division authors, are as follows:

1. Natural H_2S seepage along the upper portions of Redondo Creek approaches the 1971 New Mexico Standard (3 ppbv) on the average and can exceed the standard on any given day. Natural H_2S seepage along Sulfur Creek routinely exceeds the applicable standard by an order of magnitude and can, at times, approach two orders of magnitude. Natural seepage along the Jemez River Canyon does, on occasion, exceed the standard. No natural seepage was recorded along State Highway 4, where it crosses Baca property, or along State Highway 126 to the west.

2. Venting of steam to the air at Redondo Creek resulted in ambient level H_2S concentrations comparable to and indistinguishable from the natural background levels.
3. Leaking exploration wells can provide an emission source of several hundred parts per million of dry H_2S . With proper precautions, capped exploration wells did not contribute significant amounts of H_2S to the natural background.
4. The atmosphere is an excellent dispersive medium for H_2S resulting in a 16,000-fold dilution within 25 feet downwind of an emission source. Thus, measurements of ambient-level H_2S concentrations are very dependent upon exact sensor location in relation to the H_2S source.
5. The occurrence of rain lowers ambient concentrations of H_2S .

In addition to providing some initial information on baseline H_2S concentrations in Baca Location No. 1, this study helped to define the structure of future investigations. Recommendations for future studies included:

1. Baseline meteorological studies using portable mechanical weather stations, a 60-meter meteorological tower, precipitation gauges and an upper air monitoring program of passive weather balloons and twice-per-day radiosonde observations.
2. Baseline air quality studies continuing the Colortec H_2S analysis and the eventual installation of continuous analyzers for H_2S/SO_2 , $NO/NO_2/NO_x$ and particulates.
3. Emission estimates from well venting and periodic analyses of trace elements in the venting steam.
4. Dispersion modeling using Gaussian point-source dispersion models using the Stearns-Roger IBM 370/15B computer.

A number of these recommendations were subsequently funded and are reported in later Stearns-Roger progress reports.

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EXECUTIVE SUMMARY

SECOND PROGRESS REPORT
METEOROLOGICAL AND HYDROGEN SULFIDE
BACKGROUND OBSERVATIONS
BACA LOCATION NO. 1, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
ENVIRONMENTAL SCIENCES DIVISION
STEARNS-ROGER INCORPORATED
PROJECT C-15474
JUNE 1975

Summary Prepared By

WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

This study represents a second investigation to determine background hydrogen sulfide concentrations within the Baca Location No. 1 proposed project area and covers a fourth-month period beginning in January 1975.

Four portable weather stations for measuring wind speed, wind direction, and temperature were installed along Redondo Creek, in the area of major geothermal well drilling, along with a hygromograph and heated precipitation gauge at the Union Oil office. A 24-site hydrogen sulfide detector network was also established in the same area. Continuous measurements were recorded by the meteorological stations for the fourth-month period while three 24-hour hydrogen sulfide concentration observations were taken at the 24 sites each month between January and May. The monitoring program described in this report was continued through 1975 with some modifications and is documented in three subsequent progress reports.

INTRODUCTION AND SCOPE

A preliminary survey of the spatial distribution of hydrogen sulfide (H_2S) in the Baca Location No. 1 yielded some very instructive data on baseline H_2S levels. It was decided to continue the routine H_2S sampling program and to deploy meteorological monitoring equipment to correlate air quality and weather data. Because of winter access problems this study was confined to the Redondo Creek drainage except for one H_2S monitoring station near Jemez Springs.

The winter monitoring program began in early January 1975, and continued until early May of the same year. The meteorological monitoring consisted of four portable weather stations for measuring wind speed, wind direction, and temperature which were installed along Redondo Creek, in the area of major geothermal well drilling, along with a hygrothermograph and heated precipitation gauge at the Union Oil office.

The mechanical weather stations (MWS) are self-contained and require only monthly chart changes. They were mounted on 10-foot tripods inside a fenced enclosure. One weather station was deployed near Baca Well No. 6 with two stations upstream at Upper and Lower Forks and one station downstream in a large open area called Henry's Meadow. Unfortunately, the low tripod and rising snow level during the winter may have somewhat distorted the mean wind distribution because of surface frictional effects, but the data do provide a meaningful characterization of the principal Baca area windflows.

Concurrently with the meteorological data program, a 24-site hydrogen sulfide detector network was also established in the same area. The H_2S network employed the same H_2S -sensitive chemically treated paper samplers (Colortec samplers from Metronics Associates) as in the initial survey. Where possible, the same sites used in the fall of 1974 were used in the winter to examine seasonal variations in the H_2S concentrations. Baseline H_2S sampling was intermittent, with three 24-hour hydrogen sulfide concentration observations taken at the 24 sites each month between January and May.

SUMMARY AND CONCLUSIONS

For those weather stations that were readily accessible, (Henry's Meadow and Baca Well No. 6) data recovery exceeded 95 percent. For the two stations at Upper and Lower Forks that could not be visited except by snowmobile or on snowshoes, problems with frozen chart-drive gears reduced data recovery to less than 50 percent at Upper Forks and less than 70 percent at Lower Forks.

The wind monitoring network produced results generally expected in channeled complex terrain airflow. Winds below the treeline in canyon environments have upslope winds by day, downslope winds at night and

display an unusually high frequency of calm winds. Winds at Baca Well No. 6 were upslope from the south-southwest by day and downslope from the north-northeast at night. The average wind speed was 3.2 mph with 42.6 percent of all observations reported as calm (≤ 2 mph). The Meadow site had a more open exposure to the west with somewhat higher windspeeds of 4.3 mph and 38.4 percent calms. Daytime winds were upslope from the west and nighttime winds drained from both Redondo Creek and Banco Bonito across the Meadow. Wind data at the upper sites showed the daytime upslope from the southwest, but also experienced some funneling of the prevailing westerlies aloft through the passes on which the upper stations were located. Since these stations are at the top of the cold air nocturnal drainage pattern, their winds were often calm with calms present on over 50 percent of all observations at both sites.

Temperature data indicated probable strong nocturnal temperature inversions within Redondo Creek. Minimum nighttime and maximum daytime temperatures were observed at the Meadows station with much smaller temperature oscillations at the higher elevation stations. Such strong inversions and calm winds suggested considerable potential for nocturnal air pollutant stagnation close to any low-level H_2S sources.

H_2S concentrations for the three days per month of monitoring were similar to the fall study except for considerably higher average concentrations. Snow cover did not suppress natural H_2S emissions as had been anticipated. Average H_2S concentrations for all monitoring days in the area where high H_2S levels from natural emissions had been observed during the fall were about three times higher in the winter. Maximum background concentrations of 19.3 ppb for all days and a 24-hour maximum of 65 ppb were far in excess of the New Mexico hourly standard of 3 ppb. The presence or absence of snow cover did not appear to affect daily average concentrations; the winter rise in H_2S concentrations was apparently correlated more to diminished dispersive capacity.

The recommendations following this study paralleled the recommendations of the first Stearns-Roger report for continuing the ongoing meteorology and air quality program and initiating preliminary upper air observations and dispersion modeling programs. These recommendations were adopted and results are detailed in the three subsequent technical reports.

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REPORT NO. 3
EXECUTIVE SUMMARY

THIRD PROGRESS REPORT
METEOROLOGICAL AND HYDROGEN SULFIDE
MONITORING PROGRAMS
BACA LOCATION NO. 1, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
ENVIRONMENTAL SCIENCES DIVISION
STEARNS-ROGER INCORPORATED
PROJECT C-15474
OCTOBER 1974

Summary Prepared By

WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

This is the third in a series of investigative reports to determine background hydrogen sulfide concentrations within the Baca Location No. 1 proposed project area. This study covers the five-month period through September 1975 and summarizes all data collected to that date.

Monitoring activities reported in this document include a continuation of the mechanical weather station network, an upgrading of the 24-station H₂S measurement program to ten samples per month, the addition of a periodic upper air wind and temperature program, and periodic suspended particulate monitoring using hi-volume dust samplers.

The Third Progress Report provides a tabulation of observations and analyses for data collected between May and September 1975, summarizes all information through September 1975 and includes the first upper-air study.

INTRODUCTION AND SCOPE

During late spring, summer and early fall of 1975, the baseline hydrogen sulfide (H_2S) and meteorological monitoring program begun in the fall of 1974 and expanded during the winter of 1975 was continued on a regularly scheduled basis. The monitoring system in May 1975 consisted of four self-contained, battery powered mechanical weather stations (MWS) at locations identified as Upper Forks, Lower Forks, Baca Wells (Baca Well No. 6) and the Meadows (Henry's Meadow). In addition, a hygrothermograph and heated precipitation gauge was operated at the Union Oil Co. Geothermal Division office trailer. H_2S monitoring consisted of long-period exposure chemically treated paper tabs that develop a characteristic stain color as a function of cumulative H_2S exposure. The weather stations were visited twice per month and the H_2S network was operated for three days each month.

As site access became easier during the early summer of 1975 following the melting snow, the three monthly H_2S readings were expanded to ten per month. In addition, an intermittent upper air monitoring program and a hi-volume dust monitoring program were included in the program scope beginning in August and September of 1975, respectively. The upper air program was an eight-day field campaign conducted onsite in August 1975 by Colorado International Corporation. During these upper-air studies, six weather balloons were released daily. Two of the daily balloon releases carried radiosonde transmitters to measure temperatures aloft to determine frequency of occurrence and heights of temperature inversion layers, which are extremely important in assessing the atmospheric dispersion potential in the project area.

Dust monitoring was initiated early in September 1975. Twenty-four hour total suspended particulate (TSP) monitoring was scheduled for ten days during the H_2S sampling program and on an every 6th day schedule during non- H_2S measurement periods at the Union trailer headquarters.

SUMMARY AND CONCLUSIONS

Levels of hydrogen sulfide in the Redondo Creek drainage varied from 0.0 ppb to complete saturation of the Colortec detectors (>180 ppb). Distance from H_2S sources (whether natural seeps or geothermal wells) and configuration of each well (whether capped, leaking or vented) appeared to be the major factors in governing ambient H_2S concentrations.

Time of day played an important part in concentration levels as the wind would change directions in early morning and late evening. No detectable concentrations were observed in eight of the monitoring stations during the nine months even after 30-day exposures, indicating average H_2S concentrations less than 0.04 ppb. Except for one location near Baca Well No. 4 which had a leaky casing, there was no H_2S observed upstream of Baca Well No. 13 or along the road toward Baca

Well No. 4. Downstream concentrations dropped to zero near Baca Well No. 12, with no H₂S observed beyond that point anywhere along the road to State Highway 4.

From the recorded observations, there does not appear to be a seasonal trend in concentrations. The variations were very localized with large day-to-day changes. There was a tendency for the concentrations at the stations along the Redondo Creek fault to rise and fall in cycle with each other with trends to indicate a common cause - possibly meteorological conditions or out-gassing along the fault.

Gaussian diffusion models predict that pollution concentration is inversely proportional to wind speed, i.e., low winds cause high concentrations, and vice versa. To evaluate how the H₂S monitoring data obeyed this relationship, a correlation plot between wind data near Baca Well No. 11 and nearby H₂S data was performed. The correlation was poor with a slight positive correlation (higher H₂S with higher wind speeds) rather than a negative correlation. No plausible explanation for the failure of the data to obey classical diffusion laws could be offered.

Surface meteorological observations at the weather stations at Upper and Lower Forks, near Baca Well No. 6, in Henry's Meadow, and at the Union headquarters trailer showed a continuing pattern of upslope/downslope winds, a high frequency of calm winds, warmer temperatures in lower elevations, except when very cold air pools in the valley at night, with patterns dominated almost completely by local topography instead of any broadscale general circulation.

An eight-day upper-air field campaign was conducted by Colorado International Corporation, under the direction of Ralph Papania, Certified Consulting Meteorologist, at the Meadow Station during the period August 16 through 23. Wind direction and speed observations were made six times per day. At the surface, the prevailing south-southwest through west-northwest daytime upslope winds were seen along with the nighttime northeasterly drainage winds. This same pattern had been recorded by the weather station at this site. As altitude increases, the prevailing winds gradually shifted to west and west-northwest at the higher levels.

In the lower atmosphere, wind speeds normally increase with height approximated by a power law relationship:

$$S_2 = S_1 \left(\frac{H_2}{H_1} \right)^r$$

where

S_2 = wind speed at height, H_2 in m/sec

S_1 = wind speed at height, H_1 ($H_2 > H_1$) in m/sec

r = dimensionless exponent

In prior studies over flat terrain, "r" has averaged around 0.14 ("one-seventh power law").

Upon analyzing the upper air wind data from the 8-day study, "r" was found to be greater than 0.14, indicating that the increase of wind speed with height is greater at this location. This was to be expected in this mountainous region where the low-level winds are sheltered by the surrounding terrain. The strongest winds aloft are associated with cold front passages.

Temperature and humidity soundings were made twice per day, near sunrise and again during the middle of the afternoon. The early morning soundings were made shortly after sunrise when the surface-based, radiative-cooling temperature inversion should be at its strongest. There was a very strong inversion in the lowest 500 feet with a weaker inversion extending to 1000 feet above ground level. Above 1000 feet, the temperature decreased with height. Each of the individual early morning soundings showed this surface-based inversion. The frequency of occurrence and height of these inversion layers are extremely important in estimating the pollutant dispersion potential in the proposed development area.

The average mid-afternoon temperature sounding revealed a superadiabatic lapse rate (indicative of atmospheric instability) between the surface and 3500 feet and again between 4500 and 5000 feet. This unstable air during the day should lead to excellent dispersion conditions.

Particulate observations taken during September of 1975 indicated that the maximum recorded 24-hour suspended particulate concentration during these first six samples was $100 \mu\text{g}/\text{m}^3$ which is 67 percent of the secondary National Ambient Air Quality Standard (NAAQS) of $150 \mu\text{g}/\text{m}^3$. The geometric mean of the six samples was $16.0 \mu\text{g}/\text{m}^3$ which is 27 percent of the secondary annual NAAQS of $60 \mu\text{g}/\text{m}^3$. In the semiarid regions of the west, the secondary NAAQS for suspended particulates can be exceeded on occasions due to naturally occurring windblown dust. The concentration values are expected to be lower during the winter, when the ground is snow covered, and higher during the summer when particulate concentrations will be very dependent upon the amount of rainfall that is received.

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REPORT NO. 4
EXECUTIVE SUMMARY

PRELIMINARY
GROUND-LEVEL HYDROGEN SULFIDE
CONCENTRATION ESTIMATES
BACA LOCATION NO. 1, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
ENVIRONMENTAL SCIENCES DIVISION
STEARNS-ROGER INCORPORATED
PROJECT C-15474
DECEMBER 1975

Summary Prepared By

WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

This document is the fourth in a series of reports aimed at determining levels of ambient hydrogen sulfide in the atmosphere within the Baca Location No. 1 proposed project area. Prior reports, dated November 1974, June 1975 and October 1975, dealt with measured background levels of hydrogen sulfide and documented actual atmospheric conditions at the proposed project site. This report documents calculated levels of hydrogen sulfide due to both assumed emission levels from the proposed project in addition to background hydrogen sulfide. Parameters considered are: stack height, emission concentration, and a variety of atmospheric factors. The calculations resulted in the conclusion that contributions to ambient hydrogen sulfide due to the project will be considerably lower than the existing background levels due to natural sources. Concentrations added by the project outside of property boundaries will be insignificant compared with existing natural background.

INTRODUCTION AND SCOPE

After approximately one year of baseline hydrogen sulfide concentrations had been measured in the Redondo Creek area, sufficient data were available for a comparison with probable levels of H_2S resulting from proposed geothermal development in Baca Location No. 1. Although estimating diffusion in complex terrain is very imprecise, simple dispersion calculation methodologies allow at least an order of magnitude estimate of ambient air quality impacts from project-related H_2S emissions.

Ground-level hydrogen sulfide concentration estimates were computed using the dispersion model developed by D.B. Turner (1970) for the Environmental Protection Agency as published in the "Workbook of Atmospheric Dispersion Estimates." This workbook presents methods of practical application of the binormal (Gaussian) continuous plume dispersion model to estimate concentrations of air pollutants.

Hydrogen sulfide was assumed to be emitted at a rate of 50 pounds per hour (6.3 g/sec). Since the computed concentrations are directly proportional to the pollutant emission rate, the calculated concentrations can be linearly scaled for other emission rates. The location of the proposed plant site was assumed to be near the headwaters of Redondo Creek at a location called Upper Forks at an elevation of 9400 feet. The concentration estimates were computed for emission heights of 15, 30, 60, 120, and 200 meters above the surface.

Wind speed, wind direction, and temperature had been recorded continuously at Upper Forks since January 1975. This site is located in a saddle between Redondo Border, to the northwest, and Redondo Peak, to the southeast. Lower elevations are to the southwest and northeast. There is one prevailing wind direction at this location -- south-southwest.

The entire spectrum of meteorological input conditions was considered for analysis with the Gaussian model. Possible input conditions included stable conditions with strong temperature inversions, neutral conditions with well-mixed air and unstable conditions that cause rapid mixing of buoyant emissions. However, the upper air monitoring program at the large meadow (Henry's Meadow) along the access road to the possible plant site had shown the nocturnal inversion tops to be near 9200 feet. With a plant site of 9400 feet and a warm, moist plume rising several hundred feet higher due to buoyance, such plumes would not be trapped by temperature inversions in Redondo Creek. Based on these considerations, neutral and unstable conditions were selected for analysis. The conditions investigated were:

Stability Class A (extremely unstable), wind speed = 2 m/sec

Stability Class B (unstable), wind speed = 3 m/sec

Stability Class C (slightly unstable), wind speed = 4 m/sec

Stability Class D (neutral), wind speed = 5 m/sec

Wind direction was held constant from the south-southwest.

Background hydrogen sulfide was estimated from actual background measurements reported in previous studies, but since the location and release heights of background emissions and the proposed power plant did not coincide, no superposition of background and plant emissions was attempted.

2.0

SUMMARY AND CONCLUSIONS

The highest estimated one-hour ground-level H_2S concentration, within the property boundary, of 82.6 ppbv (parts per billion by volume), occurred with a 15-meter stack at 0.3 miles downwind. Redondo Creek is in an area of naturally occurring geothermal activity where H_2S is one of the main pollutant emissions. Naturally occurring ambient H_2S concentrations as high as 65 ppbv for a 24-hour average have been observed along a fault line in the upper portion of Redondo Creek Canyon. By applying a time-scaling correction factor to the 24-hour observation as suggested in Turner's Workbook, the predicted hourly concentration is 176 ppbv. Thus, the projected maximum concentrations from the proposed power plant, even with the shortest stack, are only about half of the existing natural background. Off of the property, the estimated one-hour H_2S concentrations from the project are considerably less than 3 ppbv. In nearby areas with public access, one-hour naturally occurring H_2S concentrations as high as 400 ppbv have been measured along Sulfur Creek (hot sulfur springs) and about 20 ppbv along State Highway 4 near the Battleship Rock picnic area near Jemez Springs.

In summary, ambient concentrations of H_2S added by the project within property boundaries will be considerably lower than the existing background levels which are already present due to natural sources. Concentrations added by the project outside of property boundaries will be insignificant compared with existing natural background.

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REPORT NO. 5
EXECUTIVE SUMMARY

ANNUAL REPORT
METEOROLOGICAL AND AIR QUALITY
MONITORING PROGRAMS
BACA LOCATION NO. 1, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
ENVIRONMENTAL SCIENCES DIVISION
STEARNS-ROGER INCORPORATED
PROJECT C-15474
FEBRUARY 1976

Summary Prepared By
WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

A preliminary investigation to determine background hydrogen sulfide concentrations within the Baca Location No. 1 proposed project area and to provide recommendations for further detailed and specific studies was undertaken. This preliminary study began on September 7, 1974 with the installation of a 50-site semi-quantitative hydrogen sulfide monitoring network in and about the proposed project area. As a result of this preliminary investigation, a 24-site hydrogen sulfide detector network was established along Redondo Creek to further the investigation. Four meteorological stations, a hygrothermograph and heated precipitation gauge were put into operation between October 1974 and January 1975 along the length of the area of major geothermal drilling activity. Continuous measurements were recorded by these meteorological stations through November 1975. A high-volume sampler for measuring suspended particulate concentrations was installed at Redondo Creek in September 1975. In addition, two eight-day upper-air field campaigns were conducted onsite in August and November 1975.

The Annual Report presents observational summaries and analyses of the meteorological and air quality data collected from September 1974 through November 1975. Using the onsite surface and upper-air meteorological observations along with preliminary engineering design information for the proposed project, hydrogen sulfide concentration estimates due to the planned project were calculated using dispersion models developed by the Environmental Protection Agency.

This report summarizes all materials detailed in four previous Stearns-Roger technical reports, updates the results of ongoing air quality and meteorology programs and presents some additional modeling results. Much of the material in this volume, including text, figures and tables, has appeared in the previous four reports.

INTRODUCTION AND SCOPE

The Union Geothermal Division, Union Oil Company of California, is participating in commercial development of geothermal energy at Baca Location No. 1, located near Redondo Peak in the Jemez Mountains of north-central New Mexico about 15 airline miles west of Los Alamos.

In this region, as in most areas of geothermal activity, natural gaseous sulfur compounds, with their pungent and acrid odors, are being emitted. One of the most common of these compounds is hydrogen sulfide, identified by its malodorous rotten-egg smell. Stearns-Roger Incorporated was employed to undertake a preliminary investigation to determine background hydrogen sulfide concentrations within the project area and to provide recommendations for further detailed and specific studies. This preliminary study began on September 7, 1974 with the installation of a 50-site semi-quantitative hydrogen sulfide monitoring network in and about the proposed project area. For the next 50 days, daily hydrogen sulfide background concentrations were measured at each of the 50 sites.

After discussion of the results of this preliminary investigation among environmental scientists at Union Oil and Stearns-Roger, it was mutually agreed that further study was warranted. A 24-site hydrogen sulfide detector network was established along Redondo Creek. For the first six months of 1975, three 24-hour concentration observations were made monthly at each of the 24 sites. Starting in July 1975 and continuing for five months through November 1975, the frequency of these measurements was increased to ten 24-hour observations each month at each of the 24 sites.

To determine windflow patterns in this area with its rugged terrain along with other meteorological parameters, a portable weather station to measure wind direction, wind speed, and temperature was installed along Redondo Creek in October 1974. Three additional meteorological stations were put into operation along the length of the area of major geothermal drilling activity in January 1975. A hygrothermograph and heated precipitation gauge were installed at the Union Oil office the same month. Continuous measurements were recorded by these meteorological stations through November 1975.

A high-volume sampler for measuring suspended particulate concentrations was installed at Redondo Creek in September 1975. During the period September through November 1975, ten consecutive 24-hour samples were collected each month with the high-volume sampler during visits by Stearns-Roger personnel. During the remainder of the three months, 24-hour samples were taken every sixth day (to conform to the National schedule) by Union Oil personnel. Composites of the samples from the high-volume filters were analyzed spectrographically for trace elements.

Two eight-day upper-air field campaigns were conducted onsite in August and November 1975 by Colorado International Corporation under the direction of Ralph Papania, Certified Consulting Meteorologist. During each of these eight-day studies, six weather balloons were released daily and tracked by the double-theodolite method to determine wind speed and direction from the surface to 5000 feet above ground level. Two of the daily balloon releases carried radiosonde transmitters for simultaneous measurements of temperatures aloft to determine frequency of occurrence and heights of inversion layers.

2.0

SUMMARY AND CONCLUSIONS

The Annual Report presents observational summaries and analyses of all meteorological and air quality data collected from September 1974 through November 1975. Details of many of the observational programs and special studies have been described by Stearns-Roger in the previous progress reports. Although most previously submitted materials are again included in this report, only the general findings and any significantly new materials will be discussed in this summary.

The air quality (H_2S) monitoring program revealed that naturally occurring hydrogen sulfide ambient concentrations along the hot sulfur springs resorts at Sulfur Creek were 100 times higher than the 1974 New Mexico one-hour standard of 3 ppbv (parts per billion by volume) and background concentrations 40 times larger than the standard were observed along Redondo Creek in the area of the current geothermal energy development.

Meteorological measurements defined a very pronounced pattern of upslope/downslope day/night motion with extremely light winds below the frost canopy. Winds in the upper portion of Redondo Creek were upslope by day, but had no organized motion at night. Warmest daytime and coldest nighttime temperatures occurred along the valley floor with smaller temperature oscillations at higher altitudes. The upper air program showed that nocturnal radiation inversions were about 1000 feet deep above the valley floor with rapid dissipation of such inversions after sunrise. Wind speeds increased rapidly aloft with wind directions predominantly out of the northwest above the sheltering effects of local terrain.

Numerous problems with instrument malfunctions demonstrated the need to constantly monitor and maintain equipment in the harsh mountainous environment. Data losses were experienced from two weather stations, the hygrothermograph and the precipitation gauge because the clocks failed, gears froze, etc.

Particulate monitoring, despite the heavy dust emissions from local dirt roads, showed no exceedances of the federal primary or secondary suspended particulate standard. Twenty-four hour particulate concentrations ranged from values cleaner than the supposed global background dust level to 109.6 micrograms per cubic meter (compared to

the national secondary clean air standard of $150 \mu\text{g}/\text{m}^3$). The mean concentration of 30 dust observations was about two-thirds of the annual secondary particulate standard. Assuming particulate levels are lower in winter and spring when soils are snow-covered or damp, the area appears to be an attainment area for particulate standards.

Preliminary calculations using a Gaussian point source diffusion model had shown that a geothermal power plant constructed near the headwaters of Redondo Creek would not cause ambient H_2S standards to be violated outside the Baca property boundary. Other possible plant sites and other meteorological input conditions were used to further define the range of potential project impacts. Candidate plant sites were chosen at each site where wind data were available and more restrictive, worst-case input conditions were used for modeling analysis.

Assuming an H_2S emission rate of 50 pounds per hour released from a 50-foot stack, the following conclusions were drawn:

1. Outside of the property boundaries of Baca Location No. 1, where the 1974 New Mexico one-hour ambient H_2S standard was applied, ambient H_2S concentrations (either at ground level or along the canyon walls) from the proposed four possible plant locations would all be within the standard.
2. Within property boundaries, the lowest concentrations occurred with sites located at Upper Forks and Lower Forks. The maximum estimated concentration from these two locations was 8.2 ppbv which is an order of magnitude less than the naturally occurring background H_2S concentrations already present in the area. The highest concentrations were estimated to occur with a plant located at Baca Wells in Redondo Creek Valley. The maximum computed value of 400 ppbv at this location is about thrice the observed background H_2S levels. The estimated maximum concentrations from a plant located in the Meadow were about the same as the natural background.

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REPORT NO. 6
EXECUTIVE SUMMARY

BACA RANCH GEOTHERMAL SITE
GEOTHERMAL RADIOLOGICAL MONITORING PROGRAM

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
CONTROLS FOR ENVIRONMENTAL
POLLUTION, INC.
SANTA FE, NEW MEXICO
NOVEMBER 1974

Summary Prepared By
WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

A radiological monitoring survey of the Baca Ranch which was conducted for the Union Oil Company of California by Controls for Environmental Pollution, Inc. The survey was initiated in October of 1974 to perform air, terrestrial, and water monitoring in the areas surrounding the geothermal wells. The primary purpose of the surveillance was to provide information on the possible contamination of the environment from radiation being released from development of the geothermal resource.

Analytical results were presented and discussed along with other pertinent data. The study concluded that there is no hazard from radiation being introduced by the geothermal generations. The amounts of radiation detected were less than or equal to those taken as background levels from the literature and from sample analyses. The study recommended that periodic sampling be continued during development and use of the resource to further insure that no radiation is being introduced to the environment by the project.

1.0

INTRODUCTION AND SCOPE

The objective of the radiological survey was to provide information on the levels of radiation in the geothermal environs of the Baca Location No. 1 prior to geothermal operations. This information permits evaluation of corresponding concentrations and levels subsequent to operation, which may be attributable to the geothermal power plant.

Measurements were made for Gross Alpha, Gross Beta, and Gross Gamma activity as well as for radium -226 and lead -210 levels. Radon -222 content of the atmosphere was also surveyed. Analytical procedures varied depending on the medium being tested but were those routinely used by Controls of Environmental Pollution, Inc. in sample analyses.

High volume air particulate samples were taken from 24 sites including each of the Baca wells. Samples taken from Santa Fe and the Tsankivi Ruins were considered to represent background levels. Produced water was tested from the Baca No. 12 run-off pit and from two samples taken at Baca No. 11. Both the dissolved and suspended fraction were tested. Radiation levels in the vegetation of the area were assessed by analyzing oak leaves, conifers, and mixed grasses from three, six, and three sites, respectively. Soils were tested from twelve locations. Results were compared with levels reported in the literature for soils in the Los Alamos area. Sediment was collected from the Redondo and Sulphur Creeks and Jemez Springs for testing. Surface water was also analyzed and compared to domestic water. Three mice from two locations were analyzed to establish a data base for terrestrial animals and produced solids and drill cuttings were tested from Baca 11 and 13.

2.0

SUMMARY AND CONCLUSIONS

The report presented the interpretations and conclusions obtained for all media sampled during the Baca Ranch radiological survey. All samples were analyzed in duplicate. The results were within their respective statistical deviation. Therefore, the results presented in the report are of average values.

Numerical results of the analyses are too numerous for inclusion in this summary, however, their implications and resulting conclusions follow.

The study concluded that the radioactivity found in any of the samples was less than or equal to background levels reported in the literature or inferred from sample analyses and was predominately from major sources of radiological environmental pollution. Such sources of pollution are: (1) nuclear detonations, (2) nuclear fuel fabrications, (3) nuclear reactor operations, (4) nuclear fuel reprocessing, and (5) isotope production and use. The majority of such environmental pollution in the Baca Ranch region probably comes from nuclear detonations. Analysis of many samples also revealed that a portion of

the radioactivity detected was due to natural sources such as radio-nuclides produced in the atmosphere or earth by bombardment from cosmic particles.

The study further stated that although some activity was detected in some sample media, the concentrations were of no significance insofar as health hazards are concerned. All existing levels of radioactivity were found to be well below the maximum permissible concentrations that have been determined to protect against health impacts.

The report concludes that no radioactive pollution is being introduced into the environment by geothermal wells of the area. Periodic sampling during drilling operations and full operation of the geothermal wells was recommended.

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REPORT NO. 7
EXECUTIVE SUMMARY

THE BIOTA OF REDONDO CREEK CANYON
SANDOVAL COUNTY, NEW MEXICO
WITH EMPHASIS ON BIG GAME SPECIES AND
RARE, ENDANGERED OR THREATENED SPECIES

FROM A REPORT

Prepared for	Prepared by
UNION GEOTHERMAL DIVISION	SOUTHWEST ENVIRONMENTAL RESEARCH
UNION OIL COMPANY OF CALIFORNIA	AND DEVELOPMENT CORPORATION
LOS ANGELES, CALIFORNIA	OCTOBER 1974

Summary Prepared by
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

An initial inventory of the west slope of Redondo Peak and Redondo Creek Canyon (between 8000 and 9500 feet) was conducted during September and October, 1974. The objective of the study included limited field inventories of existing biological resources, analysis of current impact of human activities on the ecosystem of the area, and recommendations for future studies. Surveys were conducted in disturbed and undisturbed areas and included vegetation transects, avifauna surveys, small-mammal surveys, surveys for carnivores and ungulates, directed surveys for endangered species, and an organic-matter-outflow study of Redondo Creek.

Meadows and Ponderosa pine stands were found in the lower elevations of the study area. South-facing slopes at higher altitudes were predominately covered by Gambel (scrub) oak and/or Ponderosa pine, and north-facing slopes had a dense cover of fir, pine and aspen. Elevations above 9000 feet contained pine-fir or aspen communities with scattered small meadows and sedge marshes. Small-mammal diversity and density was lowest in Ponderosa parkland and was highest in pine-fir forests and pine and aspen communities. Tassel-eared squirrels, least chipmunks, red-backed voles, deer mice, and pocket gophers were common small mammals. Numerous bird species were recorded during the study, but the number decreased markedly above 9000 feet. The area also supported a variety of raptors. Black-tailed deer (mule deer) densities varied between three and eight per square mile. Pellet counts indicated that a herd of 200 to 500 elk may winter in the Redondo Creek Valley. The threatened Jemez Mountain salamander probably inhabits north- and northwest-facing slopes. In addition, prairie falcon (since delisted by the U.S. Fish and Wildlife Service) and American peregrine falcon occur in the region and may forage within the study area.

The system of pipelines and roadways present during the time of the survey presented only minor impact to biological resources. Future studies that are recommended to be conducted include vegetation mapping of the area, breeding bird census, surveys for the Jemez Mountain salamander, and deer and elk surveys.

INTRODUCTION AND SCOPE

This report represents the first major study of the Redondo Creek Canyon study area. The scope of the study included (1) inventory of existing biological resources; (2) analysis of existing impact of human disturbance to the biological resources of the area; and (3) recommend future studies to be conducted in the study area. The study was conducted in September and October, 1974, and was limited in scope as well as duration.

The following surveys were conducted during the course of the study:

- 1) Vegetation: A total of 14 sites were sampled through the use of the point-quarter method.
- 2) Small Mammals: Live-trapping grids of various sizes were used to determine small-mammal abundance. Squirrels were censused from roadside stops concurrent with avifaunal surveys. Gophers were estimated through burrow system analysis.
- 3) Large Mammals: Large-mammal activity was assessed through pellet counts and observation of tracks.
- 4) Avian Census: Roadside counts of all birds seen in ten minutes were spaced at 0.5 mile intervals from Baca gate to Baca 5A.
- 5) Rare and Endangered Species: Directed searches for Plethodon neomexicanus were conducted in likely habitat for the species.
- 6) Redondo Creek Organic Matter: One two-hour sample of organic matter transported down Redondo Creek was sampled.

SUMMARY AND CONCLUSION

Vegetation changes within the study area were due primarily to slope aspect and altitudinal gradients. The southwest-facing slopes are dry due to aspect. Scrub oak (Quercus gambelli) accounted for over 95 percent of the vegetative cover. Ponderosa pine occurred at greater frequency at higher altitudes. The northwest-facing slopes had lower tree-shrub density than the southeast-facing slopes; however the species diversity, size and canopy cover of dominant trees were greater on the northwest-facing slopes. Fir, pine and aspen were the dominant species on the northwest-facing slope. Meadows and Ponderosa pine meadows occurred in the more level area of the lower elevations of the study area. Alders and box elders were found in riparian areas and near the edge of meadows. Elevations above 9000 feet contained pine-fir or aspen communities with scattered meadows and sedge marshes. The investigators noted many plant species that were good forage materials for herbivorous large mammals.

Leopard frogs (Rana pipiens) were found along Redondo Creek in freshwater seeps, and at high densities along the edges of beaver ponds. Cricket frogs (Pseudacris triseriata) were found within the meadows. The only reptile observed was a garter snake.

Dense cover on northwest-facing slopes supported high densities of red-backed voles, deer, mice and least chipmunks. Southeast-facing slopes supported lesser densities of the above species as well as ground squirrels and woodrats. The more open Ponderosa pine meadows supported only chipmunks and tassel-eared squirrels. The investigators found that open habitats supported lower densities of small mammals than habitats containing dense vegetation. Pocket gophers were found in moderate densities in the grassy meadows of the study area. Red-squirrel signs were noted within spruce-fir forested areas. Beaver were noted in a large pond on-site. The beaver pond served as a focal point for deer, cattle, and mammalian carnivores.

Activity and area usage by deer and elk in the study area was concentrated in certain plant communities and exhibited seasonal fluctuation. Elk densities in the study area were estimated between 200 and 500 head. Elk in the Redondo Creek Canyon are winter residents who move to high meadows in spring. Concentrations of elk are expected in the canyon from November to March. The upper slopes of Redondo and Redondo Border probably support the elk during fall and spring migrations. Areas at 9500 feet and higher may support some elk during summer months. Data on deer were less comprehensive than on elk. Deer densities appear low (approximately 3.2 deer per square mile). These animals exhibit some winter concentrations at low elevations, moving to higher elevations in spring.

The area supports a high diversity of mammalian carnivores. Coyote, bobcat, badger, raccoon, mountain lion, and bear are expected to occur in the study area.

Twenty-two avifauna species were noted during the survey. Bird densities were fairly evenly distributed throughout the study area in September, but there was a marked shift of populations to lower elevational habitats in October. Bird species including the grey-headed junco, black-capped chickadee, Wilson's warbler, flicker, mountain bluebird, western bluebird, Clark's nutcracker, white-throated swift, red-breasted nuthatch and pigmy nuthatch were found within the meadows in the lower elevations of the study area. Red-tailed hawks were noted throughout the study. Other raptors censused included the sharp-shinned hawk, Ferruginous hawk, kestrel and turkey vulture. The one Cooper's hawk and a peregrine falcon were noted during the study. The area supports a good diversity of raptors and is a potential breeding habitat for many of these species.

Three rare and/or endangered species may occur in the study area:

- 1) Jemez Mountain Salamander: This species could occur on the northwest-facing slopes of the study area.
- 2) Prairie Falcon: This species probably uses the study area during migration. There is a low probability that the species nests in the study area. (This species has since been delisted by the U.S. Fish and Wildlife Service.)
- 3) American Peregrine Falcon: The individual noted during the study was probably a immigrant. There is a remote potential that peregrines nest in the study area.

A limited analysis of organic matter outflow of Redondo Creek was conducted. Organic export from Redondo Creek at the western edge of the study area was estimated at 1.7 grams dry weight/hour.

The report concluded that human activities at the study areas as of October 1974 have resulted in little adverse influence of biological resources. The report makes specific recommendations for future studies prior to development of geothermal fields:

- 1) Quantification and mapping of plant communities within the study area.
- 2) Breeding-bird-population studies with emphasis on raptor species.
- 3) Suitable habitat for the Jemez Mountain salamander must be extensively surveyed.
- 4) Identification of prime habitat for deer and elk.
- 5) Small-mammal live trapping to determine food base for predators.
- 6) Documentation of vegetation changes around wells and pipeline corridors.

In addition, the report recommends that areas around wellheads be reseeded. Beaver ponds and sedge marshes should be avoided by construction activities.

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REPORT NO. 8
EXECUTIVE SUMMARY

REPORT ON RECONNAISSANCE OF
REDONDO CREEK, REDONDO BORDER, SULFUR CANYON, ALAMO CANYON
AND VALLE SECO AREAS WITH PROPOSAL AND BUDGET ESTIMATES
FOR BIOLOGICAL BASELINE STUDIES

FROM A REPORT

Prepared for	Prepared by
UNION GEOTHERMAL DIVISION	WHITFORD ECOLOGICAL CONSULTANTS
UNION OIL COMPANY OF CALIFORNIA	LAS CRUCES, NEW MEXICO
LOS ANGELES, CALIFORNIA	MAY 1975

Summary Prepared by
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

A brief reconnaissance of Redondo Creek, Redondo Border, Sulfur Canyon, Alamo Canyon and Valle Seco was conducted between March 23 and March 25, 1975. The purpose of the reconnaissance was to determine a preliminary habitat description of the area and define future studies in order to formulate a cost estimate for subsequent studies. Twelve habitat types and five special habitat sites were tentatively identified.

1.0

INTRODUCTION AND SCOPE

A brief reconnaissance of Redondo Creek, Redondo Border, Sulfur Canyon, Alamo Canyon and Valle Seco was conducted between March 23 and March 25, 1975. The purpose of the reconnaissance was to obtain preliminary data on habitat types, formulate scope and priorities for subsequent studies and formulate cost estimates for performance of subsequent studies. It should be noted that this report only contains preliminary data for use in preparing cost estimates.

2.0

SUMMARY AND CONCLUSIONS

Based on the field reconnaissance, habitat types and special habitat types for the Baca area were tentatively identified. Habitat types identified included spruce-fir forests (two subsets), white and Douglas fir forest, Douglas fir and blue spruce forest, Ponderosa pine forests (two subsets), Gambel oak woodland, dry meadow, wet meadow, and streamside. Special habitat types included freshwater springs, seeps, ponds and pools, cliffs and Scree (talus slopes).

The report establishes priority for conducting future studies. These priorities are as follows.

- 1) Classification of vegetation types into standard habitats and mapping of vegetation.
- 2) Census of the entire area for rare or threatened species of animals.
- 3) Estimation of numbers of big game in the area during summer, and location of areas where elk or deer concentrate their activities, if such areas exist.
- 4) Census of breeding birds.
- 5) Sampling relative abundance of small mammals in the different habitats.

Cost estimates for each of these studies are included in the report.

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Cirriculum Vitae: John L. Ludwig

REPORT NO. 9
EXECUTIVE SUMMARY

WINTER ACTIVITY AND HABITAT USE BY ELK
IN THE REDONDO CREEK AREA
WITH COMMENTS ON ACTIVITIES AND
RELATIVE ABUNDANCE OF OTHER SPECIES

FROM A REPORT

Prepared for	Prepared by
UNION GEOTHERMAL DIVISION	WHITFORD ECOLOGICAL CONSULTANTS
UNION OIL COMPANY OF CALIFORNIA	LAS CRUCES, NEW MEXICO
LOS ANGELES, CALIFORNIA	AUGUST 1975

Summary Prepared by
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

Winter habitat use and activity studies of elk were conducted from late January through late April, 1975. Winter elk herds occur in numbers of 30 to 50 animals as determined by visual counts. Pellet group counts gave estimates of a wintering herd size of nearly 200 animals in the Redondo Creek area and an additional herd of approximately 200 on the south side of Redondo Peak. Elk activity was generally at lower elevations (8200 to 9600 feet). Most activity was on relatively snow-free south-facing slopes of less than 45° containing Gambel oak and scattered conifers.

Human activities within the study area did not appear to disturb the elk. Elk frequently moved along pipeline alignments and roadways.

1.0

INTRODUCTION AND SCOPE

This study was conducted subsequent to initial field surveys in 1974 (Report No. 7). The initial survey indicated that 200 to 500 elk may use the valley floor as a winter habitat area. This study was initiated to provide quantitative and qualitative data on winter use of the study area by elk. The study was conducted between late January and late April, 1975.

Because overstory vegetation precluded accurate counts of elk by fixed-wing aircraft and helicopter, the study was limited to on-foot surveys with the aid of snowshoes. Methods employed included direct observation of herds, (using binoculars and indirect observations based on transects) for pellet distribution. Observations of browse patterns were also made.

2.0

SUMMARY AND CONCLUSIONS

Initial direct observation of elk indicated that two to three herds with 30 to 50 elk per herd occurred within the study. However, based on pellet group counts, the number of herds was revised to four herds in the Redondo Canyon area (up to 200 individuals) and an additional four herds (up to 200 individuals) on the south side of Redondo Peak. Elk activity was generally at lower elevations (8200 to 9600 feet). Most activity was on relatively snow-free south-facing slopes of less than 45° containing Gambel oak and scattered conifers. Bedding areas were located in aspen groves. The report briefly lists other species encountered during the survey.

Human activity associated with geothermal operations in the winter of 1975 appeared to have no detrimental effect on wintering elk. Pipeline areas or other areas that were cleared as a result of geothermal operations may attract elk because of the ease of movement and availability of foraging materials. The report further recommends that areas of elk concentrations be avoided by future geothermal development activities.

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REPORT NO. 10
EXECUTIVE SUMMARY

THE BIOTA OF THE BACA GEOTHERMAL SITE

FROM A REPORT

Prepared for

**UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA**

Prepared by

**WHITFORD ECOLOGICAL CONSULTANTS
LAS CRUCES, NEW MEXICO
AUGUST 1975**

Summary Prepared by

**WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MAY 1980**

ABSTRACT

Vegetation was sampled at the Baca Geothermal area using a habitat type series scheme based on dominant overstory species. Eight habitat type series characterized the vegetation of the study area: spruce-fir forest, white fir and Douglas fir forest, blue spruce and alder habitat type, fir-pine-oak habitat type, oak-locust habitat site, fescue dry meadows and sedge wet meadows. A vegetation map was prepared delineating these habitat types. Studies were conducted during the summer of 1975.

Forty-one bird species were noted during breeding. The highest density and diversity of breeding birds were found at meadow edges. Rodent densities were lower than recorded in the fall of 1974 apparently due to a heavy winter die-off. The greatest small-mammal densities recorded were on talus slopes. During summer, elk confined their activity to the higher elevations of Redondo Peak. Cows migrated to open forests below 9400 feet where their activity was concentrated along Redondo Border, Alamo Canyon and San Luis Creek Canyon.

Three currently listed threatened species were identified as occurring in the study area: American peregrine falcon, bald eagle and Jemez Mountain salamander. (The Mexican duck was also identified as threatened in the report, but has been subsequently delisted by the U.S. Fish and Wildlife Service). The peregrine falcon and bald eagle are apparently transient (not resident) to the area. The Jemez Mountain salamander occurred within the study area, and its habitat was mapped during the study.

1.0

INTRODUCTION AND SCOPE

This report summarizes major biological resources of the Baca Geothermal site and serves to augment an initial biological inventory and an inventory of the habitat of winter elk of the area in the fall of 1974 (Report No. 7). This study basically includes the scope of work outlined in a field reconnaissance conducted in March 1975 (Report No. 8). This report covers field analysis completed during the spring and summer of 1975. The report is divided into two major chapters: vegetative studies and faunal studies. In addition, a brief discussion of archaeological resources is included.

Vegetation was surveyed using standard plant ecology field methods. The series field data was tabulated, and these data were series grouped by cluster analysis. Habitat types were determined from this analysis. Estimates of elk and deer herd sizes were obtained on forty 0.1-acre study plots by counting numbers of pellet groups present. Directed searches for the Jemez Mountain salamander were conducted in suitable habitats. In addition, a survey of suitable nesting habitat for peregrine falcons were checked. Breeding bird densities were estimated through the use of roadside censuses at 0.5-mile intervals. Live trapping was conducted for small mammals in each major habitat type.

2.0

SUMMARY AND CONCLUSIONS

Eight habitat type series were identified and mapped during the study. These habitat type series were:

- 1) Spruce-fir Forest: This habitat type series occurred at higher altitudes in cool habitats with well-drained soils.
- 2) White fir and Douglas Fir Forest: This habitat type occurred between 8500 and 10,500 feet on shallow and rocky soils.
- 3) Blue Spruce and Alder: This habitat type series occurred along the slopes or bends of creeks on the study area.
- 4) Fir-pine/Gambel Oak/Grass Woodland: The habitat type series was characterized by grassland areas having an overstory of large, low-density Ponderosa pine.
- 5) Oak and Locust Scrub: This habitat type series was found on very steep and rocky south- and west-facing slopes.
- 6) Fescue Dry Meadow: These grasslands were found on gently sloping valleys, canyons and mountain sides where deep, well-drained soils have developed.
- 7) Sedge Wet Meadow: This habitat type series was found along semipermanent running, meandering, slow creeks.

- 8) **Open Shrub Talus:** This habitat type series was found on steep rock slide areas of Redondo Peak.

The white fir and Douglas fir habitat type series was most extant on the study area. Spruce-fir forests covered a relatively large area near Redondo Peak. Oak and locust scrub, fir-pine/oak/grass woodlands and fescue dry meadows covered relatively large areas, but were diffuse in their distribution in the study area.

During the summer, elk bulls confined their activity to higher elevations of Redondo Peak. Cows migrated to the open forests near meadows below 9400 feet along Redondo Border, Alamo Canyon and San Luis Creek Canyon. Summer elks were estimated at 336 animals.

Small-mammal-species composition was similar to previous findings (Report No. 7). Populations declined over 80 percent from the previous studies. This decrease is probably due to the extended and unusual period of snow cover during the winter of 1974-1975.

Forty-one species of breeding birds were recorded. These included several raptor species. Peregrine falcons were observed in the Valle Seco and San Luis Creek area. This area is used as a foraging habitat. No nesting sites were observed during the study. (The report also identified this area as a potential habitat for the Mexican duck. The U.S. Fish and Wildlife Service has since delisted this species.)

The threatened Jemez Mountain salamander was found within the study areas. Concentrations of this species were found in large areas on the Redondo Border, Redondo Peak, and an isolated area on San Antonio Mountain.

Several extensive archaeological sites were also found during the survey. Materials collected were sent to qualified archaeologists for evaluation.

Several recommendations and conclusions were made in the report as follows:

- 1) Additional small-mammal surveys should be conducted to document the cause and extent of population fluctuations.
- 2) Studies should be conducted to evaluate the compatibility of breeding birds with geothermal operations.
- 3) Further studies should be conducted to evaluate the importance of the study area to the peregrine falcon.
- 4) Elk appear to be little affected by geothermal operations on the study site.
- 5) Archaeological surveys should be conducted before further exploratory work or development occurs.

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REPORT NO. 11
EXECUTIVE SUMMARY

STUDIES OF RARE AND/OR ENDANGERED SPECIES
ON THE UNION-BACA GEOTHERMAL LEASE AND SURROUNDING AREA
WITH DISCUSSION OF OTHER SPECIES

FROM A REPORT

Prepared for

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared by

WHITFORD ECOLOGICAL CONSULTANTS
LAS CRUCES, NEW MEXICO
AUGUST 1975

Summary Prepared by

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

Surveys were conducted in the spring and summer of 1977 to provide additional data on the status of the peregrine falcon, Mexican duck and Jemez Mountain salamanders within the Baca Geothermal Development area. (The Mexican duck has since been delisted by the U.S. Fish and Wildlife Service). One peregrine falcon sighting was made during 173.5 man hours of observation indicating a pair of falcons may nest some distance from the study site and made occasional hunting forays into the study area. No Mexican ducks were found during the survey. Large numbers of suitable habitat patches for the Jemez Mountain salamander containing dense populations of the species were found in the study area.

1.0

INTRODUCTION AND SCOPE

Surveys to supplement previous inventories of the Baca Geothermal area (Reports No. 7 and No. 10) were conducted during the spring and summer of 1977 to provide additional data on the status of three threatened/endangered wildlife species that may occur within the area. The species of interest were: the peregrine falcon, Mexican Duck and Jemez Mountain salamander. (The Mexican duck has since been delisted by the U.S. Fish and Wildlife Service).

Surveys were conducted during spring and early summer for the peregrine falcon. This survey included searches of potential nesting sites on rocky cliffs in areas away from human disturbance. Observations were conducted at the onsite beaver pond in order to attempt to identify Mexican ducks. Surveys were conducted along potential roadway alignments and at potential well sites for the Jemez Mountain salamander.

2.0

SUMMARY AND CONCLUSIONS

A total of 173.5 man hours of observation during 1977 resulted in only one confirmed sighting of a peregrine falcon and used the site as an occasional foraging area. Searches of potential nesting sites within the study area failed to identify any active nests. These data suggest that one or possibly a pair of falcons nested some distance from the Baca Geothermal site. The report concluded that no peregrine falcons nested within the study area during the spring and summer of 1977.

No Mexican ducks were observed during 1977. New Mexico Fish and Game observed Mexican ducks during earlier years (the Mexican duck has since been delisted by the U.S. Fish and Wildlife Service).

Extensive surveys of the Jemez Mountain salamander within the Baca Geothermal area resulted in the discovery of a large number of suitable habitat patches containing dense populations. These areas of high species densities were mapped. Populations were predominately found on dense north-facing slopes, although populations were also found on south-facing slopes. The report concluded that construction of roadways and wells would unavoidably affect some populations of the species. Efforts should be made to avoid large population concentrations.

Ancillary to the scope of the study, observations on elk were also made. The report noted that elk herds appeared to be healthy and to have grown in number from the time of previous surveys (Report No. 9).

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Assessment of the Status of Peregrine Falcons on and Around
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the Union Baca Geothermal Lease, Summer 1977.

Assessment of the Status of Jemez Mountain Salamander on and Around
the Union Baca Geothermal Lease, Summer 1977.

Assessment of the Status of Other Species on and Around
the Union Baca Geothermal Lease, Summer 1977.

REFERENCES

Report on Biological Reconnaissance of the Southeast Slope
and Valley of the Redondo Border, Baca Geothermal Location

Plethodon neomexicanus - Jemez Mountain Salamanders

Elk and Other Species

Interim Report on the Biological Surveys of the Baca Geothermal
Project Area

REPORT NOS. 12, 13, 14
EXECUTIVE SUMMARY

HYDROLOGY
JEMEZ MOUNTAINS, NEW MEXICO
and Addendum:
MODEL OF STREAMFLOW DEPLETION
OF THE
JEMEZ RIVER BY GEOTHERMAL DEVELOPMENT
IN THE VALLES CALDERA, NEW MEXICO

FROM REPORTS

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
WATER RESOURCES ASSOCIATES, INC
SCOTTSDALE, ARIZONA
MARCH 1977

Summary Prepared By

WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

Hydrologic data collected on the Baca Geothermal Lease between October 1975 and March 1977 were compiled and analyzed by Water Resources Associates. Preliminary interference and re-injection tests were performed on eleven geothermal test wells in the Redondo Canyon area by Union Oil, Geothermal Division. Data was supplied by Union Oil concerning geology and fluid levels in the Caldera, quality of the geothermal waters and other data pertinent to the hydrology and geohydrology of the area. A monitoring program was initiated as part of the research leading to this report. The purpose of this report is to present the results of the monitoring program and to evaluate regional and local groundwater conditions and water quality in their relation to hydrologic problems. A preliminary evaluation of the effects of steam production in the Valles Caldera on the hydrology of the Rio Grande Basin is presented. Recommendations as to the monitoring and evaluation programs are also included.

An addendum to the original report involved two phases of modeling. First, a simplified model was found to be too inflexible to simulate conditions from the reservoir. A refined model was then developed which better simulated conditions and the predicted impact of development in the area. Both models employed Darcy's Law.

Examination of hydrologic and water quality data indicates that groundwater discharge from the Valles Caldera occurs as leakage from a deep caldera reservoir as hot springs and seeps along the Jemez River in the vicinity of San Diego Canyon. Digital modeling of the hydrologic system of the caldera indicates that development and operation of a 55 MWe geothermal power plant will deplete streamflow in the Jemez River by about 7 gpm (0.02 cfs) after 25 years of operation.

1.0

INTRODUCTION AND SCOPE

This report on the Baca geothermal area (Hydrology: Jemez Mountains, New Mexico) is a synthesis and interpretation of the hydrology of the region surrounding the Valles Caldera. This report was prepared by Water Resources Associates (WRA), and utilized existing literature previously presented as U.S. Geological Survey Professional Papers and Water Supply Papers, field conference guidebooks of the New Mexico Geological Society, Los Alamos Scientific Laboratory Informal Reports, and several other sources. In addition, previously unpublished data from four new surface water monitoring stations established in the area of 1975, and groundwater observations in 15 non-flowing (static water level) wells, seven flowing wells and four thermal springs were used as the bases for this report.

1.1

MONITORING PROGRAM

The thermal springs monitored were San Antonio Hot Springs, Spence Springs, McCauley Springs, and Soda Springs (discharge, temperature, and quality). The new surface water monitoring stations were in Redondo Creek, Sulphur Creek, San Antonio Creek, and the East Fork of the Jemez River (interrupted flow and quality). These stations were to complement the established long-term station on the Jemez River below the confluence with the East Fork, but were found to be non-informative and abandonment was suggested.

Flowing (discharge, temperature, and quality) and non-flowing (water level and quality) wells which were examined were too numerous to give locations in this summary, but included scattered water-supply wells and geothermal wells in the Valles Caldera area. The data from the monitoring program are contained in the report as Appendices I and II.

1.2

HYDROGEOLOGIC SETTING

The landform, surface water drainage features, and water bearing characteristics of the geologic formations in the vicinity of the Baca demonstration project are controlled by the geology of the Valles Caldera. The WRA report refers the reader to a report by Union Geothermal Division for a discussion of the geology of the Caldera. Landform and surface drainage features are described from topographic maps with some of the geographic names in the region anglicized by the writers. The major drainage divides in the area are along the rim of the Caldera depression formed by the collapse of the roof and sides of a volcanic magma chamber. The lithologies involved and the age of this event are not given.

The uppermost layers of the caldera filling are essentially impermeable, whereas the remainder of the caldera filling and the rocks which compose the caldera walls are of moderate to low permeability. The shallow covering of caldera fill is of fairly high permeability. Away

from the caldera, the region is underlain by Paleozoic and Mesozoic sedimentary rocks, Tertiary valley-fill deposits, lavas and tuffs (volcanic ash deposits).

1.3

GROUNDWATER MOVEMENT IN THE JEMEZ MOUNTAINS REGION

Groundwater observations in the shallow aquifer system and from the deeper geothermal system are provided in the WRA report as Appendix II. The data indicate an 800 to 1200 foot vertical separation between the two aquifers. Groundwater data are presented in the WRA report by an illustration (Plate I) showing groundwater contours and water level profiles. Groundwater elevations are highest near the rim of the caldera except where the rim breached by the Jemez River and the East Fork of the Jemez River. Groundwater contours indicate flow paths generally into the central portion of the caldera depression or away from the caldera on all sides except in the aforementioned river canyons, where groundwater flow is indicated to be down-canyon.

The WRA report indicates that water from the deep caldera reservoir does not discharge at Sulphur Springs or San Antonio Hot Springs. The water discharging at those springs is reportedly heated in the upper aquifer. Discharge from Spence Springs and McCauley Springs is composed of a very small quantity of deep caldera reservoir water, whereas Soda Springs is composed of a larger percentage of deep circulating water. Temperature of hot springs decrease downstream from Spence and McCauley Springs to Jemez Hot Springs.

The probable eastern limit of the deep reservoir is reported to be approximately six miles east of Redondo Canyon, from which the report concludes that the deep caldera reservoir water is not moving eastward toward the Los Alamos area or the Rio Grande. The possibility of water moving from the deep caldera reservoir to the north is precluded by a groundwater divide. Westward movement of groundwater from the Valles Caldera is similarly precluded by a groundwater ridge, although very deep circulation to the thermal springs in the Rio Salado drainage is possible according to the WRA report. Groundwater discharge from the deep caldera reservoir is near the thermal springs in San Diego Canyon.

1.4

HYDROCHEMISTRY

Stiff diagrams (which express water chemistry data in a format that facilitates rapid qualitative comparison of several analyses) of the chemical composition of waters from the springs, wells, and surface flows in the Baca area are presented in Appendix III of the WRA report. The cations included on these diagrams are Na^+ , K^+ , Ca^{++} , and Mg^{++} , and the anions are Cl^- , HCO_3^- , CO_3^{--} , and SO_4^{--} . The deep, slowly circulating waters are those with high sodium and chloride and/or sulfur (sulfate) ions predominating. The shallow circulating waters are predominately bicarbonate waters with high calcium and/or sodium

concentrations. The intermediate zone contains water of mixed composition. Chemical data support the conclusion that thermal springs near Rio Salado may be associated with the deep caldera reservoir.

Electric conductivity of water in the area is illustrated as Plate II of the WRA report. Conductivity data support the interpretations of the groundwater level contours in that they show that waters of higher concentration of dissolved solids do not move out of the caldera except along the Jemez River Valley; that is, the high concentration waters are found in the deep wells in Redondo Canyon and Sulphur Creek as well as in other thermal springs and deep wells in the area. These data are also shown in the WRA report on Plate III - Sodium Concentrations.

The WRA report suggests that the caldera has been gradually sealing, (loosing permeability) as evidenced by reports that mineral springs in the area have been gradually drying up in recent years. It is considered possible that this sealing process may be well advanced.

Uranium concentration was found to be highest in Sulphur Creek (0.7 parts per billion, ppb), lowest in Redondo Creek (0.1 ppb) and intermediate in San Antonio Creek above Sulphur Creek (0.4 ppb). These data could not be used as a tracer of groundwater movement or as a source indicator. Silica concentrations were presented in the WRA report, but were not interpreted as an indicator of deep circulation.

Data on the occurrence of arsenic are presented in the WRA report as Plate IV. Arsenic concentrations are relatively low in the area except in the Jemez River Canyon, the San Ysidro Spring area, and portions of the Rio Salado and Rio Puerco drainages where the concentrations are relatively high. Low concentrations range from 10 to 40 ppb as compared to 4000 to 4500 ppb in the Baca wells. Arsenic concentrations were used to compute mixing ratios. These ratios varied from 0.00425 and 0.0175 at McCauley Springs and Spence Springs, respectively, to 0.195 and 0.275 at Jemez Springs and Soda Springs, respectively.

1.5

GROUNDWATER HYDRAULICS

Consumptive use of groundwater resulting in streamflow depletion was calculated in the WRA report for operation of a 55 megawatt power plant. It was shown that the streamflow would diminish by about 15 gallons per minute (gpm) (24 acre-free per year) after 25 years of power plant operation. Following 50 years of operation, the depletion would be about 26 gpm (42 acre-free per year). The WRA report suggests that this streamflow depletion could be mitigated by acquiring and retiring water rights from approximately 19 acres of irrigated land in 25 years and 38 acres in 50 years.

ADDENDUM

The Addendum to the WRA report on the hydrology of the region surrounding the Valles Caldera is a description of a refined model developed to estimate steamflow depletion resulting from geothermal development. Derivation of this model is presented as Appendix I, and the computational results are presented as Appendix II to the Addendum.

The original model assumed that the caldera was larger than was later determined from more detailed geologic maps, and the hydrostatic head inside the caldera was approximately that of the Jemez River where it crossed the caldera rim. In addition, possible recharge from the Jemez River was ignored. The values of the various parameters used in the original model are not given, though some become apparent from the refined model.

The refined model assumed a more realistic size for the caldera (radius of an equivalent circular caldera equal to 4.58 miles), an initial hydrostatic head at an elevation of 8281 feet (averaged from the free water surface in the Baca wells), and at an elevation of 7600 feet, elevation of the Jemez River at the caldera rim, for a later calculation run. The refined model also considered the elevation of the base of the caprock within the caldera (6435 feet), porosity (calculated at 10 percent and 1 percent), recharge to the caldera (266 ac-ft/yr), and power plant consumption (1150 gallons per minute). Initial leakage from the caldera was assumed to be 165 gpm, and boundary conditions over an arc of 70 degrees near the Jemez River were based on groundwater contours.

The refined model, using an initial head of 8281 feet elevation, a transmissivity of $7.94 \text{ ft}^2/\text{day}$, and one percent porosity, yielded a streamflow depletion of about 17 gpm after 25 years, assuming ten percent porosity yielded a depletion of about 4 gpm over the same time period. Using an initial head at 7600 feet elevation, a transmissivity of $26.1 \text{ ft}^2/\text{day}$ and ten percent porosity resulted in a streamflow depletion of 7 gpm after 25 years. The author of the Addendum favors the latter depletion calculation as most nearly representing the actual case.

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SAMPLE DATA SHEETS

EXAMPLE

Sta 3310

Same location

(STIFF DIAGRAMS)

TRACE ELEMENT ANALYSES
(Concentration In ppb).

Data No.	Date	Arsenic	Boron	Iron	Lithium	Manganese
2	12/12/74	20	150	110	100	0
3	12/12/74	7	80	80	100	0
9	8/26/72	110	2,200	800	---	--
13	9/25/74	4	210	3,000	200	70
17	10/18/74	190	8,200	---	7,100	--
18	5/ 2/73	210	20	800	---	740
20	4/ 4/74	4	110	1,700	60	0
22	6/ 5/73	0	1,800	30	1,200	20
23	6/ 5/73	360	7,500	1,400	---	90
24	10/ 2/73	2	290	0	210	13
28	5/23/73	3	50	60	---	20
29	5/23/73	0	20	30	---	0
30	9/ 5/73	2	--	15,000	640	260
31	9/ 5/73	5	1,200	80	1,100	630
32	5/24/73	86	5,800	1,500	>2,800	340
33	5/24/73	8	320	400	---	210
34	5/24/73	0	170	40	---	0
35	8/30/73	17	990	540	890	750
36	8/30/73	69	8,200	50	6,700	1,300
40	5/24/73	20	3,300	30	---	70
41	5/25/73	43	670	90	---	80
42	6/ 8/73	15	30	20	---	0
46	8/31/73	0	40	--	50	--
49	8/21/73	67	380	140	---	80
51	11/ 2/73	0	210	60	140	250
52	1/29/74	50	1,000	30	960	120
54	10/ 5/73	68	1,300	90	1,500	80
56	6/ 6/73	1	60	450	---	380
57	10/ 2/73	5	20	20	10	8
61	8/28/73	1	10	10	10	0
64	10/30/73	0	60	10	60	10
66	10/30/73	2	10	20	20	0
67	10/30/73	0	10	80	30	0
69	6/ 7/73	6	2,200	--	--	--
72	7/18/74	26	370	10	560	0
75	3/ 8/73	1,100	14,000	--	--	--
77	5/30/74	780	7,400	450	7,800	300
78	1/29/74	120	85	50	1,300	30
79	9/27/73	150	1,200	30	1,400	0
82	7/ 3/74	5	2,100	--	370	--
85	5/28/74	230	1,900	750	2,300	820
88	6/21/73	5	180	9	--	20
91	7/13/73	4	140	30	--	0
96	9/18/73	1	20	110	0	0
114	3/ 8/73	3	3,300	--	--	--

EXAMPLE

WATER QUALITY DATA
Jemez Basin and Vicinity

Data No.	Date	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ⁻⁻	Cl ⁻	TDS	Ec	pH	Temp °F
1												
2		18.0	3.5	53.0	5.0	127.0	43.0	6.8	265.0	367	--	67
3		28.0	5.0	36.0	7.6	156.0	35.0	7.3	264.0	352.0	7.4	55
4	4/27/65	57.0	10.0	29.0	--	134.0	58.0	51.0	343.0	501.0	7.8	--
5		31.0	5.9	30.0	6.4	142.0	37.0	7.4	255.0	348.0	7.5	61
6	2/26/65	112.0	17.0	60.0	--	357.0	143.0	22.0	598.0	878.0	7.5	--
7	1/21/65	60.0	11.0	69.0	--	248.0	85.0	37.0	457.0	666.0	7.5	--
8		41.0	6.8	79.0	7.9	200.0	40.0	72.0	421.0	642.0	--	81
9	8/26/72	1.2	0.3	740.0	22.0	334/226	49.0	97.0	2,460.0	3,140.0	9.5	90
10	10/ 9/73	80.0	14.0	330.0	16.0	348.0	290.0	280.0	1,220.0	1,950.0	8.1	54
11	3/10/66	54.0	7.4	175.0	--	274.0	90.0	161.0	662.0	1,110.0	7.6	--
11	6/22/66	79.0	9.5	278.0	15.0	330.0	266.0	228.0	1,070.0	1,720.0	7.5	--
12		65.0	15.0	77.0	11.0	294.0	29.0	35.0	548.0	749.0	6.6	78
13		150.0	22.0	50.0	3.0	194.0	350.0	24.0	780.0	1,050.0	--	67
13A		210.0	51.0	180.0	11.0	514.0	580.0	53.0	1,420.0	1,880.0	6.4	71
14	2/ 4/65	117.0	22.0	88.0	--	388.0	218.0	19.0	691.0	1,020.0	7.5	--
15	9/15/24	494.0	91.0	3,310.0	--	1,969.0	3,401.0	2,500.0	10,960	--	--	86
16		100.0	9.0	--	--	1,280.0	286.0	1,140.0	3,470.0	5,680.0	8.0	95
17		--	--	3,900.0	140.0	--	--	2,800.0	--	20,000.0	--	64
18	9/15/24	368.0	85.0	2,219.0	--	1,757.0	1,712.0	1,940.0	7,320.0	--	--	68
18A	5/ 2/73	300.0	68.0	2,000.0	81.0	1,970.0	1,300.0	1,900.0	6,650.0	9,930.0	6.5	63
19	2/27/65	48.0	9.0	46.0	--	158.0	66.0	36.0	330.0	519.0	7.6	--
20		49.0	1.5	56.0	5.5	228.0	57.0	4.2	332.0	490.0	7.9	63
21	1/21/65	147.0	25.0	92.0	--	205.0	450.0	22.0	872.0	1,190.0	7.3	--
22	6/ 5/73	120.0	9.0	2,400.0	6.6	241.0	4,500.0	580.0	7,760.0	10,100.0	8.5	70
23	6/ 5/73	380.0	61.0	3,500.0	88.0	1,410.0	3,300.0	3,100.0	11,100.0	15,700.0	6.8	126
24	10/ 2/73	77.0	26.0	100.0	5.5	335.0	120.0	82.0	599.0	960.0	7.9	79
25												
26	9/29/74	400.0	73.0	3,450.0	--	1,498.0	3,645.0	2,660.0	11,120.0	--	--	115
27	9/14/74	260.0	70.0	2,400.0	--	1,301.0	1,728.0	2,370.0	7,510.0	--	--	70
28	5/23/73	57.0	13.0	28.0	2.6	217.0	63.0	9.3	310.0	487.0	7.6	60
29	5/23/73	96.0	15.0	24.0	1.7	331.0	72.0	11.0	418.0	651.0	7.6	54
30	9/ 5/73	210.0	37.0	310.0	14.0	171.0	990.0	160.0	1,840.0	2,440.0	6.4	60

Data For Selected Wells, Springs and
Related Data at Surface Water Gaging Stations
Jemez Mountains Area, New Mexico

Data Number	Name	Type	Township & Range	Section	Latitude	Longitude	Land Surface (ft) Altitude	Depth To Water (ft)	Altitude of (ft) Water Level	Depth of (ft) Well	Source of Formation For Water	Temp. °F	Date Sampled	Total Dissolved Solids ppm	Electric Conductivity umhos	pH	Rate of Flow (gpm)
1	Rio Grande At Albuquerque	Surface			35°05'21"	106°40'48"											
2		Well	12N2E	14.433	35°15'46"	106°42'05"	5602	637	4965		Santa Fe	67	12/12/74	265	367	--	1,000
3		Well	12N2E	25.421	35°14'22"	106°40'42"	5370	373	4997		Santa Fe	55	12/12/74	267	352	7.4	650
4		Well	21N3E	31.134			5200			350	Santa Fe		4/27/65	343	501	7.8	
5		Well	12N3E	30.121	35°14'46"	106°40'06"	5356	420	4936		Santa Fe	61	12/12/74	255	348	7.5	1,000
6		Well	12N3E	24.423			5030			96	Santa Fe		2/26/65	598	878	7.5	
7		Well	12N4E	6.200			5050			--	Santa Fe		1/21/65	457	666	7.5	
8		Well	12N4E	5.214			5040				Santa Fe	81	9/25/74	421	642	--	
9		Well	13N3E	18.31			5733			10,000		90	8/26/72	2,460	3,140	9.5	
10	Jemez River Below Jemez Canyon Dam	Surface	13N4E	5.1	35°23'24"	106°32'03"											
11	"	Surface			35°23'10"	106°31'45"	5100										
12		Well	13N4E	1.234			5580				Santa Fe	78	9/25/74	548	749	6.6	
13		Well	13N4E	1.412			5480				Santa Fe	67	9/25/74	780	1,050	--	
13A		Well	13N4E	1.421			5100				Santa Fe	71	9/25/74	1,420	1,880	6.4	
14		Well	14N5E	19.221			5150			98	Santa Fe		2/4/65	(691)	1,020	7.5	
15	San Ysidro Group	Spring	15N1E	8.32			5540				Wingate-Chinle	86	9/15/24	10,960	(16,800)	--	
16	Indian Springs	Spring	15N1E	9.2			5580				Penn Rocks	95	8/30/62	3,470	5,680	8.0	
17		Well	15N1E	16.233			5530				Chinle	64	10/18/74	--	20,000	--	
18	San Ysidro Group	Spring	15N1E	10.14			5530				Chinle	68	9/15/24	7,320	11,200	--	
18A		Spring	15N1E	10.310			5530				Chinle	63	5/2/73	6,650	9,950	6.5	
19		Well	15N2E	22.400			5500			335	Santa Fe		2/22/65	330	519	7.6	
20		Well	15N2E	12.431			5750				Santa Fe	63	4/4/74	332	490	7.2	
21		Well	15N5E	13.330			5170			82	Santa Fe		1/21/65	(872)	1,190	7.3	
22		Spring	16N1W	29.230			5830				Chinle	70	6/5/73	7,260	10,100	8.5	2
23		Spring	16N1W	1.421			6020				Chinle	126	6/5/73	11,100	15,700	6.8	85
24		Spring	16N1E	6.321			6360				Chinle	79	10/2/73	599	960	7.2	
25	Hot Well	Well	16N1W	1.243			6021					129	3/16/64	11,000	15,300	7.3	
26	Faseran Well	Well			35°37'04"	106°52'54"	5900			550		115	9/29/24	11,120	--	--	2,450
27	Fernasco Spring	Spring	16N1E	20.32			6000					70	9/14/24	7,510	(11,500)	--	
28	Log Spring	Spring	16N1E	5.244			7175				Pre-cambrian		5/23/73	310	487	7.6	
29		Spring	16N1E	3.441			7000				Abo		5/23/73	418	651	7.6	
30		Spring	16N1E	25.244			5700				Chinle		8/5/73	1,840	2,440	6.4	2
31		Spring	16N2E	30.313			5600				Alluvial	66	9/5/73	2,350	3,190	7.0	
32		Spring	16N2E	20.332			5540				Chinle	59	5/24/73	4,150	6,420	6.4	
33		Spring	16N2E	18.214			5860				Abo	66	5/24/73	674	1,070	7.0	
34	Owl Spring	Spring	16N2E	7.441			5780				Penn Rocks		5/1/53		1,270		32
35		Spring	16N2E	7.432			5850				Nadera	61	5/24/73	482	788	7.3	
36		Well	16N2E	16.411			5580			81	Alluvial		1/19/65	589	946	7.6	

REPORT NO. 15
EXECUTIVE SUMMARY

SUMMARY SHEETS FOR
BACA WELLS NUMBER 1 TO 3

FROM A REPORT

Prepared By

THE BACA LAND AND CATTLE CO.

DUNIGAN ENTERPRISES, INC.

ABILENE, TEXAS

1971

Summary Prepared By

WESTEC SERVICES, INC.

ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

This report provides a summary of drilling data on Baca Wells Number 1 to 3, and conclusions drawn from that data. As a part of the summary, a brief history is given on the three wells and information is also given which lead to the drilling of Baca Well Number 4. Information is given on temperatures at depth and lost circulation depths. This report is a section of a larger report. The title and author of the original report is not known, however, the author is assumed to be Baca Land and Cattle Co. (BLCC) since Wells Number 1 to 4 were drilled by BLCC.

1.0

INTRODUCTION AND SCOPE

The preceding section of the original report was devoted primarily to a tabulation of facts with as little speculative material as possible. With the exception of well data, this section is more interpretive and leads to a generalized model of the Valles Caldera hydrothermal system. This section includes descriptive summaries of Baca Wells 1 through 4 and the methods used to complete them. Temperature and casing data are also summarized graphically.

2.0

SUMMARY AND CONCLUSIONS

The general conclusion proposed is that the Valles Caldera is an excellent prospect for geothermal development including the production from vapor-dominated, and liquid-dominated reservoirs. The general model consists of a high heat flow area, the caldera, situated in the path of a deep groundwater system tending to flow from north to south across the caldera. Heat flow near the center of the caldera is sufficient to cause boiling and separation of vapor-phase water. This area is prospective for the production of dry steam. The most likely area for production from a liquid-phase reservoir, which requires a potentiometric surface near the earth's surface, and a porous and permeable reservoir, is immediately north of the vapor-phase prospective area.

REPORT NO. 16
EXECUTIVE SUMMARY

SUMMARY SHEETS FOR
BACA WELLS NUMBER 4 TO 16

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

This report contains two tabular summaries of some of the data collected on Baca Wells 4 through 16. The information contained in this report is: well pad elevation, drilled depth, drilling medium at depth, entry or lost circulation depths, depth of 9-5/8 inch casing, depth of 7 inch slotted and solid liner, 450°F isotherm depth and elevation, and depths of lithological layers.

Copies of the 3 page report may be difficult to read because of poor original quality. More extensive information is available in Reports No. 17 through 20.

REPORT NO. 17
EXECUTIVE SUMMARY

WELL SUMMARY REPORTS AND
DRILLING HISTORIES
BACA WELLS NUMBER 4 TO 16

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

This report contains the completed day-by-day drilling reports, completion data sheets and graphic representations of completions for Baca Wells 4 through 16. The summaries, both graphic and descriptive, contain drilling methods, historic problems during completion, dates of drilling commencement and completion and casing and cement schedules.

EXAMPLES OF REPORT CONTENT

UNRECORDED

SHEET D

PAGE NO. 1

LEASE BACA

WELL NO. 4 FIELD BACA Land & Cattle Co.

DATE	L.T.D.	DETAILS OF OPERATIONS, DESCRIPTIONS & RESULTS
9-11-70		Finished rigging up - Drld. from 0 to 45. Set 10' of 20" conductor.
9-12-70		Drld. from 45 to 380'. (17½" hole) (with mud).
9-13-70		Drld. from 380 to 540'.
9-14-70		Drld. from 540 to 790'.
9-15-70		Drld. from 790 to 1290'.
9-16-70		Drld. from 1290' to 1442'. Ran 45 Jts. - 13-3/8" O.D. 48 - J-55 - 8 Rd. thd. casing set at 1441 feet and circulated cement.
9-17-70		WOC & nipping up.
9-18-70		Drld. from 1442 to 1722 with air. (12½ hole).
9-19-70		Drld. from 1722 to 1994 with air. Steam and water at 1827. Increase at 1988.
9-20-70		Drld. from 1994 to 2352.
9-21-70		Drld. from 2352 to 2490. Temp. survey at 2408-BHT-380°F.
9-22-70		Drld. from 2490 to 2625. Blooie line cut out, down 17½ hrs. repairing.
9-23-70		Drld. from 2625 to 2808.
9-24-70		Drld. from 2808 to 3138 with air.
9-25-70		Drld. from 3138 to 3177'. Mixing mud to mud hole up, to run casing.
9-26-70		Spotted cement plug (150 Sx) at 3177'. Top plug 2782'.
9-27-70		Spotted cement plugs as follows: 150 Sx at 1832, top cement at 2780. 150 Sx at 2379, top cement 2780. 150 Sx at 2100, top cement at 2230. 100 Sx at 1839, top cement 2179.
9-28-70		Stuck drill pipe at 1838. Pulled drill pipe in two. RBH with overshot. Ran free point. Backed off at 1811. POOH. Ran bit in hole with jars and overshot.
9-29-70		Jarred on pipe 6 hours. Ran free point. POOH, RBH with jars and screwed into fish.
9-30-70		POOH and recovered all of fish.
10-1-70		Mixed mud - conditioned hole and drld. cement plugs.

NEW MEXICO OIL CONSERVATION COMMISSION

P. O. Box 2088, Santa Fe 87501

GEOHERMAL RESOURCES WELL SUMMARY REPORT

Operator Union Oil Company of California Address Mtn. Route Box 76, Jemez Springs, NM 8
 Well Name Baca Location No. 1 Well No. Baca No. 4
 Init Letter 0 Sec. 12 Twp. 19N Rge 3E
 Reservoir Redondo Creek County Sandoval

Commenced drilling (Deepen Well) 6/7/73 GEOLOGICAL MARKERS DEPTH
 Completed drilling (Deepen Well) 6/28/73 Caldera Fill 0' - 200'
 Total depth 6378' Plugged depth 6376' Bandelier Tuff 200' - 5980'
 Plug None Paliza Canyon Andesite 5980' - 6378'

Commenced producing Not Producing (Date) _____ Geologic age at total depth: Pliocene

Static test		Production Test Data									
Shut-in well head		Total Mass Flow Data					Separator Data				
Temp. °F	Pres. Psig.	Lbs/Hr	Temp. °F	Pres. Psig.	Enthalpy	Orifice	Water cuft/Hr	Steam Lbs/Hr	Pres. Psig.	Temp.	

WELL TO BE TESTED AT A LATER DATE.

CASING RECORD (Present Hole)

Size of Casing	Weight of Csp/Hr.	Grade of Casing	New or Used	Seamless or Lapweld	Depth of Shoe	Top of Casing	Number of Sacks Cement	Top of Cement	Cement Top Determined By
13-3/8"	48#	J-55	N	S	1441'	Surface	1800 CF	Surface	Visual
9-5/8"	36#	J-55	N	S	3182'	Surface	1700 CF	Surface	Visual
7"	23# & 26#	K-55	N	S	6376'	3031'	---	---	Prod. Liner Not Cemented
7"	26#	K-55	N	S	2899'	Surface	572 CF	495'	Bond Log

PERFORATED CASING

(Size, top, bottom, perforated intervals, size and spacing of perforation and method.)

Analysis of effluent made? N/A Electrical log depths N/A Temperature log depths N/A

CERTIFICATION

I hereby certify that the information given above and the data and material attached hereto are true and complete to the best of my knowledge and belief.

[Signature]

REMEDIAL WORK (28-1)
73

REVISED	DATE	UNION	DRAWN
			FOR:
		UNION OIL COMPANY OF CALIFORNIA - GEOTHERMAL DIVISION	BY: L.D.C.
		BACA 4 CASING SCHEMATIC	DATE: 11-12-75
		BACA PROJECT	SCALE: 1" = 100'
		NEW MEXICO	DRAWING NUMBER
			1096

REPORT NO. 18
EXECUTIVE SUMMARY

LITHOLOGY LOGS
BACA WELLS NUMBER 4 TO 16

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

This report contains the lithological logs completed by Union Oil Company of California geologists for Baca Wells 4, 5A, 6, and 8 through 16. The quality of the duplication of the logs vary depending on the quality of the original.

LIST OF LITHOLOGICAL LOGS
CONTAINED IN THE REPORT

<u>BACA WELL NO.</u>	<u>DEPTH (FT.)</u>
4	5080-6378*
5A	0-6973
6	0-3715
8	0-4369
9	0-3520 2710-5303*
10	0-5940
11	0-6814
12	0-9175
13	0-8228
14	0-6824
15	0-5505
16	0-7002

*Data was collected during deepening
or redrilling of well.

REPORT NO. 19
EXECUTIVE SUMMARY

TEMPERATURE AND PRESSURE SURVEYS
BACA WELLS NUMBER 4 TO 8 AND 10 TO 16

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

This report consists of an extensive file of temperature and pressure surveys conducted beginning immediately after well completion and continuing in most cases, for several years. The report also contains the daily log of the well driller for Baca Wells Number 5 and 5A. The report is separated into 12 sections. The surveys vary in quantity of data and detail. In most cases the chronology of data begins soon after well completion and continues for between several months and several years. The most recent data in the report was collected in October 1976.

**LISTING OF SURVEYS CONTAINED
IN THE REPORT**

(All surveys are temperature and
pressure except as noted)

<u>SECTION</u>	<u>BACA WELL NUMBER</u>	<u>(MONTH/YEAR)</u>	
		<u>FIRST SURVEY</u>	<u>LAST SURVEY</u>
a	4	10/72	10/76
b	5	10/72	6/76
c	5*	7/71	9/71
d	6	10/72	9/75
e	7 & 8	7/74	9/74
f	10	10/73	10/76
g	11	12/73	9/76
h	12	7/74	9/76
i	13	11/74	9/76
j	14	2/75	8/76
k	15	6/75	10/76
l	16	7/75	7/76

*Drillers daily log of Baca Well #5 and 5A.

REPORT NO. 20
EXECUTIVE SUMMARY

ELECTRIC LOGS FOR
BACA WELLS NUMBER 10 TO 14

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

This report is a compilation of early electric wireline logs run in Baca Wells Number 10 to 14. Most of the logs were run on well completion. The logs included in this compilation may represent only a portion of the logs run in the wells, and some may have been updated by more recent logs. The types of logs included are: temperature, compensated neutron/gamma-gamma density, gamma, neutron-neutron, sonic cement bond, and casing inspection caliper. It should be noted that these are standard electric well logs, however, well log interpretation expertise is required for their use.

LIST OF LOGS INCLUDED
IN THE REPORT

<u>BACA WELL NUMBER</u>	<u>TYPE LOG</u>	<u>DATE</u>	<u>LOGGER</u>
10	Gamma	9/73	1
10	Temperature (3 runs)	9/73	1
10	Sonic Cement Bond	9/73	1
12	Temperature	7/74	2
12	Casing Inspection Caliper	7/76	3
13	Neutron-Neutron (2 runs) (Dual Induction Laterology)	9/74, 10/74	1
13	Compensated Neutron-Density	10/74	1
13	Sonic Cement Bond	10/74	1
14	Compensated Neutron-Density	2/75	1
14	Temperature	10/75	1

Logs Run By:

- 1 - Schlumberger
- 2 - Dresser-Atlas
- 3 - GO Wireline Services

REPORT NO. 21
EXECUTIVE SUMMARY

HYDROTHERMAL GEOLOGY OF THE
VALLES CALDERA, NEW MEXICO

FROM A REPORT

Prepared By

R.F. Dondanville

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

JUNE 1971

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

The purpose of this report was to gather together and summarize all available hydrothermal data on the Valles Caldera in northern New Mexico, and secondarily, to present a tentative model of the hydrothermal system for use as a basis for geothermal exploration. The studies have ranged from the academic pursuits of the United States Geological Survey to private attempts to win commercial geothermal resources. Every attempt was made to utilize reliable data.

INTRODUCTION AND SCOPE

The primary purpose of this report is to summarize the available knowledge of the Valles Caldera hydrothermal system at the time of the report, and secondarily, to present a very tentative model of the hydrothermal system for use as a basis for geothermal exploration. Over a series of years, many man-hours of study have been devoted to the Valles Caldera. The studies have ranged from the academic pursuits of the United States Geological Survey to private attempts to win commercial geothermal resources. This report is simply an attempt to bring together the pertinent, but scattered data generated by other workers. With the exception of the proposed model, there is little original work in this report.

The sources of data for this report were published geological reports, unpublished United States Geological Survey information from the files of the Baca Land and Cattle Company, drilling reports and geological reports of the geothermal wells, and geologic excursions in the Jemez Mountains.

The author has intentionally not elaborated on the topics of stratigraphy and structure. Those subjects had been well covered by the U.S.G.S. map of the Jemez Mountains by Smith, Bailey and Ross. The copy of that map included in the report should be considered an integral part of this report.

SUMMARY AND CONCLUSIONS

The Valles Caldera, sometimes called Jemez Caldera, is located in the Jemez Mountains, a complex volcanic highland of Pliocene and Pleistocene age, about 55 miles north of Albuquerque in north-central New Mexico. The caldera is circular in shape, 12 to 15 miles in diameter, and 500 to 2000 feet deep. The caldera is a relatively young structure, originating about 1.1 million years ago following an enormous eruption of rhyolitic ash and pumice. The caldera is currently in a stage of hot spring activity, although the periodicity of rhyolitic volcanism does not preclude future eruptions.

Hot springs and warm weather wells are generally distributed over several hundred square miles in the Jemez Mountains, indicating a geothermal anomaly of regional scope. The geothermal anomaly culminates in the Valles Caldera, most obviously in the western half, where a maximum temperature of 532F has been measured in the Baca No. 4 geothermal well. Because the structure of the caldera is analogous to a pot on a stove, high subsurface temperatures are probably available everywhere within the 150 square mile caldera, and certainly everywhere within the central 100 square miles.

The deep groundwater system underlying the Valles Caldera is essentially a single unit which can be described simply as the deep flow of

water from the San Pedro and Jemez Mountains into the Rio Grande drainage basin. In addition to subsurface pressure measurements, ionic and isotopic characteristics of the hydrothermal waters can be used to trace water flow in the hydrothermal system. The potentiometric surface of the deep groundwater system is near the surface in the northern half of the caldera and over a thousand feet below the surface in the center of the caldera.

Knowing the subsurface pressure-temperature relationships, a tentative model of the Valles Caldera hydrothermal system is proposed: relatively cool water enters the very hot caldera from the north. As the water flows through the subsurface the enthalpy increases, and near the center of the caldera boiling begins. In the vicinity of the Baca No. 4 well, boiling of the deep water has led to formation of a vapor-dominated reservoir about 2500 feet thick. South of the Baca No. 4 location, given a continuing addition of heat, the vapor-dominated reservoir should be thicker.

The above considerations lead to the conclusion that about 40 square miles in the southern half of the Valles Caldera are prospective for dry-steam production. Liquid-phase reservoirs with temperatures at least as high as the vapor-dominated reservoirs may be prospected for in the northern half of the caldera where the water table is near the surface. Surface manifestations (hot springs, altered rock) of the hydrothermal system are absent in the eastern half of the Valles Caldera and in the adjoining Toledo Caldera. The lack of surficial expression is due to topography and near-surface geology. At depth, the Toledo Caldera and eastern Valles Caldera are fully as prospective as the western Valles Caldera.

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REPORT NO. 22
EXECUTIVE SUMMARY

AIRBORNE INFRARED
GEOTHERMAL EXPLORATION - VALLES CALDERA
JEMEZ MOUNTAINS, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
EARTH RESOURCE OPERATIONS
NORTH AMERICAN ROCKWELL
CORPORATION
FEBRUARY 1972

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

This document is a final report to Union Oil Company of California. The report summarizes the results of an airborne infrared thermal mapping survey of the Valles Caldera, New Mexico geothermal area. The results are primarily a discussion and interpretation of the infrared imagery collected during predawn flights conducted on November 12, 1971, by the North American Rockwell Corporation, Earth Resources Operations. The report is well organized and documented. Many of the figures, however, are multi-generation copies of color photographs, and may be difficult to interpret.

INTRODUCTION AND SCOPE

An airborne, infrared thermal mapping survey was flown over the Valles Caldera area, New Mexico, on November 12, 1971, in order to locate and delineate potential geothermal energy regions. Prior to the actual flight operations, several days were spent in the area planning the flight lines, placing flight line markers, and becoming familiar with the local geology. Thermometric probe temperatures were taken at known geothermal areas to be used as ground truth in remote sensor imagery interpretation. During the predawn period of November 12, 1971, a series of infrared thermal scanner flights was made over the Valles Caldera, while ground crews directed the aircraft by beacon lights and radio. Simultaneously with the overflights, terrain surface temperatures were sampled to be utilized as additional reference points. The 70 mm strip infrared thermal imagery was developed in the field to insure coverage of the area of interest. The imagery appeared to show many geothermal areas in detail for later laboratory and exploration analysis. Laboratory interpretation and enhancement was performed at the North American Rockwell (NR), Downey, California facilities.

On December 17, 1971, a preliminary briefing on the survey results was held at the Union Oil Company's Los Angeles office. At that meeting the preliminary geothermal anomalies map developed by North American Rockwell was discussed in detail. From these discussions, a decision was made on the locations of potential geothermal anomalies which were enhanced on the NR data color processor. The resulting data, imagery and color enhancements are included in this final survey report.

In addition to the above contractual survey and interpretation requirements, NR performed a high altitude photographic flight over the area. On November 11, 1971, the NR Sabreliner obtained black and white photos of the Valles Caldera from 43,650 feet above MSL with a T-11 aerial camera. The resulting photographs are included with this report. They were utilized for accurately locating geothermal anomalies and are included as supplemental material.

SUMMARY AND CONCLUSIONS

The flight operations for the Airborne Infrared Geothermal Survey of the Valles Caldera, New Mexico area were conducted during the predawn hours the morning of November 12, 1971. The Twin Beech survey aircraft maintained an altitude of 14,000 feet (MSL) throughout all the data acquisition runs. A total of 14 data flight lines was flown; this total is listed on Table 1. The flight line number designations and direction each line was flown are indicated on the table. Aircraft take-off from Santa Fe Airport was at 03:15 for the first sortie, which covered the initial calibration passes over the survey area prior to flying the first nine (9) runs. The aircraft returned to Santa Fe Airport

to replenish the IR scanner detector with liquid nitrogen at approximately 05:30 and returned to the survey area for the second sortie at 06:19 to complete the last five (5) runs by approximately 07:00. Flight line numbers 1 through 12 flown in a north-south direction provides complete coverage of the survey area. Flight line number one-prime borders the eastern survey boundary. Flight line number eight-prime (flown from the southwest corner of the area to the northeast corner) basically traverses the area diagonally. Flight lines 1 through 9 were flown with the aid of ground lights positioned along Highway 4 in the south portion of the survey area and along a private road that runs east-west in the northern part of the area. The remaining flight lines were flown with the aid of first light of dawn.

A photo reduction of the infrared thermal imagery mosaic is shown in Figure 1. True north is oriented toward the top of the photo. Figure 2 shows the flight lines as they were actually flown superimposed over a base map of the survey area. In addition to the flight line locations, the figure also indicates the principal points (central points) of each of the 9-inch by 9-inch high altitude photographs taken on November 11, 1971. The high altitude photography was made from an altitude of 43,650 feet above sea level using the North American Rockwell Sabreliner survey craft. Further discussion regarding the camera coverage is contained in a later section entitled Aerial Photography.

The authors present detailed conclusions on the location and extent of suspected geothermal anomalies. However, they point out that each suspected anomaly should be investigated in the field before they can be considered confirmed.

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REPORT NO. 23
EXECUTIVE SUMMARY

ELECTRICAL RESISTIVITY SURVEY IN THE
VALLES CALDERA, SANDOVAL COUNTY,
NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
GROUP SEVEN, INC.
GOLDEN, COLORADO
JULY 1972

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

Group Seven, Inc. carried out an electrical resistivity survey of the Valles Caldera area in north-central New Mexico for the purpose of delineating potentially productive geothermal reservoirs. An area of moderately low resistivity (less than 20 ohm-meters, with conductance of 140 to 200 mhos) was recognized along the western edge of the prospect, extending outside of the prospect. This trend of low resistivity runs southwestward from Valle Seco, through Mushroom Basin to the vicinity of Horseshoe Spring, and another smaller area of very low resistivity at the mouth of Alamo Canyon. This first area of low resistivity exhibits a pattern typical of geothermal system in other parts of the world. Depth to non-porous basement appears to be about 1.5 kilometers in the Sulfur Creek area, based on both dipole mapping data and electromagnetic sounding data.

INTRODUCTION AND SCOPE

Group Seven, Inc. carried out an electrical resistivity survey of the Valles Caldera area in north-central New Mexico for the purpose of evaluating a geothermal system in terms of its potential for generating electric power. The survey was carried out on behalf of the Union Oil Company of California. Field operations were initiated on May 8, 1972 and completed on June 13, 1972.

The Valles Caldera prospect occupies an area some 12 miles square in Sandoval County, New Mexico, just west of the city of Los Alamos. The area is included on two U.S. Geological Survey 15-minute topographic quadrangle maps, the Jemez Springs quadrangle and the Frijoles quadrangle. The area is also covered by 7½ minute topographic quadrangle maps, but the 15-minute maps were used as the base for presenting the results of the electrical survey.

The electrical survey undertaken by Group Seven, Inc. consisted primarily of direct-current dipole mapping surveys, augmented with Schlumberger direct-current soundings and electromagnetic soundings. The dipole mapping surveys were intended to locate the lateral limits of geothermal reservoirs, but such surveys provide very little information about the variation of resistivity with depth from the surface. Such information was obtained at a few locations using the Schlumberger sounding method, capable of mapping changes in resistivity at depths up to about 400 meters, and the electromagnetic sounding method, capable of detecting changes at depths ranging from 1 to 3 kilometers.

Schlumberger direct-current soundings were made using a technique which has long been taken as standard (see Keller and Frischknecht, 1967, for a detailed discussion of resistivity sounding). Resistivity measurements were made with an array of four electrode contacts, spaced along a straight line. Current was provided to the ground through the outermost pair of electrodes, while voltage was measured with the inner pair. The depth to which a boundary in resistivity can be detected is roughly half the separation between the current electrodes. In making a sounding, this separation is increased incrementally to provide successively greater depths of investigation. Spacings ranging from 3 meters to 450 meters (half the current electrode separation) were used for the soundings described in this report. A total of seven soundings was made in areas of special interest, as indicated from the results of the dipole mapping surveys.

The details of field techniques, data reduction procedures and the field data are included in appendices at the end of the report. The resistivity structures recognized at the Valles Caldera prospect are described in the section entitled "Summary of Results." Inferences regarding the probable existence of a geothermal reservoir capable of sustaining power production are drawn in the final section of the report.

SUMMARY AND CONCLUSIONS

Dipole mapping surveys were carried out at the Valles Caldera prospect using seven dipole sources, located as shown on Figure 1 (the base map in Figure 1 is a reduced-scale copy of portions of the Jemez Springs and Frijoles 15-minute topographic quadrangles). Contour maps of the values for apparent resistivity are given on Plates 1, 3, 5, 7 and 9, accompanying this report, while contour maps of values for apparent conductance are given in Plates 2, 4, 6, 8 and 10. It should be noted that several of these plates contain data from the dipole sources, and the contours for the two sets of data so presented are not continuous from one part of the map to the other.

Histograms showing the distributions of observed values of resistivity and conductance are given in two figures. The median value for somewhat more than 600 determinations of apparent resistivity is 31 ohm-meters, while the median value for conductance from the same group of measurements is 80 mhos. Considering the definition of apparent conductance, the average thickness of the surficial porous rocks in the prospect area is no greater than 2.4 km (the product of the median resistivity and the median conductance).

The results of dipole mapping are summarized in two maps showing the locations of regions with low resistivity and high conductivity. In this presentation, a low resistivity is taken to be a value of 200 mhos or more.

Considering all the data, it appears that the swath of ground with low resistivity paralleling Sulfur Creek has an average resistivity of 10 to 15 ohm-meters to a depth of 1400 meters on the average. The strong anomaly north of Horseshoe Springs probably represents rocks with a comparable thickness, but with a resistivity reduced to 3 to 4 ohm-meters. This pattern of resistivity -- a sharply bounded region with resistivity of 3 to 10 ohm-meters -- is typical of geothermal systems in other parts of the world. The total conductance observed in the anomalous areas is considerably lower than that in most geothermal fields. Typically, conductance reaches values of 1000 to 2000 mhos at places such as Wairaki. The low values in the Valles Caldera probably result from the combined effect of a relatively thin section of porous rock, and a porosity that is somewhat lower on the average than in most geothermal fields found in volcanic rocks.

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REPORT NO. 24
EXECUTIVE SUMMARY

ADDITIONAL ELECTRICAL GEOPHYSICAL
SURVEYS IN THE VALLES CALDERA AREA,
SANDOVAL COUNTY, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
GROUP SEVEN, INC.
GOLDEN, COLORADO
DECEMBER 1972

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

Group Seven, Inc., in this report, extended the resistivity surveys originally carried out in the Valles Caldera area of Sandoval County, New Mexico, by using one additional source to make both dipole mapping measurements and electromagnetic soundings. These measurements were concentrated along a profile extending up Redondo Creek and into the headwaters of Jaramillo Creek. The patterns of high and low resistivity seen with this survey do not differ essentially from those seen earlier. This report is an extension of a previous report with a similar title. Most of the volume of the report is a compilation of data gathered.

INTRODUCTION AND SCOPE

Group Seven, Inc. carried out additional electrical resistivity surveys in the Valles Caldera area of north-central New Mexico to further detail an area studied earlier during May and June 1972. The earlier study was documented in Report No. 23. Both studies were carried out on behalf of the Union Oil Company of California. Field operations for this report covered the first two weeks of October 1973.

The Valles Caldera prospect occupies an area some 12 miles square in Sandoval County, New Mexico, west of the city of Los Alamos. The area in which the present survey was carried out lies within the limits of four U.S. Geological Survey 7.5 minute topographic quadrangle maps; these are the Bland, Valle Toledo, Redondo Peak and Valle San Antonio quadrangles. The results of the current surveys are presented on a basemap at a scale of 1:24000 prepared from these quadrangle maps. Results of the earlier surveys were presented on base maps at the same scale prepared from the 1:62500 scale quadrangles of the same area, the Jemez Springs and Frijoles quadrangles.

The resistivity surveys carried out by Group Seven, Inc., during May and June of 1972 delineated an area of moderately low resistivity generally west of Sulfur Creek, along the western edge of the prospect. The survey indicated only very limited areas of moderate resistivity along Redondo Creek, where both early and recent drilling has produced geothermal fluids. The additional electrical surveys described in this report were carried out to clarify the possible association of the producing wells with a geothermal reservoir.

For the surveys described in this report, a single dipole source was used, located in Valle Grande, near the Ranch headquarters. Most of the measurements, both dipole mapping and electromagnetic sounding, were made along a traverse extending up Redondo Creek and into the headwaters of Jaramillo Creek. Some measurements were also made to the north and west of this traverse, and three electromagnetic soundings were made to the southeast of the source, along the edge of Valle Grande.

SUMMARY AND CONCLUSIONS

Both the dipole mapping data and the electromagnetic sounding data from the single source substantiate earlier conclusions regarding the small size of the anomalously conductive area in Redondo Creek Valley. Generally, the conductive surface rocks along Redondo Creek were found to be less than one kilometer thick, and to have a moderately high resistivity, 40 to 60 ohm-meters. The anomalous area at the head of Redondo Creek was found to have an area of less than one square mile, if the 100 ohm contour is considered to be its boundary. Because of this limited area, it is difficult to obtain reliable depth estimates

with any of the electrical surveying techniques. However, the electromagnetic sounding data and the dipole mapping data both indicate that the 100 mho conductance contour is associated with an area in which the surface resistivity is 20 ohm-meters or less. The corresponding depth to resistant rock is, therefore, of the order of 2 kilometers or less.

The source data show clearly two boundaries marking off areas with distinctively different electrical properties. One is an east-west boundary along Jaramillo Creek, south of which the resistivity is quite high. The area along Redondo Creek does not belong to this category, and a boundary must exist to the east of Redondo Creek outside the area where measurements were made. The other major boundary trends northwest-southeast, at the southwest end of Redondo Creek, and bounds an area of high conductance to the southwest.

SAMPLES OF DATA SHEETS

Appendix I.

N	R1	R2	D	T	V1	V2	X	I	RT	SA
R01	6.150	8.200	30.	90.	-75.	-295.	30.	32.0	128.8	42.
R02	6.270	8.450	28.	90.	-110.	215.	30.	32.0	108.2	49.
R03	6.300	8.600	28.	90.	-170.	-170.	30.	32.0	106.9	50.
R04	6.250	8.720	27.	90.	18.	-255.	30.	32.0	110.7	46.
R05	6.530	9.070	25.	90.	130.	205.	30.	32.0	117.9	45.
SAMPLE										
R06	6.700	9.280	25.	90.	90.	185.	30.	32.0	105.6	51.
R07	6.800	9.480	23.	90.	-235.	-265.	30.	32.0	190.0	28.
R08	6.950	9.710	22.	90.	45.	135.	30.	32.0	80.4	66.
R09	7.520	10.250	20.	90.	-85.	150.	30.	32.0	121.1	47.
R10	7.950	10.450	20.	90.	180.	88.	30.	32.0	166.3	37.
R11	2.400	2.500	125.	90.	3150.	3550.	30.	32.0	104.9	23.
R12	2.470	2.970	103.	90.	150.	4150.	30.	32.0	124.0	21.
R13	3.600	3.760	72.	90.	-910.	2050.	30.	32.0	168.9	22.
R18	0.750	3.570	165.	90.	16600.	1220.	30.	32.0	58.7	15.
R19	1.000	3.320	164.	90.	7900.	3200.	30.	32.0	51.2	23.
R20	1.300	3.030	163.	90.	6500.	1620.	30.	32.0	62.9	25.
R21	6.200	8.020	32.	90.	88.	105.	30.	32.0	58.6	97.
R22	6.320	8.000	32.	90.	105.	90.	30.	32.0	62.8	93.
R23	6.350	7.820	48.	90.	165.	-220.	30.	30.0	104.4	62.
R24	6.450	7.730	33.	95.	235.	295.	30.	30.0	203.3	31.
R25	6.430	7.540	34.	90.	-105.	-140.	30.	30.0	88.8	71.
R26	6.500	7.420	35.	90.	-40.	-100.	30.	30.0	55.2	118.
R27	6.550	7.270	36.	90.	75.	230.	30.	30.0	123.3	54.

VALLES EM SOUNDING 801
 OFFSET DISTANCE IS 6850. METERS
 LOOP AREA IS .1664 SQUARE KILOMETERS
 SOURCE LENGTH IS 4290. METERS
 CURRENT IS 32.0 AMPERES
 DEFLECTION ANGLE IS 24.0 DEGREES
 DIGITIZING SCALE IS 0.229 MICRO VOLTS/DIV

EDITED AND STACKED DATA

TIME	NUMBER	AVERAGE	ST. DEV.	EARLY R
.02	5	0.145E-03	0.164E-04	0.324E+02
.04	5	0.203E-03	0.841E-05	0.454E+02
.06	5	0.216E-03	0.929E-05	0.482E+02
.08	5	0.204E-03	0.833E-05	0.456E+02
.10	5	0.170E-03	0.162E-04	0.381E+02
.12	5	0.145E-03	0.198E-04	0.325E+02
.14	5	0.123E-03	0.214E-04	0.276E+02
.16	5	0.108E-03	0.234E-04	0.242E+02
.18	5	0.977E-04	0.230E-04	0.218E+02
.20	5	0.734E-04	0.137E-04	0.164E+02
.22	5	0.550E-04	0.141E-04	0.123E+02
.24	5	0.427E-04	0.189E-04	0.954E+01
.26	5	0.390E-04	0.201E-04	0.872E+01
.28	5	0.372E-04	0.211E-04	0.831E+01
.30	5	0.344E-04	0.158E-04	0.769E+01
.32	5	0.317E-04	0.119E-04	0.708E+01
.34	5	0.289E-04	0.150E-04	0.646E+01
.36	5	0.261E-04	0.154E-04	0.585E+01
.38	5	0.243E-04	0.123E-04	0.544E+01
.40	5	0.133E-04	0.967E-05	0.297E+01
.42	5	0.780E-05	0.109E-04	0.174E+01
.44	5	0.596E-05	0.143E-04	0.133E+01
.46	5	0.321E-05	0.133E-04	0.718E+00
.48	5	0.826E-05	0.133E-04	0.185E+01
.50	5	0.123E-04	0.152E-04	0.287E+01
.52	5	0.101E-04	0.195E-04	0.226E+01
.54	5	0.275E-05	0.141E-04	0.615E+00
.56	5	0.367E-05	0.133E-04	0.821E+00
.58	5	-0.917E-06	0.140E-04	-0.205E+00
.60	5	0.917E-06	0.127E-04	0.205E+00
.62	5	-0.183E-05	0.922E-05	-0.410E+00
.64	5	-0.133E-05	0.117E-04	-0.308E+00
.66	5	-0.133E-05	0.171E-04	-0.410E+00
.68	5	0.550E-05	0.191E-04	0.123E+01
.70	5	0.229E-05	0.135E-04	0.513E+00
.72	5	-0.133E-05	0.105E-04	-0.308E+00
.74	5	-0.734E-05	0.114E-04	-0.164E+01
.76	5	-0.101E-04	0.101E-04	-0.226E+01
.78	5	-0.826E-05	0.924E-05	-0.185E+01

GROUP SEVEN

GROUP SEVEN

REPORT NO. 25
EXECUTIVE SUMMARY

REPORT ON THE
RECONNAISSANCE RESISTIVITY SURVEY
OF THE
BACA PROPERTY,
VALLES CALDERA AREA
SANDOVAL COUNTY, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
McPHAR GEOPHYSICS
SEPTEMBER 1973

Summary Prepared By ,
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

The purpose of this Reconnaissance Survey was to locate and delineate low-resistivity zones that might indicate areas of concentrated thermal activity. Measurements were made with 2000 foot dipoles at one-through-four dipole separations along widely-spaced reconnaissance lines through most of the valley in the area for easier accessibility. The resistivity survey results are shown on data plots. Also enclosed with this report is a plan map of the survey area showing the location of the six survey lines. Anomalous responses which may represent increased geothermal activity have been located on five of the six survey lines. A discussion of the resistivity results along each survey line is given.

1.0

INTRODUCTION AND SCOPE

McPhar Geophysics has completed a Reconnaissance Resistivity Survey on the Baca Property, Valles Caldera Area, Sandoval County, New Mexico. The reader is referred to Reports No. 23 and 24 for related studies. The geology of the Valles Caldera is described in an Outline of the Geology of the Jemez Mountains, New Mexico, by C.S. Ross, et al., New Mexico Geological Society, Twelfth Field Conference, pgs. 139-143. Generally, the geology consists of a thick volcanic pile varying from basalt to rhyolite which represents successive effusions during the Pliocene. Post-caldera rhyolite forms most of the hills in the survey area and solfataric and hot-spring activity are present within the area. The Valles Caldera had been designated as a KGRA prior to this study.

The purpose of the Reconnaissance Survey was to locate and delineate low-resistivity zones that might indicate areas of concentrated thermal activity. Measurements were made with 2000 foot dipoles at one-through-four dipole separations along widely-spaced reconnaissance lines through most of the valley in the area for easier accessibility. A frequency of 0.125 Hz was used in order to minimize attenuation of the electric field due to eddy current dissipation of energy and at the same time, avoid telluric noise.

2.0

SUMMARY AND CONCLUSIONS

The resistivity survey results are shown on data plots. Also enclosed with this report is a plan map of the survey area showing the location of the survey lines at a scale of 1" = 2000'. The definite, probable and possible resistivity low anomalies are indicated on the plan map as well as on the data plots. The representations on the map and plots are the surface projections of the anomalous zones as interpreted from the location of the transmitter and receiver electrodes when the anomalous values were measured.

The variation of the resistivity response of the reconnaissance survey is indicative of the complex geology of the Valles Caldera area. Anomalous responses which may represent increased geothermal activity have been located on five of the six survey lines. A discussion of the resistivity results along each survey line is given in the text of the report.

The reconnaissance resistivity survey of the Valles Caldera area has outlined some areas of high conductivity which may represent increased geothermal activity. One survey line of this survey exhibits low-resistivity values for its entire length and may represent a possible fault zone which is a conduit for geothermal fluids. Another line crosses this proposed fault zone and suggests that the possible lateral extent of this zone is approximately 4000 feet.

The definite anomalies on the south end of one of the survey lines and the north-west end of another line are also of interest. Refer to the report for actual locations and orientations.

The survey line across Valle Grande failed to locate any anomalous zones.

A complete correlation of all geological, geochemical, geophysical and well data was recommended prior to the selection of drill-hole locations.

REPORT NO. 26
EXECUTIVE SUMMARY

SUPPLEMENTAL REPORT ON THE
RECONNAISSANCE RESISTIVITY AND
SCHLUMBERGER DEPTH SOUNDING SURVEYS
OF THE BACA PROPERTY
VALLES CALDERA AREA
SANDOVAL COUNTY, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
McPHAR GEOPHYSICS
JANUARY 1974

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

This report should be considered an appendix to the previous, related report entitled "Report on the Reconnaissance Resistivity Survey of the Baca Property, Valles Caldera Area, Sandoval County, New Mexico," McPhar, 1973. Included in this report are notes on geothermal exploration using the resistivity method and a supplemental report of a similar title to the aforementioned survey. The notes on the resistivity method of exploration included detail as to how and why the measurements are made and how the results are interpreted. The supplemental report is actually a continuation of the original study. Where the first study completed six survey lines, the supplement completed two more, plus it includes five depth sounding surveys by Schlumberger.

INTRODUCTION AND SCOPE

McPhar Geophysics, Inc., has continued and completed reconnaissance resistivity and five Schlumberger depth sounding surveys in Valles Caldera Area, Sandoval County, New Mexico. The initial survey was terminated in July 1973 by mutual agreement of Union Oil and McPhar. Termination was caused by excessive telluric noise resulting from intense thunderstorm activity in the area. The survey was resumed and completed following the end of the active thunderstorm period. For related information refer to Reports No. 23 through 25.

The purpose of the reconnaissance survey was to locate and delineate zones of low resistivity that might indicate areas of concentrated thermal activity. The Schlumberger depth sounding surveys were made to provide additional information on the thickness and resistivity of the geoelectric column in selected anomalous zones defined by the previous survey. In both cases, a frequency of 0.125 Hz was used in order to minimize attenuation of the electric field due to eddy current dissipation of energy and at the same time, avoid telluric noise. The reconnaissance survey was made with 2000 foot dipoles along two reconnaissance lines. The Schlumberger depth soundings were made with the expanding Schlumberger electrode array with spacings expanding from 500 feet to as much as 15,000 feet where required by survey specifications.

SUMMARY AND CONCLUSIONS

No summary and conclusions are appropriate for the notes on resistivity measurements. The reader is referred to the text of the report.

The resistivity survey results are shown on plots in the manner described in the notes which accompany this report. The definite, probable and possible resistivity low anomalies are indicated on a plan map as well as on data plots. The representations indicate the surface projection of the anomalous zones as interpreted from the location of the transmitter and receiver electrodes when the anomalous values were measured.

The thickness and resistivity of the various layers are illustrated graphically on each depth sounding curve and are tabulated. The geoelectric section has been derived by standard curve matching techniques.

Anomalous resistivity responses are present on each survey line. The complex resistivities present on the first six surveys of the original report do not occur in two surveys of this report. A discussion of the results of each survey line is given.

The geoelectric section was derived from the depth sounding data by curve-matching techniques using a set of curves calculated for a layered earth. As illustrated on the dipole-dipole resistivity profile, the

area surveyed with the depth sounding technique is not layered but complex, with vertical and horizontal discontinuities. Therefore, the geoelectric section is an estimate that ignores all vertical discontinuities, and errors of unknown magnitude are always present. A discussion of each depth sounding line is given.

The reconnaissance resistivity survey has further delineated an area of interest indicated by two of the survey lines of the previous survey. A definite anomaly was located. As suggested by Bell in Report No. 25, the anomalous zone defined by three survey lines appears to be a northwest-trending fault zone. The fault zone may serve as the plumbing system for ascending geothermal fluids.

A definite anomaly at 20 East to 20 West, open to the west, is also of interest. This open anomaly may be the northern extension of a zone indicated on two survey lines. Additional lines are necessary to fully delineate and define this possible zone.

The Schlumberger depth soundings indicate excellent shallow conductivity on two of the sounding lines further establishing this zone as a potential thermal area.

Comparison between the geoelectric section derived from the depth soundings with the dipole-dipole data at each point shows poor to good correlation. The lack of correlation in each instance is immediately apparent when the geologic complexity of the region surveyed is considered. Schlumberger depth soundings are designed to delineate the geoelectric section in a layered earth. As illustrated on the dipole-dipole profiles, the Valles Caldera is definitely not a layered earth situation.

REPORT NO. 27
EXECUTIVE SUMMARY

QUANTITATIVE GRAVITY INTERPRETATION
VALLES CALDERA, NEW MEXICO

FROM A REPORT

Prepared By

R.L. Segar

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

A gravity survey of the Baca Ranch which comprises the Valles Caldera, New Mexico, was run by Union Oil Company personnel in October and November 1973. The purpose of the survey was to better define the structural configuration of the caldera floor that resulted from events that occurred in the Pleistocene era. The report details the findings of the survey and includes eight maps which display the findings and successive interpretations of the study. This study augments previous geological data and may have been updated by more recent geological and geophysical studies and data.

INTRODUCTION AND SCOPE

From surface geology, it is known that the Valles Caldera is a relatively negative gravity area, filled with various types of rock materials that are all less dense than a normal granite or limestone (2.7 g/cc). Theoretically, this situation would produce a large negative gravity anomaly coincident with the collapsed area. This certainly is the case as shown by the USGS reconnaissance gravity work. After establishing that the gravity in a broad sense agrees with the surface geology and is not influenced to a great extent by other extraneous sources, it is then only necessary to understand the density contrast and its variation with depth in order to give a good structural picture of the collapsed area.

Since there were no suitable density analyses or logs for this area, one must make approximations of the density variations from past experience or data from similar areas. In spite of the lack of density information and that it would be a limiting factor in the accuracy of interpretation, it was decided to proceed with the survey. The goal was to map the ring fault system and obtain some estimate of the shape and depth of the deeper rocks (Paleozoic and Pre-Cambrian).

In this geophysical investigation, the primary concern was discerning the present structural configuration of the caldera floor that resulted from events that took place in Pleistocene times.

SUMMARY AND CONCLUSIONS

Three distinct trends are noted. The first is in the Sulphur Creek and Redondo Creek area. This negative is probably due to the caldera fill in the area causing a higher density contrast than 0.35 g/cc. The second is the Redondo Creek, Redondo Peak and Jaramillo Creek area where a large positive residual is present. The positive corresponds to the approximate outcrop pattern of the Bandelier Tuff which could mean that the anomaly could have been generated by an incorrect Bouguer correction. In this case it would be an underestimate for the tuff (2.45 g/cc). It could also be caused by too deep a Paleozoic surface. The other negative trend along the east edge of the caldera is probably caused by the presence of substantial amounts of lake beds or caldera fill. This negative means that there is a larger density contrast than 0.35 g/cc.

This investigation has shown that the large negative gravity anomaly is caused primarily by a collapsed volcano. It has also shown that there is an apparent density contrast of 0.35 g/cc and that a Top Paleozoic map structure could be generated by computer processing at Research Center. This work indicated that there is as much as 15,000 feet of lighter density material within the caldera. Also this map has shown that the ring dike system is not always coincident with the ring fracture system, and that the ring fracture is located at a considerable distance inward

from the topographic rim. The concept of "resurgent" doming was neither enhanced or disproved, however, the gravity does indicate that the effect of resurgent doming is much more localized than that envisioned by Smith and Bailey (1968).

It is recommended that this interpretation be combined with the geological and geophysical data to form a more complete understanding of the physical nature of this caldera. A specific recommendation on areas of exploration interest within the caldera cannot be made at this time. This should be done by persons with more knowledge of the electrical and thermal properties of the near-surface rocks.

REPORT NO. 28
EXECUTIVE SUMMARY

MERCURY SOIL GAS SURVEY
BACA PROSPECT
SANDOVAL COUNTY, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
APPLIED GEOPHYSICS, INC.
SALT LAKE CITY, UTAH
AUGUST 1974

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

This study was conducted by Union Oil Company as a brief analysis of the usefulness of the mercury soil gas method of detecting or analyzing a geothermal anomaly. The sample area was approximately one-half mile of road in the Valles Caldera in north-central New Mexico. The reasons and procedures for conducting a mercury soil gas survey are given. This study may be of use as background information on the geothermal reservoir although it was not intended to be.

INTRODUCTION AND SCOPE

Mercury is the only metal that exists as a liquid at ordinary temperatures. As such, it is a highly mobile element having sufficient vapor pressure to cause it to move great distances, even when confined by low permeability barriers such as exist in the subsurface of the earth. When activated by high temperatures, however, its capability to migrate is increased many fold.

The Hg soil gas method for prospecting for geothermal cells is thus based on three premises: 1) the ability of heat to mobilize mercury in pre-existing subsurface rocks, and 2) the contribution of juvenile mercury accompanying juvenile hydrothermal fluids, and 3) the lower pressure existing at the surface of the earth which causes the mercury to move toward that surface. The mercury soil gas method should, therefore, be an ideal prospecting tool for outlining potential areas of geothermal energy.

The mercury soil gas grid was carried out along the existing road network as specified by the Union Oil Geothermal Division. The sample interval was one-half mile along roads in the caldera.

SUMMARY AND CONCLUSIONS

A more uniform two-dimensional sampling net, with scattered sampling points between roads, would have provided a better picture of the distribution of mercury soil gas in the area, but was not judged necessary for this preliminary test. The assay values are given in parts per billion and appear above each sample point in a graphical representation of the data. Above the assay value appears the weighted average calculated according to the formula: $Av = (a+2b+c)/4$, where b is the sample value being averaged and a and c are the assay values on either side.

An even dozen anomalies were encountered by this survey, an anomaly in this case being defined as an area having samples with averages greater than 100 ppb. Only two of these show averages exceeding 200 ppb, and these occur around the two high assays at two points. In both of these areas adjacent samples support the high assays of the central points.

The background level in the area may be judged by references to a graph of the data, where the "most frequent value" appears to be approximately 62 ppb Hg. If the area as a whole is elevated in mercury content because of the pronounced geothermal activity, then this average value may be likewise elevated, and the true background value may be somewhat lower, perhaps 50 ppb. The above mentioned anomalous areas can, therefore, be considered as having Hg soil gas levels at least twice background.

Since no geological or geothermal parameters were provided for comparison with the Hg soil gas results, it is not possible in this report to evaluate the effectiveness of the Hg soil gas technique as a prospecting tool on the Baca prospect.

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REPORT NO. 29
EXECUTIVE SUMMARY

MERCURY ANALYSIS - 1974 GRADIENT HOLES

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
ROCKY MOUNTAIN
GEOCHEMICAL CORP.
MIDVALE, UTAH
DECEMBER 1974

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

This report is a tabulation of mercury analyses from 47 samples. It consists of two pages: a cover letter and a data sheet. The samples were taken from two to three levels in 16 gradient holes at the Valles Caldera geothermal reservoir in north-central New Mexico. The samples were taken from the 100, 200, and 250 foot levels in the holes, except where the holes were not deep enough. The data sheet has hand-written notes on which wells indicate an anomaly on the basis of mercury concentration. No text or relative locations for the wells are given. The data may be useful as background for related studies.

THE DATA SHEET

Samples are from an H.V. of 1974 Gradient holes

Sample No.

ppb
Mercury

Sample No.

ppb
Mercury- TH -
51-100'

380

59-250'

620

51-200'

620

60-100'

80

51-250'

510

60-200'

190

52-100'

460

60-250'

135

52-200'

430

61-100'

80

52-250'

730

61-200'

55

53-100'

55

61-250'

55

53-200'

80

62-100'

25

53-250'

55

62-200'

55

54-100'

270

62-250'

80

54-200'

295

63-100'

55

54-250'

460

63-200'

25

55-100'

160

63-250'

55

55-200'

55

64-100'

25

55-250'

110

64-200'

80

56-100'

1480

64-250'

80

56-140'

755

65-100'

25

57-100'

2370

65-200'

25

57-200'

190

65-250'

55

57-250'

110

66-100'

55

58-100'

945

66-200'

25

58-200'

915

66-250'

110

58-250'

430

59-100'

1030

59-200'

945

Def An

Def An

Not Anom
Pyritic
Why where.

Def An

Probable

Definite

Definite

Definite

Def

De A

Prob

No

No

No

No

No

No

By

Lawrence R. Reid

ROCKY MOUNTAIN GEOCHEMICAL CORP.

SALT LAKE CITY, UTAH • DENVER, COLORADO • SPOKANE, WASHINGTON • TUCSON, ARIZONA

REPORT NO. 30
EXECUTIVE SUMMARY

GEOTHERMAL GEOLOGY OF THE REDONDO CREEK AREA
BACA LOCATION, NEW MEXICO

FROM A REPORT

Prepared By

T.R. Slodowski

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

APRIL 1976

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

This report is a brief four-page summary of all Valles Caldera geological and geophysical data that was available in early 1976, although no references are cited. It proceeds beyond the summary to analyze the causes of success or failure of obtaining a productive well. Further, the report recommends potential areas to explore with drilling maps which display the area geology, structure sections, isotherms, and an isopach.

1.0

INTRODUCTION AND SCOPE

The two main prerequisites for success in developing a geothermal field as adopted by Union Oil Company are: sufficiently high temperatures and permeable reservoir rocks. Success in the Baca project, to the date of this report, has been marginal because of the lack of sufficient primary interstitial porosity and permeability and the necessity to encounter fracture porosity and permeability. This report analyzes the parameters of temperature, geologic structure, reservoir lithology, and past drilling experience to reach recommendations on future drilling.

2.0

SUMMARY AND CONCLUSIONS

Temperature has been a problem in only one well, Baca 5, which has a large temperature reversal. Reference to Figures 4-6 (400F and 500F isothermal maps) shows the isothermal surfaces to dip steeply toward and roughly parallel the northwest slope of Redondo Peak. This is probably caused by most of the large amount of rainfall and snow melt on this slope infiltrating deeply into the subsurface via large vertical faults, instead of being carried off in surface streams.

As the maps show, the highest temperatures are encountered along Redondo Border with a lobe extending east and southeast of Baca Wells No. 11 and 15.

The structure map on the base of the Bandelier Tuff and the structure section through the wells on the west side of Redondo Creek suggest that the high temperature area may be controlled by both stratigraphy and structure. The Baca 10, 6, 15, and 11 wells encountered Tertiary sands beneath the Paliza Canyon andesite. These sands have sufficient porosities and permeabilities to serve as aquifers and permit deeper hot water to the west to convect up-dip towards Redondo Border. Fairly closely spaced cross-faulting and associated fractures in the area of the above mentioned wells could also allow convection of hotter, deeper waters in this area. The structurally high areas, although somewhat complicated by faulting, coincide rather well with the isothermal surface highs. The structural high is readily apparent on the structure section where Baca 15 is on the highest part of the structural high.

The greater majority of producing zones thus far encountered in wells in the Redondo Creek area have been in the Bandelier Tuff. The Paliza Canyon andesite appears to contain tuffs or open fractures, locally, which are capable of producing fluid. However, generally the andesite is very highly altered to clays and most fractures may be closed. The Tertiary sands which occur beneath the andesite are probably the zones most capable of producing fluids, but their extremely fine grain size and unconsolidated character cause the sand to flow with the fluids.

The success or failure of wells, then, is almost entirely dependent upon encountering open fractures in the Bandelier Tuff. Fractures are obviously most abundant at the intersection of two faults and, for a better future success ratio, wells must be located at fault intersections and not merely at locations which are easier to build (at the expense of the well).

Three of the figures show that the area approximately outlined by Baca 6, 4, 13, and 16 contains the highest temperatures encountered. It is expected that most of Redondo Border and its northwest flank may have similar temperatures and future exploratory wells should be located west and northwest of Baca 11, 15, and 16. The isopach map shows this area to have 2000 feet to 4000 feet of Bandelier tuff below the 400F isotherm.

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- 4 400F Isotherm Map
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REPORT NO. 31
EXECUTIVE SUMMARY

A MAGNETOTELLURIC - TELLURIC PROFILE SURVEY
OF THE VALLES CALDERA PROSPECT
SANDOVAL COUNTY, NEW MEXICO

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
GEONOMICS, INC.
BERKELEY, CALIFORNIA
DECEMBER 1976

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

This report describes the results of a combined magnetotelluric (MT) telluric profile (TP) survey performed by Geonomics, Inc. of Berkeley for the Union Oil Company of California. The survey took place at the Baca Location in Sandoval County, New Mexico, during June and July 1976. Its purpose was to determine the thickness and structure of the volcanic sediments and underlying formations, and to interpret the results in terms of local geothermal potential.

INTRODUCTION AND SCOPE

This report describes the results of a combined magnetotelluric (MT) telluric profile (TP) survey performed by Geonics, Inc. of Berkeley for the Union Oil Company of California. The survey took place at the Baca Location in Sandoval County, New Mexico, during June and July 1976. Its purpose was to determine the thickness and structure of the volcanic sediments and underlying formations, and to interpret the results in terms of local geothermal potential.

Telluric profile data were recorded using Geonics' Mark II telluric receiver and a Brush 2-channel chart recorder. Stations were spaced 1000 feet apart on seven surveys and 500 feet apart on the last survey; locations are shown on a map included in the report.

Magnetotelluric (MT) data were recorded on the Geonics Mark II system which utilizes a cryogenic magnetometer and a 4-channel FM tape recorder. Results were computer-processed. Layered resistivity models were obtained from MT data by matching input data to 2 and 3-layer model curves. These curves must be viewed as merely an aid in defining the local resistivity structure. Since the area does not even grossly approximate horizontal layering, the curves are given as a best fit set for each station. Several MT profiles were also drawn from raw apparent resistivity data. These offer the advantage of a direct qualitative interpretation of data that has not been subjected to the prejudices of the interpreter.

The recordings and the daily reports of the Space Environment Services Center, Department of Commerce, show the geomagnetic field during June and July was quiet to unsettled. Although such conditions provide fair to good signal for MT and TP surveying, the daily lightning storms in this part of New Mexico interfered considerably with data acquisition in the early afternoon when natural signals are strongest.

SUMMARY AND CONCLUSIONS

The complex sequence of volcanic rocks beneath the survey area and the multiple fracture patterns have a profound effect on the electric currents measured by the telluric profile and magnetotelluric methods. These effects can be enumerated as follows:

1. Elongate conductive fracture zones tend to channel telluric currents and polarize the incoming electric field signal. These features can yield misleading MT results.
2. There is significant evidence that such features cause incoherency and phase shifting of incoming signal. This effect is herein called telluric "noise" for convenience. This is not meant to imply that geologic features generate noise; rather, the features affect incoming signal so as to make it incoherent or "noisy." One

aspect of this "noise" is that it lessens data quality at stations near noisy structures. Other aspects of noise are more thoroughly discussed in the report.

A total of eight telluric profiles was measured across the Baca Prospect; locations of profile lines are given in Plate I. The lines varied in length from 1-13 km; seven lines were measured with stations spaced 1000 feet apart while the eighth profile, H, utilized 500 foot stations for greater detail. Data quality throughout the time of the survey was generally good with signals much stronger on the north-south lines than the east-west. (This phenomenon is explained with the magnetotelluric results, Section IV). Data was taken in four discrete frequency bands for all profiles. These bands (8 Hz, .5-2 Hz, .03-.06 Hz, and .008-.045 Hz) provide variable depth recordings beneath each site.

Plates II-VII show the results of telluric profiles. On each is indicated all the necessary data for qualitative interpretation, including a topographic profile, a J-value profile and an interpreted subsurface pseudo-section. Faults are noted by their telluric signature as o (conductive) or p (resistive). The scale of these plates is the same as the base map. Topographic corrections were not taken except for a mathematical correction of line lengths; in most cases this is no setback since the correlation between high frequency tellurics and topography is usually apparent, while low frequency telluric topography corrections are not significant.

Twenty-five magnetotelluric sites were occupied in the Baca Prospect in July 1976. Four additional planned sites were to be occupied in December 1976. Data quality was generally good but signals were low. Interpretable data was extracted from all but three stations. It was computer analyzed and evaluated by polarization, apparent resistivity and modeled resistivity values.

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SAMPLES OF DATA SHEETS AND GRAPHS

NO. 4-ROTATED APPARENT RESISTIVITIES

PERIOD	BANDWIDTH	EX PRED EX	EY PRED EY	SKEWNESS	POINTS IN BW	QUALITY	APPARENT RX	APPARENT RY
.025	.0664	.8441	.7721	.6923	355	2	1.9233	2.2767
.026	.0567	.8697	.7995	.6772	381	2	2.4217	2.9866
.026	.0521	.8858	.8125	.6418	411	1	3.4020	4.2884
.027	.0479	.8997	.8225	.5539	447	1	5.6404	7.1069
.038	.0922	.8765	.8394	.4862	232	1	14.7510	15.6560
.041	.0893	.8791	.8560	.5308	240	1	13.3940	13.5550
.043	.0868	.8677	.8516	.5966	247	1	12.0120	12.3300
.047	.0848	.8496	.8153	.6001	252	1	10.6480	10.5830
.059	.1407	.8750	.7340	.3249	153	2	8.3407	7.0633
.064	.1419	.8857	.7225	.3299	151	2	7.2380	5.9684
.072	.1447	.8956	.7380	.4150	148	2	6.8355	5.7012
.083	.1500	.9039	.7703	.5454	144	2	6.8311	6.0151
.089	.2148	.9220	.8177	.7832	100	1	6.7959	6.4825
.102	.2253	.9521	.9148	1.4111	96	1	6.9538	6.5344
.121	.2411	.9616	.9323	1.7832	90	2	7.5892	6.5529
.137	.3278	.9670	.9420	2.0754	86	2	8.2033	6.5655
.147	.2653	.9616	.9311	2.0056	81	2	8.2889	6.5810
.163	.3579	.9557	.9154	2.0217	60	2	8.1646	6.4513
.201	.4018	.9408	.8830	1.6324	54	2	7.2956	5.9878
.208	.5004	.9397	.8792	1.5333	44	2	7.0996	5.8806
.258	.5684	.9315	.8721	1.7054	39	2	6.7645	6.3251
.261	.4694	.9297	.8696	1.7279	46	2	6.6793	6.3385
.318	.7638	.9250	.8596	1.6046	28	2	6.5774	6.8642
.335	.6697	.9192	.8636	1.6634	33	2	6.5235	6.8732
.410	.9027	.9150	.8815	1.6987	24	2	6.5190	7.5044
.481	.8305	.9089	.8673	1.3916	27	2	6.3186	7.9432
.486	1.1657	.9141	.8755	1.5391	20	2	6.4370	8.5153
.558	1.1161	.9098	.8521	1.1746	20	2	6.3256	9.1082
.604	1.4498	.9230	.9076	1.4617	355	3	.8066	1.2344
.614	1.3492	.9220	.9076	1.2916	381	3	1.2590	1.9661
.625	1.2498	.9378	.9076	1.2231	411	3	1.9098	3.1003
.639	1.1498	.9493	.9029	.9644	447	3	2.8357	5.1732
.652	1.4337	.9101	.8473	1.1008	16	2	6.4989	9.7977
.741	1.7793	.9039	.8588	1.1157	13	2	6.4889	9.2664
.816	1.4693	.8918	.8294	1.4392	16	2	6.7308	9.9798
.922	2.2128	.7239	.8621	.7266	232	3	8.3094	16.4350
.930	1.8602	.8958	.8221	1.7566	12	2	7.9261	10.8510
.974	2.1428	.5339	.7486	1.4359	240	3	6.2903	12.5570
1.034	2.2770	.8674	.8244	2.2219	11	2	7.8552	12.1980
1.041	2.0820	.5840	.8109	1.1491	247	3	7.2085	14.9190
1.130	2.0343	.6175	.8159	.8936	252	2	8.0828	16.7760
1.132	2.7157	.8728	.8018	2.5285	9	2	8.2639	12.9010
1.407	3.3775	.6198	.8128	.7688	153	2	9.8288	20.2740
1.444	2.5996	.8847	.7681	2.1092	9	2	9.3391	15.9670
1.542	3.4048	.7358	.8647	1.3612	151	3	11.9780	24.5260
1.550	3.1004	.8869	.7740	2.1901	8	2	10.1010	16.7320
1.644	3.6165	.8877	.7696	2.0065	6	2	10.5680	17.3710
1.727	4.1451	.8967	.7630	2.0891	6	2	11.4220	18.7140
1.736	3.4716	.7211	.8548	1.4317	148	2	13.3740	25.8440
1.999	3.5991	.7148	.8503	1.5750	144	2	15.8200	28.1300
2.148	5.1549	.7168	.8473	1.6678	100	2	17.1470	29.2960
2.458	5.4077	.6766	.8258	1.6890	96	2	19.1380	31.7510
2.555	4.5992	.8407	.6864	6.6163	5	2	15.2680	24.9020
2.584	5.1674	.8407	.6864	6.6163	5	2	15.4380	25.1790
2.611	5.7438	.8407	.6864	6.6163	5	2	15.6010	25.4440
2.626	6.1247	.8273	.6824	6.3841	4	2	16.6400	27.6370
2.943	5.7860	.6244	.7961	1.4445	90	2	22.1930	34.8210
2.278	7.4644	.5576	.7644	1.1446	66	3	22.6140	36.7130
3.638	6.3678	.5345	.7544	1.1320	81	3	24.0120	38.5410

SAMPLE

Station 1

31.10

○ R_x
△ R_y

Y 1:3:30 // .3

Y 1:10

X 1:1:3 // .3

SAMPLE

Station 1
Non-Rotated Data

X = 130°; Y = 220°

$\sqrt{T, \text{sec.}}$

REPORT NO. 32
EXECUTIVE SUMMARY

GEOLOGICAL RESUME OF THE VALLES CALDERA

FROM A REPORT

Prepared By

T.R. Slodowski

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

JUNE 1977

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

In 1977, T.R. Slodowski of Union Oil Company compiled a summary of existing knowledge of the historical geology and present day geothermics of the Valles Caldera in north-central New Mexico. This summary contains synopsized information on the present regional geology, stratigraphy through the Pre-Cambrian, Paleozoic, Tertiary, and Quaternary periods, and the present day stratigraphy and geothermics of the area. References are cited throughout the text of this documentary. This report contains six reference maps.

1.0

INTRODUCTION AND SCOPE

Geological studies performed from 1968 to 1977 and geological and geophysical observations by Union Oil Company of the Valles Caldera of north-central New Mexico are summarized in this report. Extensive attention is given to the chronology of the formation of the caldera and its stratigraphic layering or lack of it. The report includes a detail of the structure developed during the Pre-Cambrian, Paleozoic, Tertiary and Quaternary periods. The area geothermics and results of exploration activities are discussed.

2.0

SUMMARY AND CONCLUSIONS

The Valles Caldera (Figures 2, 3, 4, and 5) is a subcircular, volcanic depression 12 to 15 miles in diameter, with its walls rising from a few hundred to more than 2000 feet above the floor. A central structural dome, Redondo Peak, near the center of the caldera has a relief of nearly 3000 feet and is bisected by a northeasterly-trending central graben. Over ten large rhyolite volcanic domes are located on or close to a ring-fracture zone circling the central dome; caldera collapse occurred along this fracture zone.

At the date of this report, 16 geothermal exploration wells had been drilled in the Valles Caldera; 5 in the Sulphur Springs area and the remainder in Redondo Creek. The wells vary in depth from a little over 2000 feet to a maximum depth of 9212 feet. Although very high temperatures have been found in all wells, exploration activity had been concentrated in the Redondo Creek area because of the thicker section of Bandelier Tuff present there and the fracture permeability it possesses. Almost all the production comes from this formation.

The principal geothermal resource discovered is a deep reservoir of hot water with temperatures varying from 535F to 627F. Permeable reservoir rock is not usually found above depths of 3000 feet. The water contains about 7000 ppm total dissolved solids. The chemistry of thermal water from a typical well is given in the report.

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REPORT NO. 33
EXECUTIVE SUMMARY

GEOHERMAL POWER PLANT
FEASIBILITY REPORT

FROM A REPORT

Prepared For	Prepared By
UNION GEOTHERMAL DIVISION	ROGERS ENGINEERING COMPANY, INC.
UNION OIL COMPANY OF CALIFORNIA	SAN FRANCISCO, CALIFORNIA
LOS ANGELES, CALIFORNIA	OCTOBER 1974

Summary Prepared By

WESTEC SERVICES, INC.

ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

This engineering feasibility report was prepared in October 1974 and presents economic and technical comparisons of the various alternatives available to industry at that time to utilize hot geothermal brines for electrical power generation.

The evaluation of alternatives was based on geothermal brine qualities and well productivity data obtained from the exploratory wells, Baca 4, 6 and 11, located in the Redondo Creek area of the Baca Location No. 1, New Mexico. The analysis proceeds through conceptual designs and cost estimates for single flash, double flash and binary cycle power plants, conceptualization of fixed and variable operations and maintenance costs, electric utility interconnection costs, and incremental environmental protection costs. Conclusions and recommendations are presented based on this analysis.

INTRODUCTION AND SCOPE

This engineering feasibility report was prepared in October 1974 and presents economic and technical comparisons of the various alternatives available to industry at that time to utilize hot geothermal brines.

The evaluation of alternatives was based on geothermal brine qualities and well productivity data obtained from the exploratory wells, Baca 4, 6 and 11, located in the Redondo Creek area of the Baca Location No. 1, New Mexico. The power plant options considered were based on the current state of available geothermal power plant technology along with the availability of hardware. Each of the power producing cycles considered was evaluated in mid-1975 dollars based on a 50 MW plant size.

The scope of the feasibility report includes:

1. The determination of the cost benefits of a single flash steam power plant; double flash steam power plant utilizing mixed pressure, multi-stage, condensing turbines; and the binary fluid cycle power plant, based on the "Magmamax Power Cycle."
2. The development of cost estimates for the flash steam and binary cycle power plants, which were prepared after each system, was designed to economically utilize the geothermal resource conditions prevailing at the site.
3. The development of cost estimates for additions or modifications to the power plant for environmental protection. These estimates were done on an incremental cost basis. The additions or modifications for environmental protection which have been evaluated include:
 - a. The use of dry cooling towers combined with direct contact condensers to eliminate atmospheric discharges of water vapor and noncondensable gasses.
 - b. The use of surface condensers in conjunction with wet cooling towers, to eliminate direct contact absorption of hydrogen sulfide into the cooling water, and thereby eliminate atmospheric contamination.
 - c. The use of a Stretford unit for the absorption of hydrogen sulfide from the condenser vacuum system vent gasses and the reduction of the hydrogen sulfide to elemental sulfur.

SUMMARY AND CONCLUSIONS

The results of the feasibility analysis of 50 MW power plant alternatives using geothermal fluids from Baca wells 4, 6 and 11, show that:

1. The Single Flash Steam Cycle power plant is about four percent (4%) lower in capital cost than the Double Flash Steam Cycle plant. However, the Single Flash Steam Cycle power plant requires about twenty-one percent (21%) more geothermal well production for the same power output. The Single Flash Steam power plant is the more common type of geothermal power plant operating on geothermal hot brine, and it has a longer operating history. However, there are 90 MW of Double Flash Steam Cycle power plants in operation at Power Station No. 2, Wairakei, New Zealand. Indications are that these plants have comparable operating load factors.
2. Turbine-generators for either single or double flash plants can be obtained in various sizes and from different manufacturers. Therefore, the decision regarding which type of plant to install should be based on an evaluation of the operating cost for the twenty-one percent (21%) increase in well production versus the four percent (4%) increase in plant investment.
3. The removal of noncondensable gasses from the main condenser requires about 94,000 pounds per hour of steam for steam jet gas ejectors in the Single Flash Steam Cycle plant. The same noncondensable gas removal using motor driven compressors would require 900 KW of electrical energy. The incremental capital cost of the gas ejector system is \$542,000 while the cost of the gas compressor installation is \$1,640,000. Based on the high cost and increased maintenance required for the gas compressors relative to the steam ejectors, it does not appear feasible to buy and use compressors for noncondensable gas removal unless steam (fuel) values are high. For the purposes of these cost estimates steam (fuel) values are assumed to be high. The steam jet ejectors were included, however, on the flow sheets to provide a backup when the gas compressors are down for maintenance. The cost estimates for the power plants include the costs for both the gas compressors and the steam jet ejectors. If the high steam cost assumptions are not borne out, the power plant capital costs may be reduced by \$1,640,000 each, based on the use of steam jet ejectors alone.

A combination of steam jet ejectors and compressors may ultimately be justified. The first stage compressor costs about sixty percent (60%) of the total, but the motive steam to each ejector stage is about equal, so the use of a steam jet on the first stage and a gas compressor on the second stage may prove to be the most economical arrangement.

4. The binary cycle plant costs about forty-five percent (45%) more than either the Single or Double Flash Steam Cycle power plants. Aside from its high first cost, the binary fluid cycle power plant

has no commercial operating experience. Therefore, there is no way to assess the cycle's performance or the reliability of the plant. The consideration of the type of power plant to be constructed at this time should be limited, therefore, to the Single or Double Flash Steam Cycle power plant. With a savings of twenty-one percent (21%) in well production cost at a difference of four percent (4%) in plant investment, the Double Flash Steam Cycle power plant is recommended.

5. Hydrogen sulfide contamination at the cooling tower may be prevented by utilizing a closed condensing system. This can be accomplished by use of a surface condenser combined with a wet cooling tower or by use of a dry cooling tower combined with a direct contact condenser. The incremental cost increases to convert to the closed condensing system were calculated.

The combination of the surface condenser and the wet tower is recommended because its incremental cost is approximately twenty-four percent (24%) of the cost of the direct contact condenser with dry cooling tower, and also gives better plant performance.

6. The hydrogen sulfide discharged from the condenser vents can be treated by adding a Stretford process unit. The cost of this unit is \$1,450,000. Operating costs are approximately \$31 per day for chemicals, and power consumption is approximately 130 KW.

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DRAWING LIST FROM THE COMPLETE REPORT

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E-07-001	Schedule, Design & Construction
E-02-002	Power Cycle Flow Diagram - Single Flash Steam Cycle
E-17-002	Single Line Power Diagram - Single Flash Steam Cycle
E-02-001	Power Cycle Flow Diagram - Double Flash Steam Cycle
E-04-001	Plot Plan
E-04-002	Power House Operating Floor Plan
E-04-003	Power House Operating Floor Plan
E-04-004	Power House Ground Floor Plan
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E-42-003	Elevations
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E-04-005	Plot Plan Binary Cycle Geothermal Plant
E-17-101	Single Line Power Diagram - Binary Cycle
SK-P1	Noncondensable Gas Purification - Stretford Process

REPORT NO. 34
EXECUTIVE SUMMARY

BACA WELL NO. 11
SCALE EVALUATION

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

APRIL 1975

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

FEBRUARY 1980

ABSTRACT

Erratic flow characteristics of Baca Well No. 11 in the Redondo Creek Area, New Mexico, in the latter part of August and September of 1974, necessitated a thorough inspection of surface and subsurface facilities. This inspection disclosed the presence of scale in both locations. Scale had been noted prior to this on the coils of the test heat exchanger which were in contact with the wellbore fluids. This report was prepared to consolidate all information existing at the time relating to the scale problem for purposes of information, analysis of the problem, possible effects on the project, and to provide a basis for recommendations for further evaluation.

INTRODUCTION AND SCOPE

Erratic flow characteristics of Baca Well No. 11 in the latter part of August and September 1974 necessitated a thorough inspection of surface and subsurface facilities. This inspection disclosed the presence of scale in both locations. Scale had been noted prior to this on the coils of the test heat exchanger which were in contact with the wellbore fluids.

This report has been prepared to consolidate all information relating to the scale problem for purposes of information, analysis of the problem, possible effects on the project, and to provide a basis for recommendations for further evaluation. The report analyzes the drilling and production histories of Baca Well No. 11, and compares the results to those observations made in other wells in the area.

SUMMARY AND CONCLUSIONS

The formation scale was verified downhole in the bore of Baca Well No. 11, in the Redondo Creek area, New Mexico Project. The scale was found to be primarily calcium carbonate, with possibly some silica associated. This situation, along with Union Oil Company scale experience in the Philippines, indicates that scaling tendencies may be present in all hot water geothermal wells. An economical and practical solution for the problem must be found in order to have a viable geothermal project.

Recommendations are made which form a consensus of opinion of research and operations personnel as to the best methods to attack the problem here and at other projects. Most recommended testing was to be done at the Baca Location site in New Mexico because of better logistics.

Briefly, the main emphasis of recommended testing was to involve the development of scale prediction capabilities, the magnitude of mechanical scale removal required for uncontrolled scale formation, scale inhibitor injection testing, investigation of a removable, disposable liner, and the use of downhole pumps. Some conclusions were made, but only to discard possible solutions to the scale problem.

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REPORT NO. 35
EXECUTIVE SUMMARY

EFFECTS OF TURBINE POWER CYCLE
ON DEVELOPMENT WELL REQUIREMENTS
IN THE REDONDO CREEK AREA

FROM A REPORT

Prepared By

J.D. Hartz

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA
OCTOBER 1977

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

This report presents a brief review of productivity and reservoir data from the Redondo Creek area wells and discusses the Union Oil Company concept of initial development of the project. Mass balance calculations are included to show how well productivity and produced enthalpy affect the number of wells that would be required to develop steam for a 50 MW single-flash or dual-flash turbine generator. Noncondensable gas and steam condensate data are included to provide a basis for preliminary turbine design.

1.0

INTRODUCTION AND SCOPE

Production testing at Baca Well No. 15 has indicated that it should be considered a relatively high steam producer with high steam fraction and resultant high enthalpy compared to the other wells in the Redondo Creek area. Two figures plot deliverability, produced enthalpy and steam fraction versus wellhead pressure. Geologic and reservoir data indicated that the area northwest of Baca Well No. 15 may be underlain by a steam cap or steam reservoir but the reservoir geologists are unable to determine its size or extent from the current data.

A development forecast has been made utilizing production and reservoir data from 1975-1976 interference tests. The report relies in part on the Rogers Engineering Feasibility Study of October 1974, and briefly reiterates some of the findings of the study. Mass balance calculations were made to determine well requirements for 50 MW single and dual-flash steam systems. The author included a self-imposed 10 percent excess steam requirement, which was not considered in the Rogers study.

2.0

SUMMARY AND CONCLUSIONS

The reservoir and productivity data developed at this time indicate the presence of a steam-dominated reservoir in the area of Baca 15 in addition to the liquid-dominated reservoir as penetrated by Baca 4, 6, 11 and 13. Calculations of development well requirements based on observed productivity lead to conclusions listed in the text. Briefly, the author calculated that 13 wells would be required to supply fluids to a plant using a single-flash system, while a dual-flash system would require one less well. However, it was found that the savings due to the lesser well requirement would be offset by: 1) higher gathering system costs which would include an automated crossover; 2) the costs of duplication of facilities if separate gathering systems are used; 3) complications in balancing the two stages which may result in lower turbine efficiency and capacity factor; and 4) the possibility of finding difficulty in achieving proper excess or backup steam requirements.

Based on reservoir data, well productivity data, and simplicity of design and operation, the author found that a single-flash turbine would be better suited to the resource conditions in the Redondo Creek area. The operating pressure of the turbine was found to be optimal in the range of 100 to 110 psia. Further, the author recommended study of the feasibility of using steam ejectors or compressors to remove non-condensable gases because of the effects on steam requirements and capital costs.

REPORT NO. 36
EXECUTIVE SUMMARY

TEMPERATURE GRADIENT HOLE DATA
1970, 1972-1974 AND LOCATION MAP

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

The report contains a tabular summary of about 55 gradient holes drilled in 1970, and survey data sheets for 66 gradient holes drilled in 1972, 1973, and 1974. The report also contains a location map for each of the wells mentioned. There is no text of discussion or summary. The area covered by the gradient hole grid is the general area of the Baca Geothermal Project/Generating Station, in the Valles Caldera.

SAMPLES OF DATA SHEETS

1970

Data On Shallow Temperature Holes (100' Deep)

Hole Number	Completed	Dates & Temperatures			
T-1	11A 6-23-70	7-2 43°	7-9 43°		
T-2 (58')	12N 6-24-70	7-2 45°	7-12 45°		
T-3	8P 6-24-70	7-2 45 1/2°	7-13 45 1/2°		
T-4	11A 6-25-70	7-2 45 1/2°	7-8 45 1/2°	7-12 46°	
T-5	12N 6-25-70	7-2 45°	7-8 45°	7-12 44°	
T-6	3P 6-25-70	7-2 44 1/2°	7-8 45°	7-12 45°	
T-7	7P 6-25-70	7-2 43°	7-8 43°	7-12 43°	
T-8	12N 6-26-70	7-2 52°	7-8 52°	7-12 50°	7-29 51°
T-9	5P 6-26-70	7-2 48°	7-8 47°	7-12 48°	
T-10	11A 6-27-70	7-2 46°			
T-11	3P 6-27-70	7-2 44°			
T-12	6P 6-27-70	7-2 44°			
T-13	2P 6-29-70	7-2 46°			
T-14	8P 6-29-70	7-2 46 1/2°			
T-15	6P 6-30-70	7-2 54 1/2°	7-21 57°		
T-16	8P 6-30-70	7-2 58°			
T-17	10A 7-1-70	7-2 53 1/2°			
T-18	12N 7-1-70	7-2 67°	7-9 67°		
T-19	3P 7-3-70	7-6 84 1/2°	7-7 85°		
T-20	2P 7-1-70	7-3 104°	7-6 104°	7-7 104°	
T-21 (68')	7P 7-1-70	7-3 74°	7-6 72°	7-7 75°	
T-22	3P 7-6-70	7-7 85°			
T-23	10A 7-2-70	7-3 86°	7-6 87°	7-7 87 1/2°	
T-24	7P 7-2-70	7-3 76°	7-6 74°	7-7 75°	
T-25	9P 7-2-70	7-3 73 1/2°	7-6 73 1/2°	7-7 74°	
T-26	10A 7-6-70	7-7 80°			
T-27	12N 7-6-70	7-7 69 1/2°	7-9 70°		
T-28	9A 7-7-70	7-7 78 1/2°	7-9 82°		
T-29	8P 7-9-70	7-10 88°	7-14 86°		
T-30S (20')	4P 7-9-70	7-10 51°	7-14 50°		
T-31 (100')	2P 7-9-70	7-10 105 1/2°	7-14 104 1/2°	7-22 105 1/2°	
T-31S (20')	3P 7-9-70	7-10 56°	7-14 56°		
T-32S (20')	10A 7-9-70	7-10 53°	7-14 52 1/2°		
T-33S (20')	6P 7-8-70	7-10 44°	7-14 42 1/2°		
T-34	2P 7-11-70	7-12 49°	7-13 49°	7-15 49°	7-29 49°
T-35	4P 7-12-70	7-12 46°	7-13 45°	7-29 45°	
T-36	12N 7-11-70	7-12 48°	7-13 48°	7-29 47°	
T-37	12N 7-14-70	7-16 47°	7-29 45°		
T-38	11A 7-13-70	7-15 44°			
T-39	9A 7-14-70	7-15 57°	7-16 59 1/2°	7-29 58 1/2°	
T-40	5P 7-14-70	7-15 46 1/2°	7-29 58 1/2°		
T-41	11A 7-15-70	7-16 47°	7-16 46°		
T-42	1P 7-14-70	7-15 46°			
T-43	3P 7-14-70	7-15 46°			
T-44	9A 7-16-70	7-29 52°

Hole Number	Completed	Dates & Temperatures	
T-45	3P 7-15-70	7-16	47°
T-46	12N 7-16-70	7-17	47°
T-47	10A 7-16-70	7-17	47°
T-48	9A 7-17-70	7-19	50°
T-49	5P 7-17-70	7-20	46°
T-50-D (300' Hole Twin to T-31)			
	8P 7-23-70	7-24	202°
T-51	12N 7-24-70	7-25	97°
T-52	7P 7-24-70	7-25	65°
T-52-D (300' Hole)			
	3P 7-27-70	7-28	107°
T-8-D (300' Hole)			
	11A 7-30-70	7-31	72°
T-53	3P 8-4-70	8-6	54°

UNION GEOTHERMAL DIVISION GRADIENT HOLE SURVEY

5-23-72 1130
SPUD DATE

5-23-72, 1530
COMPLETION DATE

Prospect : BACA Location : T. R. Sec.
Hole No. : T.H. 1 SULPHUR CREEK, TWIN TO DEEP #1
T. D. : 250' Elevation : COUNTY STATE

Gradient : 32 F°/100 ft. Interval : 150 - 250 ft.
Temp. : ° at ft.

BH Gradient : 32 F°/100 ft. Interval : 150 - 250 ft.
Max. Temp. : 134 F° at 250 ft.

SAMPLE LOG	DATE OF SURVEY	5-24-72	5-31-72
	TIME SINCE COMPLETION	1d	8d
DEPTH	TEMP.	TEMP.	F°
25	60°	56°	
50	69°	67°	
75	79°	76°	
100	87°	87°	
125	95°	94°	
150	102°	102°	
175	110°	110°	
200	118°	118°	
225	126°	will not pass	
250	134°	205°	
275			
300			
325			
350			
375			
400			
425			
450			
475			
500			

MRT :

Remarks :
DRILLED w/ AIR,
MOIST DUST RETURNS
5-24-72 - Bubbles pulled
to within 20' w/ water

Orig. Contractor :

REPORT NO. 37
EXECUTIVE SUMMARY

BACA PROJECT INTERIM REPORT
OF TEST RESULTS

FROM A REPORT

Prepared By

A.J. Chasteen

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

1974

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

This report presents the results of drilling and testing six geothermal wells in the Redondo Creek area of the Baca prospect. Of the twelve wells that had been drilled in the Valles Caldera as of the date of this report, six had been drilled in the steam productive Redondo Creek area. It is those six wells which are the subject of this report. The conclusions contained in this report were based on the data from the first twelve wells drilled in the Valles Caldera. Since the date of this report, substantially more wells have been drilled which will yield further data on the reservoir.

INTRODUCTION AND SCOPE

Exploration on the Baca Ranch began with the drilling of Bond #1, an oil exploration well, by the Westates Petroleum Company in 1960. The well encountered shows of geothermal steam production and active geothermal steam exploration began with the drilling of Baca #1 by the Baca Land and Cattle Company in 1963. The Baca Land and Cattle Company drilled three more exploration wells before Union Oil Company took over with the drilling of Baca #5 in 1971. Since that time, Union has drilled six more wells. A summary of these wells is included as Figure 1 and a map showing their locations is included as Figure 2.

Of the twelve wells drilled thus far, six of them have been drilled in the steam productive Redondo Creek area. It is these six wells which are the object of this report.

SUMMARY AND CONCLUSIONS

This report presents the results of drilling and testing six geothermal wells in the Redondo Creek area of the Baca prospect. An analysis of these data, in conjunction with geologic information, indicates the existence of 5.55×10^{12} lbs. of liquid reserves within the 2560 acre area which has so far been defined as productive. This is over seven times the amount of fluid required to supply a 50 MW pilot generating plant for 30 years. To date, however, only one well produces at a high enough rate to be regarded as commercial. Further drilling is necessary to confirm that commercial wells can be drilled in the Redondo Creek area.

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REPORT NO. 38
EXECUTIVE SUMMARY

SPECIAL CORE ANALYSIS STUDY
FOR UNION OIL COMPANY
BACA NO. 13 WELL
REDONDO CREEK FIELD, NEW MEXICO

FROM A REPORT

Prepared For	Prepared By
UNION GEOTHERMAL DIVISION	CORE LABORATORIES, INC.
UNION OIL COMPANY OF CALIFORNIA	PETROLEUM RESERVOIR ENGINEERING
LOS ANGELES, CALIFORNIA	DALLAS, TEXAS

1975

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
JUNE 1980

ABSTRACT

Presented in this report are the results of formation resistivity and acoustic velocity measurements. The samples used in this study are identified and lithologically described. This report concerns itself with core sample analyses of Baca Well No. 13. The study was completed in March 1975. Portions of the reproduced report are difficult to read due to poor original quality.

INTRODUCTION AND SCOPE

In preparation for this study, cylindrical plug-size samples, one inch in diameter, were drilled from full-diameter core segments recovered from the subject well. The samples used for electrical measurements were drilled parallel to the bedding and the samples used for acoustic velocity measurements were drilled perpendicular to the bedding planes. All test samples were thoroughly cleaned and dried; then air permeabilities and Boyle's Law porosities were measured. These measurements were verbally transmitted to a representative of Union Oil Company of California, and samples were selected for further testing. Selected samples were evacuated and saturated with simulated formation water synthesized from a water analysis submitted for use in this study.

Electrical resistivities of both the brine and the brine-saturated samples were measured. These measurements were repeated until the results stabilized, indicating ionic equilibrium within the core sample. The test samples were then desaturated by capillary displacement, and electrical resistivities of the samples were measured at equilibrium saturation conditions. The results of these measurements appear in both tabular and graphical form.

SUMMARY AND CONCLUSIONS

The formation resistivity factor-porosity relationship yields a cementation exponent "m" of 2.10. This was obtained by drawing a visual best-fit line through the data points plotted on log-log paper. All samples contain pyrite and this mineral could influence the measurements considerably. A composite plot of resistivity measurements versus water saturations yielded a saturation exponent "n" of 1.92.

The brine-saturated vertical (perpendicular to the bedding planes) plugs selected for acoustic velocity measurements were confined hydraulically and transit times were measured at several effective overburden pressures while maintaining zero psi pore pressure. These results are presented in both tabular and graphical form.

REPORT NO. 39
EXECUTIVE SUMMARY

BACA RESERVOIR STUDIES

FROM A REPORT

Prepared By

M.S. Gulati

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

1975

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

This report consists of a compilation of seven interdepartmental memos documenting separate studies by the author all concerning the Geothermal Reservoir at the Baca Location in New Mexico. All of the memos are dated in late August 1975. The subjects of the studies are: reservoir datum pressures, tests which will and will not yield reservoir information from hot water wells, the role of heat transfer in the pressure build-up in hot water wells, pressure build-up and drawdown studies in Baca Well No. 6, and individual pressure build-up studies for Baca Wells No. 11, 13, and 15. Each study appears to be well documented. Most discussions include data organized in tables and results of calculations in graphs.

1.0

INTRODUCTION AND SCOPE

In August 1975, M.S. Gulati, an employee of Union Oil Company of California, compiled a series of seven interdepartmental memorandums addressed to A.J. Casteen. The purpose of the seven memorandums was likely to document the geophysical work completed by M.S. Gulati to that date. All of the studies included in the report are directly or indirectly related to the geology and geophysics of the Baca Location geothermal anomaly in New Mexico.

2.0

SUMMARY AND CONCLUSIONS

The seven memorandums which form this report answer many questions for the Baca Location anomaly which arise in most geophysical reservoir investigations.

In the first memorandum, Gulati has compiled and summarized well pressure data and has interpreted the results to yield datum pressures, i.e., well pressure at a given elevation.

The second memorandum, entitled, "Obtaining Reservoir Information from Hot Water Wells - Tests that Work and Tests that Won't Work" documents research by Gulati where he examined the types of information available versus required results from that information. For example, he has gone into great detail on pressure measurement both static and transient, and elaborates on the types of reservoir information which can be deduced from pressure data.

Third in the series is a memorandum entitled, "The Role of Heat Transfer in the Pressure Build-Up in the Hot Water Wells." Gulati has summarized pressure data and has come to conclusions as to how heat transfer in the reservoir affects the pressure in some of the wells at the Baca Location before, during and after the well has been produced. Darcy's Law is used in the analysis.

Section four is a memorandum on pressure build-up and drawdown studies in Baca Well No. 6. The balance of the memorandums document related studies on pressure build-up tests in Baca Wells No. 11, 13, and 15. The memorandums include data, calculations and graphical representations of the results.

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SECTION I	Datum Pressures in Baca, N.M.
SECTION II	Obtaining Reservoir Information From Hot Water Wells - Tests That Work and Tests That Don't Work
SECTION III	The Role of Heat Transfer in the Pressure Build-Up in the Hot Water Wells
SECTION IV	Pressure Build-Up and Drawdown Tests in Baca No. 6
SECTION V	Pressure Build-Up Tests on Baca No. 11
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SECTION VII	Pressure Build-Up Analysis, Baca No. 15

REPORT NO. 40
EXECUTIVE SUMMARY

GEOHERMAL RESERVOIR EVALUATION
OF THE REDONDO CREEK AREA, NEW MEXICO

FROM A REPORT

Prepared By

J.D. Hartz

UNION GEOHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

JUNE 1980

ABSTRACT

The purpose of this report was to evaluate the geothermal potential of the Redondo Creek area based on the geologic and reservoir data which existed in November 1976. The findings and conclusions of this report were intended to form the basis for a feasibility study to determine if geothermal energy for electrical generation could be economically extracted. Recommendations are presented for follow-up work needed to establish initial geothermal development and achieve the full potential of the Redondo Creek area and Valles Caldera. The conclusions drawn in this report will change based on more extensive data, and a changing available energy picture.

1.0 INTRODUCTION AND SCOPE

The purpose of this report was to evaluate the geothermal potential of the Redondo Creek area based on the then existing geologic and reservoir data. The findings and conclusions of this report were intended to form the basis for a feasibility study to determine if geothermal energy for electrical generation could be economically extracted. Recommendations are presented for follow-up work needed to establish initial geothermal development and achieve the full potential of the Redondo Creek area and Valles Caldera.

2.0 SUMMARY AND CONCLUSIONS

Prior to this report, engineering and geologic studies of the Redondo Creek area wells had indicated the existence of an extensive, high temperature hydrothermal system. Conclusions were derived from the studies completed up to the date of this report. The total amount of water in place in the reservoir was calculated to be on the order of 4.6×10^{12} lbs. of hot water. The average reservoir temperature was estimated to be 600F. From this the estimated potential generating capacity was estimated between 220 and 385 MW.

Well interference testing indicated reservoir communication between Baca Wells No. 6, 10, 11, 12, 13 and 14. Well production tests indicated that no measurable reservoir depletion was evident. Total production from the reservoir had been 4935×10^6 lbs. total mass; total injection had been 2340×10^6 lbs. resulting in a net withdrawal of 2595×10^6 lbs. total mass. Deliverability of an average well was found to be on the order of 200,000 lbs/hr. total mass with a 35 percent steam fraction.

Further, it was concluded that 16 wells would be required for initial development of a 55 MW generating facility, and that initial development would require drilling 11 additional wells and redrilling 2 wells. Productivity was found to be a result of fracturing in the Bandelier Tuff which is connected to a deeper, more extensive hot water aquifer. The fracture system extent and orientation was indeterminate from the data available at the time of this report. It was concluded that the success of future wells depends on locating fracture permeability. The investigators found no primary or secondary steam cap to be associated with the liquid phase reservoir. An isolated, low-pressure steam zone appeared to exist in the Redondo Creek area, but its extent and size were not determined. No evidence existed to the investigators to prove or disprove active recharge of the hot water reservoir in the Valles Caldera. Scale deposition, primarily calcium carbonate and silica, was decidedly a serious problem which could potentially affect the production facilities, injection facilities, and possibly the reservoir fracture system.

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REPORT NO. 41
EXECUTIVE SUMMARY

BACA WELL NO. 5A
PRESSURE FALLOFF AND INJECTIVITY

FROM A REPORT

Prepared By

J. D. Hartz

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA
JANUARY 1977

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
FEBRUARY 1980

ABSTRACT

The study leading to this report was a result of concern as to whether Baca Well No. 5A, a marginally productive well on the Baca Location geothermal reservoir, could be used as an injection well for disposal of geothermal fluids. A short injectivity and pressure falloff test was performed on Baca Well No. 5A during the period of December 20 to 22, 1976. The objectives of the test were to measure injective capacity of the well and determine reservoir and wellbore characteristics. Results of injectivity testing indicate injection capacity to be 2.72 gpm/psi pressure increase over reservoir pressure. Results of the pressure falloff portion of the test indicate a reservoir of 55218 md. ft/cp and a skin factor of -3.58. The report includes calculations, discussion and graphical summaries of the data and results. The conclusions drawn in the report may have been later modified with the benefit of more recent developments and considerations.

INTRODUCTION AND SCOPE

During the period of December 20 to 22, 1976, a short injectivity and pressure falloff test was conducted on Baca Well No. 5A. The objectives of the test were to measure injective capacity of the well and determine reservoir and wellbore characteristics. The injectivity test consisted of injecting water into the well for a 24-hour period and measuring the injection pressure. The injection rate varied during the test period but averaged 395 gpm for the entire test. The rate during the injection pressure survey was 417 gpm and this value was used for calculation purposes. The injection rate versus time was plotted for the test period. Total injection during the test period was 570,900 gallons. The injectivity index was calculated from the results of the test. Previous injectivity tests were compared to the one performed for this study.

At the end of the 24-hour injection test a flowing pressure and temperature gradient survey was run. Tools were hung at 5500 feet for about one hour to measure injection pressure and then the well was shut in to measure the pressure falloff. Tools were left at 5500 feet for 6 hours and then pulled from the well. Another survey was run the next day before returning the well to injection. The pressure falloff was then plotted versus dimensionless time.

SUMMARY AND CONCLUSIONS

To date, 72,852,400 gallons (1.73 MM bbls) of produced fluids have been reinjected in Baca Well No. 5A. The well was completed in the Paliza Canyon Andisite at a depth of 6973 feet. The well was then cased to 2828 feet with 13-3/8 inch pipe, from 2692 feet to 4400 feet with a 9-5/8 inch liner and 8-3/4 inch open hole from 4400 feet to 6973 feet T.D. During drilling of the well fractured zones were noted from 5010 to 5016 feet, 5290 to 5310 feet, 5655 feet, and 6070 to 6075 feet in the open hole portion of the well. An injection profile run in the well on February 12, 1976 indicated about 50 percent of the water was leaving the wellbore in the interval 5550 to 5880 feet. Tools stopped at 5886 feet but it was assumed that the rest of the water was being injected into the Bandelier Tuff between 5880 to 6600 feet.

A subsequent pressure and temperature survey done in June 1976, also stopped at 5865 feet, which indicated possible scale deposition, bridging in the open hole or both. Results of this injectivity test and those done previously indicated that there had been no significant change in the injective capacity though the calculated capacities ranged from 2.46-3.55 gpm/psi. The present test indicated 2.72 gpm/psi and this was thought to have been the most representative of the injectivity tests done on the well.

The pressure falloff test was thought to have given some information as to the reservoir characteristics around the wellbore and the mechanical condition of the well, whether or not the well was "damaged". The fluid mobility ratio, kh/μ , calculated was 55218 md. ft/cp. This value was compared to values determined from pressure build-up tests done on productive wells which ranged from 20,300 to 64,000 md. ft/cp. From this the reservoir around Baca No. 5A appeared to have the same fluid mobility characteristics as that of the reservoir rock penetrated by other wells in the same vicinity.

Further conclusions were drawn and discussion made concerning the permeability thickness product kh , and its relationship to the entire reservoir versus the close vicinity of this well. Also considered was the skin effect and whether it changed with time.

REPORT NO. 42
EXECUTIVE SUMMARY

BACA WELL NO. 15
PRODUCTION TEST AND
RESERVOIR EVALUATION

FROM A REPORT

Prepared By

J. D. Hartz

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

MAY 1977

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

FEBRUARY 1980

ABSTRACT

This report presents the results and analyses of data gathered during production and pressure buildup tests conducted on Baca Well No. 15 from October 1976 to April 1977. Production performance, reservoir characteristics and fluid chemistry data are presented and discussed in relation to previous tests and findings in the Redondo Creek area wells. The report includes calculations and extensive discussion and tabular and graphical representations of the data and results. More recent information and discussion may be available in more recent studies.

INTRODUCTION AND SCOPE

This report presents the results and analyses of data gathered during production and pressure buildup tests conducted on Baca Well No. 15 from October 1976 to April 1977. Production performance, reservoir characteristics and fluid chemistry data are presented and discussed in relation to previous tests and findings in the Redondo Creek area wells. The well was completed in June 1975 and was used as an observation well until these tests were performed. Initially, the well was cased to 2509 feet with 9-5/8 inch casing and left as an open hole completion from 2509 to 5505 feet. A two-phase flow test done from June 27, 1975 to July 14, 1975, indicated a total mass rate on the order of 170,000 lb/hr. at 65 psig wellhead pressure and a steam fraction estimated at 70 percent.

During the interference test from October 1975 to May 1976, the well was used as an observation well. In September of 1976, the well was recompleted and a 7 inch liner with alternating blank and slotted joints was hung over the interval of 2371 to 5503 feet. A string of 2-3/8 inch tubing was also run in the well from surface to 5472 feet with perforations at 100, 1000, 2000, 3000, 4000, and 5000 feet. The tubing was utilized to gather flowing pressure and temperature data during the subsequent production test.

SUMMARY AND CONCLUSIONS

Baca Well No. 15 is completed in a steam cap or steam dominated reservoir, but it also has been found to have access to liquid-phase reservoir. Deliverability of the well had been about 178,000 lb/hr. total mass and 107,000 lb/hr. steam, at a wellhead pressure of 150 psia. The steam fraction of the produced fluids at Baca Well No. 15 was much higher, about 61 percent of the total mass, than that of any other well in the Redondo Creek area at the time. The size of the steam cap or reservoir could not be determined from data developed to the date of the report. Geologic and engineering data suggested that the area to the northwest of Baca Well No. 15 should have the potential for tapping additional steam production and that further drilling may help determine its size and reserves.

Analysis of data gathered in the production test of Baca Well No. 15 led to the following conclusions.

1. Baca Well No. 15 produced from a steam cap or steam dominated reservoir but it also had productivity from the liquid-phase reservoir. The two production zones appeared to be separated and commingled only within the wellbore, as evidenced by flowing pressure and temperature data.
2. The drainage area of Baca Well No. 15 appeared to be confined or partially confined because of a hydrologic discontinuity separating it from the reservoir penetrated by Baca 4, 6, 11, and 13.

3. Geochemical data suggested that the liquid-phase produced at Baca Well No. 15 came from the same reservoir as the liquid produced at Baca 4, 6, 11, and 13.
4. Productivity index, determined from flowing pressure surveys, was about 410 lb/hr/psi drawdown, about 50 percent greater than the average for other Redondo Creek area wells. Productivity was not restricted by wellbore design.
5. Estimated deliverability of Baca Well No. 15 was about 178,000 lb/hr. total mass and 107,000 lb/hr. steam at a wellhead pressure of 150 psia.
6. Reservoir fracture system (kh) in the Baca Well No. 15 drainage area was at least 5,500 md/ft., which is comparable to the kh determined in the other Redondo Creek area wells.
7. The static reservoir pressure had not built up to the initial pressure (2347 hours after shut-in) but it was anticipated that it would. Therefore, no pressure depletion was evident.
8. No flow barriers or drainage area boundaries were evident from the pressure buildup data.
9. The size of the steam cap or steam dominated reservoir penetrated by Baca Well No. 15 was indeterminate from the data available. Further drilling and testing would be necessary to establish the reserves and the size of the reservoir or steam cap.
10. Pressure observations at Baca 11 were inconclusive in regard to interference from Baca 15. Pressure disturbances at Baca 11 were probably caused by wellbore boiling and condensation. Any pressure disturbance caused by interference would have been minor compared to the localized pressure fluctuations in Baca 11. Therefore, the wellbore phenomena tend to dominate and mark reservoir disturbances if they occurred.

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EXECUTIVE SUMMARY

GEOHERMAL DEMONSTRATION

POWER PLANT

COMPLETE PROPOSAL

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION

UNION OIL COMPANY OF CALIFORNIA

LOS ANGELES, CALIFORNIA

AND

PUBLIC SERVICE COMPANY OF NEW MEXICO

ALBUQUERQUE, NEW MEXICO

JANUARY 1978

Summary Prepared By

WESTEC SERVICES, INC.

ALBUQUERQUE, NEW MEXICO

MARCH 1980

ABSTRACT

This proposal was submitted to the U. S. Department of Energy (DOE) in response to a request by DOE for project proposals. DOE issued Program Opportunity Notice EG-77-N-03-1717 in 1977 and the Union Oil Company of California and the Public Service Company of New Mexico (PNM) submitted this proposal to DOE which involves the initial development of the BACA geothermal resource in North-Central New Mexico. The proposal consists of an introductory text and five additional volumes which provide a comprehensive discussion of the technical, legal and economic aspects of the proposed project. The six volumes are entitled: 1) Project Description; 2) Volume I, Project Abstract; 3) Volume II, Technical and Management Proposal; 4) Volume III, Business Proposal; 5) Volume IV, Cost Proposal; and 6) Volume V, Economics Information. The project for which this proposal was competitively submitted has been funded by DOE as a result of this successful proposal.

INTRODUCTION AND SCOPE

The area known as the Valles Caldera was originally confirmed as a geothermal resource by the Baca Land and Cattle Co., the owner of the property. The rights to the geothermal resource were then leased to Union Oil Company of California. Public Service Company of New Mexico and Union Oil Company have joined together to explore the possibility of utilizing the thermal energy in the caldera for generating electricity, and have found that the resource can support the generation of at least 400 MW. The initial phase of planned development is a 50 MW demonstration plant, for which this proposal has been written.

The proposal includes background information, a plan for the development of the field to support 50 MW demonstration, a management plan, a proposed assignment of responsibilities, and an extensive analysis of the economics of the project.

The total cost of the proposed project was estimated in the proposal to be slightly in excess of \$100 million. Of this amount, Union and PNM proposed that DOE contribute as a maximum \$45,435,500, with Union and PNM assuming a responsibility for the balance of project costs. In addition, a revenue sharing concept was offered which proposed to return to DOE as much as 50% of DOE's total contributions. The result is that the net project cost to DOE could be as little as half of DOE's initial financial responsibility.

SUMMARY AND CONCLUSIONS

The project area is privately owned land in the Redondo Creek area of the property known as Baca Location No. 1, and is located approximately 60 miles north of Albuquerque and 19 miles west of Los Alamos. the Baca Location, in the Jemez Mountains, encompasses the major portion of a large caldera. This is a circular depression, 12 to 15 miles in diameter, which represents the latest stage of a volcanic sequence which began 1.4 million years ago. The most recent volcanic event was about 100,000 years ago. The principal geothermal reservoir discovered to date consists of several trillion pounds of slightly saline hot water. A second steam reservoir has also been encountered, but its extent is unknown at this time.

Eighteen wells have been drilled to date at the Baca location, and of the wells drilled in the Redondo Creek area, 8 are useable as either production or injection wells. An additional 13 to 16 wells will be required for the proposed 50,000 kilowatt demonstration project. The production and injection system will involve handling 3.4 million pounds per hour of hot water and steam. Steam will be separated at a pressure of 125 psig for use in the generating plant and all of the water from the separation process will be returned to the reservoir via injection wells.

The generating plant will incorporate a single-inlet-pressure turbine generator with a gross output of 50,000 kilowatts. The exhaust steam will be condensed in a closed system to facilitate the handling of noncondensable gases. While the steam contains only trace amounts of hydrogen sulfide, the plants will incorporate a suitable hydrogen sulfide abatement system. The electrical energy generated at the plant will be fed into PNM's existing transmission and distribution network. The cost of the electrical energy supplied from the plant to PNM's existing transmission and distribution network. The cost of the electrical energy supplied from the plant to PNM's customers is expected to be competitive with the cost of power from an alternative coal-fired generating plant.

The organization responsible for construction and operation of the plant and facilities is created ad hoc from the existing organizations of PNM and Union. Union will be responsible for drilling the wells and delivering steam to the generating plant while PNM will own and operate the generating plant and transmission facilities. Executive control of the project is vested in an Operating Committee, which is composed of senior officials from both companies. Reporting to the Operating Committee is a Project Manager, who is presently an employee of PNM. He will be responsible for overseeing the normal daily activities of the project.

The Baca geothermal resource shares common features with a large number of the more important geothermal resources in the western United States. Accordingly, a successful demonstration project at Baca is expected to serve as a strong stimulus to development of geothermal resources for electrical power generation in many years.

LIST OF VOLUMES IN THE PROPOSAL

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REPORT NO. 50
EXECUTIVE SUMMARY

HISTORICAL COST DATA
RECONCILIATION OF SUMMARY
SCHEDULES

FROM A REPORT

Prepared By

UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

JULY 1978

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MARCH 1980

ABSTRACT

This report is a compilation of cost summary schedules for Union Oil Company expenditures for development of geothermal resource in the Valles Caldera in North-Central New Mexico. The period covered is from inception to July 1978. Expenditures are itemized as to well completion expenses per well, types of facility, and types of overhead. Costs are broken down on a yearly basis for the time dependent items such as salaries, employee benefits, rent and utilities. No explanatory text is included with the report.

REPORT NO. 51
EXECUTIVE SUMMARY

SOILS INFORMATION FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA
AND
PUBLIC SERVICE COMPANY
OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

Prepared By
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AND
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ALBUQUERQUE, NEW MEXICO

1979

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MARCH 1980

ABSTRACT

This report consists of two sections containing soil data and qualitative comments concerning its appearance. The data covers the Santa Fe National Forest adjacent to the southern boundary Baca Location No. 1 properties, and the Bandelier National Monument. Section 1 of the report contains data sheets on 28 mapping units of the Santa Fe National Forest completed by the U. S. Forest Service. These data sheets include climatological, geological, and biological information in addition to the soils data. Section 2 contains 22 mapping units of the Bandelier National Monument. The soils of each unit are discussed individually. No introductory or summary tests are included in Section 1, while Section 2 discusses how the data was formed, and explains the overall geology, climate, and biology in separate sections. Maps are included which display the location of the mapping units.

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FORMATION OF THE SOILS

Factors of Soil Formation

Parent Material Factor

Climate Factor

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Topography Factor

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SOILS MAP - BANDELIER NATIONAL MONUMENT

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Map unit 9 is changed to 8

Mapping Unit: 8 -- Entic Haploborolls, Cumulic Haploborolls - complex,
0-15% slopes

PRELIMINARY
DRAFT

DRAFT

Acres: 2107

Landform: Nearly level to gently sloping flood plains and stream terraces.

Parent Material: Recent alluvium from various volcanic rocks.

Slope: 0 to 15 percent, average 5 percent.

Elevation: 7,100 feet to 8,000 feet.

Temperature: Mean annual 32°F to 47°F; mean summer 47°F.

Precipitation: 20 to 30 inches per year.

Potential Natural Vegetation: Douglas fir-ponderosa pine forest or
ponderosa pine forest.

Existing Vegetation: grass.

Modal Profiles

Entic Haploboroll

Typifying Pedon:

0 to 4 inches -- very dark grayish brown (10 ^{4R} 3/2) loam, very dark
brown (10 ^{4R} 2/2) moist; soft, very friable, nonsticky,
non plastic; about 10 percent coarse fragments; slightly
alkaline (pH 7.4). (3 to 5 inches thick)

4 to 11 inches — dark grayish brown (10 ^{ys}yr. 4/2) gravelly sandy loam,
very dark grayish brown (10 ^{ys}yr. 3/2) moist; soft, very
friable, non-sticky, non plastic; approximately 30
percent coarse fragments; slightly alkaline (pH 7.6).
(5 to 10 inches thick)

11 to 14 inches --grayish brown (10 ^{ys}yr. 5/2) very gravelly sandy loam,
dark brown (10 ^{ys}yr. 3/3) moist; soft, very friable, non-
sticky, non plastic; approximately 40 percent coarse
fragments; slightly alkaline (pH 7.8). (3 to 5 inches
thick)

14 to 32 inches --light brownish gray (10 ^{ys}yr. 6/2) extremely gravelly
sand, dark grayish brown (10 ^{ys}yr. 4/2) moist; loose,
nonsticky, non plastic; approximately 75 percent
coarse fragments; slightly alkaline (pH 7.8). (15
to 60 inches thick)

Range in Characteristics: The mallic epipedon has hue of 10 ^{ys}yr. or 7.5
^{ys}yr., value of 3 through 5 dry, 2 or 3 moist and chroma of 2 or 3. It
is loam or sandy loam and has 5 to 25 percent coarse fragments. Reaction
is neutral to slightly alkaline.

The substratum has hue of 10 yr. or 7.5 yr., value dry of 5 or 6, 3 or 4
moist and chroma of 2 or 3. It is sand or loamy sand and has 5 to 80
percent coarse fragments. Reaction is slightly alkaline to moderately
alkaline and it is calcareous.

Cumulic Haploboroll

Typifying Pedon:

0 to 8 inches — brown (10 ^{ys}yr. 4/3) light clay loam, very dark grayish
brown (10 ^{ys}yr. 3/2) moist; slightly hard, friable, slightly
sticky, slightly plastic; approximately 5 percent gravel;
slightly alkaline (pH 7.4). (2 to 8 inches thick)

REPORT NO. 52
EXECUTIVE SUMMARY

TRANSMISSION SYSTEM
ARCHEOLOGICAL ANALYSIS
FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA

Prepared By
EILEEN CAMILLI
ALBUQUERQUE, NEW MEXICO
1979

AND
PUBLIC SERVICE COMPANY
OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

Summary Prepared By

WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO

MAY 1980

ABSTRACT

The purpose of the analysis was to predict the presence and extent of archeological resources in the vicinity of the proposed transmission line from the Baca Geothermal Project to Public Service of New Mexico's existing transmission system. Two transmission corridors were proposed as a result of an archival research effort which revealed information on known archaeological sites in the study area.

1.0

INTRODUCTION

The purpose of this study was to predict the presence and extent of archeological resources in the vicinity of the proposed transmission line from the Baca Geothermal Project to Public Service of New Mexico's (PNM's) existing transmission system, an area of unknown archeological potential. Information gathered during the course of the study also provided baseline data for future cultural resource management.

2.0

METHODS

The study was based on archival research conducted at the Museum of New Mexico Laboratory of Anthropology and agencies such as the U.S. Forest Service and the Bureau of Land Management. From this data an inventory of known prehistoric and historic archeological sites and surveyed areas was compiled. This resulted in the delineation of the study area (sampling universe) comprising approximately 2110 square kilometers located within 14 USGS 7.5 minute quadrangles in north-central New Mexico. Areas previously surveyed for archeological resources were then used as sample units from which inferences were drawn about the nature and frequency of such resources over the entire study area. The sample units consisted of transects of different lengths varying in width from 10 to 528 feet, quadrants ranging in size from 1/16 section parcels to entire sections, and irregularly shaped areas. To ensure greater accuracy in results, the entire study area was stratified into 15 environmental zones through the use of Landsat imagery, with each zone exhibiting a more uniform distribution of archeological resources than the study area as a whole. Site density figures calculated on the basis of the sample units within each strata were then used to predict the expected frequency of archeological sites in portions of the study area.

3.0

RESULTS

Site inventory results indicated Anasazi sites to be the most common component (80.9 percent of total sites inventoried) located at higher elevations within the project area. In general, habitation sites were found to be the most common site type (60.9 percent of total sites inventoried). Eighty-two percent of the known Anasazi site types were habitations. Combined limited activity sites comprised 23.5 percent of total sites inventoried. Survey restrictions and investigator and archeological biases which may have skewed the data are discussed by the author.

A 4.3 percent sample of the study area was obtained. Within each zone, the proportion of area sampled varied from 2 to 14 percent. Sampling results indicated a relatively wide range of variation in site density, from 1.19 to 24.26 sites per square kilometer, between sampling strata. Highest site densities were found to occur in Zones 1, 2, and 13. Highest densities for habitation site types were also found to be present in Zones 1, 2, and 13.

CONCLUSIONS

Location of corridors within specific environmental zones and length of corridor within each zone were the two parameters used in considering the impact of transmission line construction upon the archaeological resources present in the study area. Since the actual routes of the proposed transmission lines were unknown at the time of the study, location and length of corridors were suggested and assessed. Two main routes were considered: 1) a southern route leading from the Baca geothermal plant site to the town of San Ysidro, and 2) an eastern route from the plant site to Station TA-3 near Los Alamos.

Zones 12 and 10C are crossed by both the hypothetical southern and eastern corridors. A greater portion of the eastern route would cross Zone 12, while the southern route would extend across greater amount of area in Zone 10C. Comparison of routes on the basis of these two zones alone indicates that the eastern corridor would be less likely to encounter substantial archeological remains at high densities. The remainder of the southern route would be contained in Zones 1, 4, 7, and 6. Comparison with the remainder of the eastern route contained in Zones 11, 10A, and 10B also indicates that the eastern route would traverse areas expected to have lower site densities. This conclusion only holds, however, if the length of the eastern corridor is kept to a minimum within Zone 10B.

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REPORT NO. 53
EXECUTIVE SUMMARY

LAND USE INVENTORY FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA
AND
PUBLIC SERVICE COMPANY
OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

Prepared By
WIRTH ASSOCIATES
PHOENIX, ARIZONA
1979

Summary Prepared By
WESTEC SERVICES, Inc.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

The land use inventory prepared by Wirth Associates for Public Service Company of New Mexico (PNM) and Union Geothermal Company of New Mexico (Union) is a portion of the environmental studies conducted for the proposed Baca Geothermal Demonstration Project. The purpose of the report was to provide a data base and land use resource inventory for use in PNM's planning process and the preparation of an environmental impact statement by the U.S. Department of Energy (DOE). In addition, the land use data needs of both Visual Resource Inventory, prepared by the Environmental Affairs Department of PNM, and the socioeconomic analysis, prepared by Mountain West Research Company, are served by this document. The land use study identifies, describes and delineates all significant land use features within the study area in both graphic and narrative form.

1.0

INTRODUCTION

The purpose of the study was to inventory all land uses, existing or planned, that could potentially be affected physically or visually by the construction and/or operation of project facilities including the proposed geothermal station cooling towers, well field pipeline system and transmission line. The project area is located in the Jemez Mountains of Sandoval County, New Mexico, approximately 20 miles west of Los Alamos and 60 miles north of Albuquerque. The study area was delineated by analyzing the potential visibility of proposed project facilities in relation to present land uses within the region.

2.0

SCOPE

The land use inventory covers five land use components: 1) Land Ownership, 2) Preservation and Recreation, 3) Existing Land Uses, 4) Planned Land Uses, and 5) Geothermal Resource Development. The study methodology was first described for each component, then each component was inventoried in relation to both the entire study and the station site (project site).

Land Ownership: The entire project site is located within Baca Location No. 1 land grant, which is owned by the Baca Land and Cattle Company. U.S. Forest Service land, with some private inholdings, is adjacent to the west, south and north of Baca, while Los Alamos Ski Club land and Forest Service land are adjacent to the east boundary. National Park Service land lies southeast of the project site. Eight categories of land ownership were identified and mapped during the land use study; these included: 1) U.S. National Park Service (Bandelier National Monument), 2) U.S. Forest Service (Santa Fe National Forest), 3) U.S. Department of Energy (Los Alamos Scientific Laboratory), 4) U.S. General Services Administration, 5) Indian Lands, 6) Los Alamos County, 7) Baca Land and Cattle Company, and 8) private and other.

Preservation: Under the Natural Landmarks Program, National Natural Landmarks are designated "to encourage the preservation of nationally significant properties regardless of ownership. . . . and to assure the preservation of such a variety of significant natural areas. . . ." The Valles Caldera National Natural Landmark is contained in the Federal Register (Volume 43, No. 82, April 27, 1978); the boundaries of the designated site coincide with those of the Baca Location No. 1 land grant.

The Redondo Peak and Redondo Border sites, which are adjacent to the northwest and southeast of the proposed station site location, will be recommended to the U.S. Fish and Wildlife Service for preservation as natural areas with unique ecosystems.

The following Preservational Designations are inventories of park and natural areas which are designated or recognized as unique or undisturbed natural environments. The designations and boundaries vary

widely in legal status and importance. They include 1) Bandelier National Monument, 2) the RARE II areas of the Santa Fe National Forest, 3) the Monument Canyon Research Natural Area, 4) the Jemez State Monument, and 5) the Recommended State Recreation and Natural Areas. Monument Canyon and Valle Grande have been recommended as State Natural Areas and two fumarole locations were identified as unique geologic features.

Recreation: The Pajarito Ski Area, owned and operated by the Los Alamos Ski Club, Inc., is located west of Los Alamos at the Baca location No. 1 land grant boundary. A relatively large number of recreational resources and facilities exist to the west and southwest of the Baca station site including five National Forest campgrounds, five private or group camps, five day use sites and five points of interest. A few of these sites are located in the canyons along the fishing waters of the Jemez River (including the East Fork) and San Antonio Creek. Most of this area receives very heavy recreational use and is considered by the Forest Service to be an area of high scenic quality. The Forest Service on the National Park Service maintain all hiking and riding trails located in the study area. Fishing is popular along the Jemez River and its tributaries. Redondo Creek, which flows next to the project site, is designated as fishing waters.

Existing Land Uses: Areal and lineal land uses were identified and described, and include the following: 1) the Los Alamos urbanized area, 2) other residential, commercial and/or institutional land uses, 3) Los Alamos Airport, 4) areas closed to unauthorized entry (including the Baca Land and Cattle Company and the Los Alamos Scientific Laboratory), 5) state highways, paved roads, and unpaved, maintained roads, 6) a natural gas pipeline, 7) transmission lines, and 8) others, such as timber, forage and mineral land uses. The project site is located on land owned by the Baca Land and Cattle Company, and the only existing land use which is directly associated with the site is an unpaved and maintained road to the proposed well area. Two major second-home, forest settlements (La Cueva/Horseshoe Spring and Vallecitos de los Indios) are located in the vicinity of the site, while State Highways 4 and 126 and several Forest Routes to the west and south comprise the significant elements of the transportation system near the site.

Planned Land Uses: This section addressed planned uses in both Los Alamos and Sandoval Counties, and focused upon existing and future planning documents for each county as well as the Los Alamos Scientific Laboratory and the Santa Fe National Forest. The only planned land use directly associated with the proposed site, the paving of the well field road, FR-268 realignment, is a part of the proposed project facilities. Two subdivided areas of private land within the National Forest are expected to further expand. These are Cueva/Horseshoe Springs and Vallecitos de los Indios. In addition, the Cerro Pelado area is expected to develop in about five years, Thompson Ridge is presently

being developed, and the Primos Hermanos area is currently partially developed.

Geothermal Resource Development: The Baca KGRA covers a total of 51,571 acres (approximately two-thirds of the study area). The proposed project site is situated within this resource area with project facilities proposed near the center of the existing major steam well area. Several natural hot springs are located to the west of the site. The federal government has issued competitive leases for geothermal exploration to the west and south of the site.

3.0

CONCLUSION

This report focused upon an identification of existing and planned land uses. No analyses of potential land use conflicts were included and no alternatives were suggested.

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REPORT NO. 54
EXECUTIVE SUMMARY

SOILS INVENTORY FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA
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Summary Prepared By
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MARCH 1980

ABSTRACT

The intent of this report was to prepare soils information that could be used in assessing the impact of the construction of an electric transmission line from the site of the proposed 50 MW Geothermal Demonstration Project to the Los Alamos, New Mexico electrical grid. Much of the information in this report was provided by the soil conservation service of the United States Drug Administration (USDA) and from a soil survey report of Los Alamos County. The report includes a detailed account of the methods used in analyzing and classifying the soil types of the 16 mapping units surveyed. Each mapping unit is individually discussed and maps are included for reference.

The information in this report may have been augmented by subsequent studies.

1.0

INTRODUCTION AND SCOPE

The survey objective was to prepare soils information (maps and descriptions) that could be used in assessing the impact of putting in an electric transmission line. The soil survey maps of the Baca are provided at an order 3 level. The soil survey of the Los Alamos portion of the transmission line is at an order 2 level and is attached as an appendix. The order 3 maps of the Baca are attached to the report and are at a scale of 1:31,680. The soils of the order 3 map were identified by transecting, traversing and some observations. Boundaries were plotted by observation and interpretation of remotely sensed data and verified with some observations. The types of map units were mainly associations. The map unit components were mainly phases of soil series and phases of soil families. USDA-SCS Agriculture Handbook 436 was used for definition of the soil families (Soil Taxonomy).

2.0

SUMMARY AND CONCLUSIONS

A survey of this type is intended as a tool for planning purposes and is not site specific in that it includes the area from which the site is to be selected. In many instances, on-site investigations were required for intensive study. The estimates given for the types of soils, amounts of inclusions, and extent of each mapping unit may vary by 20 or more percent. The limitations of the order 3 map were considered before intense or detailed planning was initiated. The conclusions of this report are in the form of the area classification and analysis data to be used in the selection of the transmission line siting.

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REPORT NO. 55
EXECUTIVE SUMMARY

STATION AND WELL SITE
ARCHEOLOGICAL ANALYSIS
FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For	Prepared By
UNION GEOTHERMAL DIVISION	THE OFFICE OF CONTRACT ARCHEOLOGY
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Summary Prepared By

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MAY 1980

ABSTRACT

The purpose of the report was to present the results of an areal survey intended to comprehensively examine the archeological resources within the Baca Location No. 1 study area. The report also assessed the possible adverse effects of construction of a proposed geothermal power plant and associated wells. Results indicated one alternative and additional recommendations to the proposed development.

1.0

INTRODUCTION AND SCOPE

The report presented the results of an areal survey conducted by the University of New Mexico Office of Contract Archaeology for Public Service Company of New Mexico (PNM) and Union Oil Company of California (Union Oil). The purpose of the survey was to provide a comprehensive examination of the archeological resources of the area, and to assess the possible adverse effects of construction of a proposed geothermal power plant and associated well pads. The report provided baseline data for an environmental assessment to be submitted to the Department of Energy (DOE) by PNM and Union Oil.

2.0

SURVEY METHODS

The survey was conducted between July 20 and August 11, 1978 by a field crew of 3 persons temporarily augmented by 2 others. The study area consisted of 1984 acres located in the privately owned Baca Location No. 1 Land Grant. Survey of the study area involved the location of the borders of the tract as guides to the initial transect lines. A series of transects was then walked, the lowermost person flagging the transect, while the uppermost person recovered flags from the previous transect. The spacing interval was about 20 meters, allowing visual coverage of the entire transect. Slopes of 90 percent or more were not surveyed due to the difficulty involved, and because it was determined that any surface manifestations would not be *in situ*, but would probably have been moved downslope. The valley bottom below the steep valley side slopes was transected and all drainages were investigated.

Archeological site parameters were defined and flagged with orange tape. Site locations were plotted onto a USGS 7.5 minute topographic map, which occasionally proved difficult given the heavily forested nature of the area. Site areas were closely examined and artifacts were marked with orange pin flags for mapping and photographing. Stakes displaying site numbers were placed near the centers of the sites. Standard Office of Contract Archaeology site forms and site provenience, lithic, and historic artifact forms were completed, and sites were sketch mapped. The mapping procedure included plotting the contour of the area, and placing the artifacts on the map in locations derived from their relationship with those contours thereby indicating the internal structure of each site and the spatial relationship between artifact distribution and topography. All measurements used in mapping were paced. Lithic artifacts were coded by artifact type and basic flake morphology and indicated on the site map. Information on site setting, vegetation, artifactual assemblage, and construction (where applicable) was included. A black-and-white photograph or color slide was taken of each site. No artifacts were collected; scale drawings of significant artifacts were made and mapped in place. In many cases, all lithic artifacts present on sites were recorded. When this was not possible a sample was taken, generally consisting of one or more concentration areas defined by extensive reconnaissance of the site area. In

most cases, artifacts located on roads were not monitored. All notes, photographs, maps, and data forms were placed on file at the Office of Contract Archeology and copies were sent to Mr. Charles Carroll of PNM.

3.0

RESULTS AND CONCLUSIONS

Twenty-nine archeological sites were located during the course of the survey. Of that number, 25 contained prehistoric components and 8 contained historic components.

With regard to prehistoric occupation of the study area there appears to have been five base camp locations in the valley, with a series of probable specialized activity sites related to them. The major base camps are located in areas allowing not only the exploitation of a range of habitat zones, but also of more than one valley. The minor base camps are in locations allowing exploitation of a range of habitat zones only. Site location choice appears to have been based upon the most productive floral habitat available, but also appears to have been responsive to localized habitat diversity. The main period of utilization of the canyon is hypothesized to have been during the late summer, based on the floral exploitation values for the various parts of the summer season.

The historic components comprise 8 sites, 1 locality, and 121 aspens with inscriptions on them. The historic sites consist of an isolated cabin, a cluster of cabin sites, a multicomponent site containing an historic trash scatter and an occupied ranch, and a multicomponent site containing a scatter of historic trash.

4.0

RECOMMENDATIONS

If it is determined that there is no prudent and feasible alternative to land altering activities affecting the identified and potential cultural resources in the study area, a program of investigation to mitigate adverse effects will be necessary. Three alternative strategies for mitigation exist: 1) intensive study of a sample of the documented resources prior to any further land altering activities. 2) A combination of investigation of sites known to fall within areas for which surface alteration is planned, avoidance of sites which fall outside such areas and archeological monitoring of construction in areas which have suffered no prior disturbance, and, therefore may contain occluded sites. 3) No action. The second alternative is preferred.

A clearance for land altering activities by the Baca Geothermal Project must proceed on a site-by-site basis. In all cases, avoidance should be considered the preferred alternative. Where avoidance appears to be a feasible alternative but land altering activities are projected for the immediate vicinity of a documented site, the avoidance procedure may be enhanced by fencing the site perimeter. If land altering activities

are projected for areas in which sites have not been documented but which have not been previously disturbed, a competent archeologist should be present as a monitor during construction activities. If subsurface remains are encountered, construction should cease and the appropriate authorities should be notified. In keeping with these recommendations, activities should be confined to existing roads (which are numerous in the survey area) in so far as possible. Improvements on existing roads will have to take into account the existence of documented resources.

If these recommendations are complied with, clearance is recommended. The religious significance of the area will have to be carefully considered in all future plans and possible nomination to the National Register of Historic Places should be given thoughtful attention.

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REPORT NO. 56
EXECUTIVE SUMMARY

STREAM ECOLOGY INVENTORY FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared for

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Summary Prepared by

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MAY 1980

ABSTRACT

A study of the Redondo Creek and Sulfur Creek stream system was conducted to provide a description of the biological and physical characteristics of the streams. The streams were divided into fourteen sections for descriptive purposes. The streams have a great deal of heterogeneity along their entire lengths. The higher wooded sections of the streams were characterized by steep flows and a high percentage of rubble and boulders in the stream, and thus were quite different from the rest of the streams. Below the wooded section, the pattern of communities depended on relative flow rates and the fineness of the bottom type. The pH levels on most of the streams ranged near 7.0, although, Sulfur Creek was quite acidic (pH of 3.75). Other physical characteristics were adequate to support fish and other aquatic organisms. A wide variety of algal and invertebrate taxa were found during the study. Development of the geothermal resources could present water quality concerns due to erosion which would produce increased turbidity of the waters.

1.0

INTRODUCTION AND SCOPE

A study of the Redondo Creek and Sulfur Creek stream system was conducted during the summer of 1978 in order to provide a description of the biological and physical characteristics of the streams. These data were collected in order to provide baseline information from which to predict environmental impact resulting from development of a geothermal electrical generation plant within the watershed of the stream.

The streams were walked and described as to vegetative cover and species composition, bottom composition, depth, presence of pools and obstructions, and flow rate. Physical characteristics of the waters were assessed. These physical characteristics included temperature, pH, total hardness, dissolved-oxygen concentration and transmittance. Algae was sampled at eight locations along the stream. Aquatic animals were sampled using a Surber sampler.

2.0

SUMMARY AND CONCLUSIONS

The streams were divided into fourteen sections for descriptive purposes. Brief descriptions of these fourteen sections are listed below in sequence of highest to lowest in elevations:

- 1) Marsh Wood: This section included the source spring of Redondo Creek and 336 m of the stream flowing through coniferous forests and open marshy areas.
- 2) Drywood: This section of Redondo Creek included a marshy area which flowed into a wooded area containing Douglas and white fir, blue spruce, aspen, and some maples. The section stopped at a small dam.
- 3) Alder Meadow: This section of Redondo Creek was approximately 2.5 km long and flowed through dry meadows with alder thickets of Redondo Creek.
- 4) Gambel Oak Gully: This section of Redondo Creek was approximately 1.1 km long and flowed through a gully with densely wooded slopes containing pines and oaks.
- 5) Pine-Alder Slope: Redondo Creek flowed through a densely vegetated area containing pine and alder.
- 6) Darnell Ranch Meadow: This section of Redondo Creek flowed through a somewhat disturbed meadow area.
- 7) Narrow Wet Meadow: This section of Redondo Creek flowed through a somewhat disturbed meadow area.
- 8) Pine Meadow: This section of Redondo Creek flowed through an area shaded by large pines on slopes adjacent to the stream.
- 9) Open Dry Meadow: This section of Redondo Creek ran through a dry meadow containing scattered Ponderosa Pine.

- 10) Marsh: The marsh area was found near the confluence of Redondo and Sulfur Creeks.
- 11) Pine-Alder Gully: This section of Sulfur Creek ran through a rocky slope bordered by pine and alder. Several small waterfalls were present.
- 12) Alder-Pine Meadow: This section of Sulfur Creek flowed through an open pine meadow.
- 13) River Valley: This section of Sulfur Creek flowed through a valley containing homes, pastures, and camping grounds.
- 14) River Canyon: Sulfur Creek flowed through a narrow canyon prior to its confluence with the Jemez River.

The source of Redondo Creek maintained a constant temperature of 11°C. The water temperatures of the remainder of the streams were directly proportional to air temperature. The pH at the source of Redondo Creek was 6.85, and the pH of the downstream portion of the creek ranged near 7.0. Sulfur Creek, before its confluence with Redondo Creek, was acidic (pH of 3.75). After Sulfur Creek's confluence with Redondo Creek, pH ranged up to 7.5 indicating a buffering action by Redondo Creek waters. Hardness of the creek waters ranged between 20 to 35 ppm of CaCO_3 . Dissolved-oxygen concentrations ranged from 6.0 to 8.1 ppm. All waters were clear and lacking in turbidity. All chemical parameters (with the exception of pH of the Sulfur Creek waters were acceptable to most aquatic organisms).

Thirteen taxa of diatoms, three taxa of filamentous algae and one filamentous chrysophyten taxa were found during algae surveys. In only a few areas along the streams were algae macroscopically visible.

Eighty-one taxa of animals were found during aquatic samplings. These taxa included 6 mite taxa, 10 beetles, 17 nonmidge diptera, 12 midge taxa, 6 mayflies, a semi-aquatic bug, 2 odonata, 6 stoneflies, 18 caddisflies and 5 mollusca.

The streams appear able to support a fish population, although only a few sculpins were found during the survey. Downstream barriers may affect upstream fish migration.

The probable effects of the geothermal development on the streams (other than geothermal water leakage) would be silting caused by exposed-topsoil runoff and water removal. Both these factors would alter the nature of the streams. The long-term effect of such perturbations would depend upon the streams' self-cleaning properties, which are functions of its flow rate and proximity to other streams which would serve animal recolonization. Unless the marginal vegetation is damaged, there should be little effect on the heterotrophic food base of the streams.

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REPORT NO. 57
EXECUTIVE SUMMARY

VISUAL RESOURCE INVENTORY FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

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PUBLIC SERVICE COMPANY

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ALBUQUERQUE, NEW MEXICO

1979

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MAY 1980

ABSTRACT

A visual resource inventory was prepared by the Environmental Affairs Department of Public Service Company of New Mexico (PNM) to document visual resources in the vicinity of the proposed 50MW Geothermal Demonstration project at Baca Location No. 1. The purpose of the inventory was to identify areas and degrees of visual quality and interest for use in furthering PNM's planning process and in preparation of the subsequent Environmental Impact Report to be filed by the Department of Energy (DOE). A land use inventory prepared by Wirth Associates provided the data base for references to area land use.

1.0

INTRODUCTION

Because of the importance of visual senses, aesthetics are closely related to other human interest values. Public enjoyment of recreational, historic and cultural resources are enhanced by visual quality, therefore, the greater the degree of visual quality present in an area, the greater the need for careful planning. By identifying and ranking the visual resources of an area, visual quality becomes manageable, greatly improving the planning process. The Baca inventory is specifically directed toward facilitating visual evaluation of the proposed project, which includes selection and analysis of the transmission system and analysis of the well field and generation facilities.

2.0

SCOPE

The visual resource inventory is divided into four major sections: 1) Methodology; 2) Baca Analysis; 3) Baca Inventory; and 4) Glossary, Abbreviations/Acronyms and Bibliography.

Methodology: The technique used in analyzing the Baca study area (the study area described in the land use inventory prepared by Wirth Associates) is based on the Visual Management System (VMS) developed by the Forest Service. The data base consisted of USGS 7.5 minute topographic maps, aerial photography, helicopter flights and/or ground confirmation. Definitions of character type, variety classes, sensitivity levels and visual quality objectives were discussed at length.

Category levels used in analyzing the Baca study area characteristics are defined as follows:

Category 1 (Preservation):	Allows natural ecologic changes only.
Category 2 (Retention):	Provides for management activities which are not usually evident.
Category 3 (Partial Retention):	Allows activities which remain visually subordinate to the characteristic landscape.
Category 4 (Modification):	Allows activities which may visually dominate the original characteristic landscape, but must borrow from natural form, line, color or texture.
Category 5 (Maximum Modification):	Permits management activities of vegetative and land form alteration which may dominate the characteristic landscape.

Baca Analysis: This analysis included a geomorphological analysis of the Baca study area. The Baca study area is described to center on the Valles Caldera in the Jemez Mountains, and is one of the world's largest calderas. A Variety Classification Matrix had previously been established by the Santa Fe National Forest for the San Juan Section of the southern Rocky Mountain Province, which includes the study area. Primary, secondary and tertiary travel routes and use areas within the study area were defined by the Forest Service and used in the inventory. The matrix was used as the basis for determining variety classes.

Baca Inventory: The analysis summarized the sensitivity levels of the Baca study area visual resources by categorizing the resources into the previously described category levels. These levels suggest the amount of alteration permissible within a given area.

Baca Preservation Areas

- 1) Bandelier National Monument wilderness area (NPS).
- 2) Caballo roadless area (FS).
- 3) Dome roadless area (FS).
- 4) Monument Canyon Natural Research area (FS).

Baca Retention Areas

- 1) Canon de San Diego.
- 2) East fork of the Jemez River.
- 3) Redondo Peak.
- 4) Shell Mountain.
- 5) Cerro Grande.
- 6) The foreground and some middleground views from some roads and use areas; these include portions of State Highway 4 (NM-4), FR-280, FR-268, East Jemez Road, FR-132, FR-133, FR-289, FR-1. These also include Pajarito Ski Area, Camp May, and Quemazon and Guaje Canyon trails.
- 7) Middleground views of Los Alamos Canyon.
- 8) The two forested knolls in the Valle Grande.

Baca Partial Retention Areas

- 1) All but one valley of the Valles Caldera: Valle Grande, Valle de los Posos, Valle Jaramillo, Valle Santa Rose and Valle Seco.

- 2) Forested slopes within the caldera and on the mountainous ring surrounding it which fall within middleground range.
- 3) The mixed conifer slopes along NM-4, NM-126, and the Pipeline Road that are generally within viewing range of NM-4, NM-126, the Pipeline Road, and FRs 106, 10, 280, 268, 286 and 376.
- 4) Three development areas west of the Baca: La Cueva, Horseshoe Springs and Thompson Ridge.
- 5) Canyon routes: FR-106, unofficial routes along Water Canyon, Canon de Valle, and Los Alamos Canyon on the eastern slope of Sierra de los Valles.
- 6) Middleground views of the eastern slopes of Sierra de los Valles.
- 7) Community of Los Alamos and surrounding roads.

Baca Modification Areas

- 1) The forested domes within the Baca: San Antonio Mountain, Dead Indian, Cerro San Luis, Cerro Santa Rosa, Cerros del Abrigo, and Cerro del Medio.
- 2) Forested slopes of Redondo Border and Redondo Peak, seldom seen and invisible areas south of NM-4, headwaters of Frijoles Canyon, seldom seen eastern slopes of the Sierra de los Valles, and the background logged areas on Cerro Toledo, Turkey Ridge, and Cerro de los Posos.
- 3) Restricted entry areas of LASL.

Baca Maximum Modification Areas

- 1) Many logged areas which occur on the Baca.
- 2) Mesa tops.

3.0

SUMMARY

The visual resource inventory identified, described and ultimately placed into sensitivity levels the visual resources of the Baca study area. No conclusions, recommendations, or alternatives were described.

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REPORT NO. 58
EXECUTIVE SUMMARY

BIOTIC INVENTORY FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For	Prepared By
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1979

Summary Prepared By

WESTEC SERVICES, INC.
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MAY 1980

ABSTRACT

Vegetation and wildlife surveys were conducted within a 22-mile long by 2-mile wide corridor to develop baseline information to assess biological impacts of construction of a geothermal electrical power plant and an electrical transmission line. Nine vegetation habitats were identified during the study. Six species of small mammals and 109 species of birds were recorded during the survey. No threatened or endangered species were found during the survey. However, there is potential that the Jemez Mountain salamander and blue gramma cactus could be found along the alignment.

1.0

INTRODUCTION AND SCOPE

Vegetation and wildlife surveys were conducted in conjunction with the proposed construction of a geothermal generating station and electrical transmission lines. The study area consisted of a 22-mile long by 2-mile wide corridor extending from the proposed generating station site (in the southwest corner of Baca 1) in a southeastern direction through the Baca site to Los Alamos.

Five collection sites were sampled for plant materials within the Baca site. An additional eight locations were sampled along the transmission corridor off the Baca site. Small mammal censuses were conducted in representative habitat. Pellet transects were used to estimate deer and elk herd size in the study area. Roadside censuses were conducted to determine avifauna densities. Directed searches were conducted for the Jemez Mountain salamander and the peregrine falcon.

2.0

SUMMARY AND SCOPE

Nine vegetation habitats were identified during the study. These habitats were spruce-fir forest, mixed conifer forests, Ponderosa pine forests, aspen forest, open meadows, riparian vegetation, logged areas, tallus slopes and pinyon-juniper savannah. No threatened or endangered plants were found during the survey. However, the blue gramma grass cactus (Pediocactus papyracanthus) could occur in grasslands between 7500 and 5000 feet.

Six species of small mammals were trapped during the survey. The least diverse habitats were the dry meadows, spruce-fir forest, and logged areas. Ponderosa pine habitat was moderately diverse. The most diverse habitats were wet meadows, semixerix habitat and mixed conifer habitat.

Elk density was estimated to be 13 times greater than deer density. Elk sign was found in all portions of the study area except lower elevations near Los Alamos. Deer and elk densities were higher in fall and winter than summer, indicating the area was primarily used as migratory and winter habitat. Logged areas at Cerro del Medio were utilized heavily for calving during June and July.

One-hundred-nine species of birds were noted during the study. Avian diversity was highest in mixed conifer habitats. Logged habitats were second highest in density. Meadows were the least diverse habitat.

No specimens of the endangered Jemez Mountain salamander were found during the survey. There is a potential the the species would occur along some portion of the higher elevations of the corridor (above 8000 feet).

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REPORT NO. 59
EXECUTIVE SUMMARY

SOCIOECONOMIC ANALYSIS FOR THE
PROPOSED BACA GEOTHERMAL PROJECT

FROM A REPORT

Prepared For
UNION GEOTHERMAL DIVISION
UNION OIL COMPANY OF CALIFORNIA
LOS ANGELES, CALIFORNIA
AND
PUBLIC SERVICE COMPANY
OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

Prepared By
MOUNTAIN WEST RESEARCH, INC.
TEMPE, ARIZONA
1979

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MAY 1980

ABSTRACT

Public Service Company of New Mexico (PNM) and Union Geothermal of New Mexico (Union) requested that Mountain West Research, Inc. conduct appropriate socioeconomic studies and related work in preparation for an environmental impact statement to be filed by the Department of Energy (DOE). (The EIS has since been completed and filed.) This report represents the results of that impact assessment, including a description of the methods used and some suggested mitigation strategies for application in areas where possible adverse impacts may occur.

The types of socioeconomic effects that Mountain West evaluated are related to economic growth and community life. The general categories studied were economy, population, housing supply and demand, public services and facilities, transportation, recreation, land use, government fiscal analysis and social attitudes. Following an analysis of changes that introduction of the plant could cause, positive and negative aspects of the project relating to socioeconomic environment were assessed. Of particular interest were those benefits that were then unanticipated and those adverse conditions that were considered sufficiently serious to warrant some preliminary planning for their eventual mitigation.

1.0

INTRODUCTION

The report began with a description of the proposed geothermal plant, the transmission line, and construction procedures for each, then described the existing environment focusing on a regional and local study area, presented the impact analysis, and concluded with proposed measures for mitigation of the determined socioeconomic difficulties.

The assessment procedure utilized throughout the report is in the format described below:

- 1) Sectors or activities that could be affected by the project were identified.
- 2) Future levels of activity were projected as they would be expected in the absence of the proposed project.
- 3) Future levels of activity were then projected with the proposed project.
- 4) The difference between the projections without the proposed project and those with the proposed project was the measure of impact.

2.0

SCOPE

Methodology: An integral part of the socioeconomic investigation was the agency and interest group contact program. The purpose of the program was to disseminate project information and gather the necessary data for completion of the socioeconomic analysis. Letters of introduction were sent to individuals in key governmental agencies at the federal, state and local levels, as well as to leaders of environmental interest groups in the state. These were followed by personal visits by members of Mountain West with participation by members of the Environmental Affairs Department at PNM and the staff at Union.

Impact Assessment: It was determined that the average peak year construction work force will be about 165 people, with the work force that would operate the plant and maintain the well field expected to be 55 people.

Operation Period

It was felt that the Baca project would be an important source of long-term or permanent employment for residents of the local impact study area. Approximately one-half of the 55 permanent jobs were anticipated to be held by existing residents of the Jemez Valley, and the other half split between existing residents of the three other subareas of the local impact study area: Bernalillo, San Ysidro and vicinity, and Los Alamos.

Overall, it was felt that the long-term impacts of the project should be generally beneficial. The plant represents a significant increase in the economic base of the Jemez Valley. These jobs would lead to increased income and better employment, both in terms of salary levels and job stability. This would probably cause some new housing construction and a gradual attraction of the work force to the Jemez Valley as single-family units become available there. Also, substantial fiscal benefits should accrue to Sandoval County. No significant adverse impacts were anticipated in the long-term, especially if care were taken to maintain good relations during the construction period with the communities in the Jemez Valley.

Construction Period

Housing for construction workers was determined to be a potential problem during this time, especially in the Jemez Valley. In addition, travel along State Highway (NM) 4 is expected to increase approximately 11 percent, and during the peak hour by 29 percent. The greatest increase in traffic will occur during the peak employment period, approximately three months, and will be about 63 percent greater. This will create an incremental increase to the presently unsafe conditions at potentially hazardous locations. A third impact is anticipated to occur to an already minimal number of indoor recreation facilities and opportunities in the Jemez area. A fourth possible problem with the fiscal impact is that an imbalance may arise from the spatial difference between where the new expenditures might be required and where the plant-related revenue increases would occur.

Potential Mitigation Measures. 1) To mitigate any housing impacts, the most favorable solutions were either development of a temporary RV/trailer park on leased land in Jemez Springs, or locating workers as near as possible to the plant site either in Jemez Springs, campgrounds or wherever it may be feasible to locate facilities in the Santa Fe National Forest; 2) in order to decrease potential unsafe travel along NM 4, the energy companies should begin to inform the Department of Highways Planning Department of the traffic increases that are expected. Because major traffic congestion problems are not anticipated during the project, this strategy of early notification to highway maintenance authorities is expected to assuage the potential problems; 3) to mitigate potential impact to the recreation facilities, it was suggested that the development companies contact the local school board and request initiation of several athletic nights at the gymnasium in Canon, and that the companies establish a continual communication with local government officials regarding recreation in the area where the temporary workers settle; 4) to improve fiscal imbalances, the County could award grants from a fund established by a certain amount of the property tax revenues to local governments anticipating necessary improvements; 5) because the general route of the transmission line corridor had not been determined during the course of this study,

yet was an identified areawide concern, it was advised that the companies plan a public information program to advise area residents and the greater public of the final corridor selection.

3.0

SUMMARY

This study presented a complete break down of the existing socio-economic environment, formulated potential impacts created by both construction and ongoing operation of the proposed geothermal plant, and presented mitigation measures to alleviate these impacts.

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REPORT NO. 60
EXECUTIVE SUMMARY

PUBLIC HEARING ON THE
ENVIRONMENTAL IMPACT STATEMENT
GEOTHERMAL DEMONSTRATION PROGRAM

AUGUST 30, 1979
TRANSCRIPT OF PROCEEDINGS

Prepared For
THE UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
ALBUQUERQUE, NEW MEXICO

Prepared By
HOWARD W. HENRY & COMPANY
ALBUQUERQUE, NEW MEXICO

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MARCH 1980

ABSTRACT

On August 30, 1979, a public hearing was held on the Environmental Impact Statement submitted by the U. S. Department of Energy (DOE) on the 50 MW Geothermal Demonstration Program at the Baca Location No. 1 in North-Central New Mexico, to hear testimony on whether the United States Government should accept the EIS as complete. The participants in the proposed project at that time were Public Service Company of New Mexico (PNM) and Union Geothermal of New Mexico (Union). Representatives of DOE, PNM, Union and the legal community were available for questions. Presentations were made by DOE, the Bureau of Indian Affairs, the All Indian Pueblo Council, the Pueblo of Zia, the Jemez Pueblo, the Cochiti Tribe, the Los Alamos Mountaineers, and various other institutions and private citizens. This report is the transcript of the proceedings as recorded by a court reporting service.

HEARING APPEARANCES

MR. THOMAS A. HARRELL, Chariman

MR. ROBERT P. HARTLEY, Member

MR. JOSE L. M. CORTEZ, Member

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Public Service Company of New Mexico

MR. DICK ENGBRETSSEN
Union Oil

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MS. KATHY OAKES

MS. MARY MORAN

REPORT NO. 61
EXECUTIVE SUMMARY

FINAL ENVIRONMENTAL IMPACT STATEMENT
GEOTHERMAL DEMONSTRATION PROGRAM
50 MW POWER PLANT

FROM A REPORT

Prepared By
UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
WASHINGTON, D. C.
JANUARY 1980

Summary Prepared By
WESTEC SERVICES, INC.
ALBUQUERQUE, NEW MEXICO
MARCH 1980

ABSTRACT

This report is the Final Environmental Impact Statement (FEIS) of the 50 MW Geothermal Demonstration Plant of the Baca Location No. 1 in North-Central New Mexico, as published in January 1980. This FEIS was submitted after a draft EIS (DEIS) was considered by the public sector and comments were submitted on its content. This FEIS, as do all FEIS's, considers impacts and possible mitigations of all aspects of the project on land use, geology, soils, geothermal resources, hydrology and water quality, meteorology and air quality, ecology, historic and archeological resources, socioeconomy, noise, visual resources, and Pueblo Indian culture and religion. The FEIS also considers impacts of whether or not the project is approved, environmental trade-offs, and an analysis of the steady-state impact of the operating plant. Written comments to the DEIS are attached as an appendix.

INTRODUCTION AND SCOPE

In pursuit of the Federal Geothermal Program objective to accelerate the commercialization of geothermal energy in an environmentally sound manner, the DOE issued a program opportunity notice (PON) on September 30, 1977, inviting organizations to submit proposals for the design, construction, and operation of a geothermal electric power plant. The PON specified that the power plant must (1) use a liquid-dominated geothermal reservoir, and (2) be located in the United States. The objectives of the PON were chosen to provide the maximum stimulus to non-Federal development of the widest spectrum of hydrothermal resources that can be used for electricity production.

The Federal action addressed by this Environmental Impact Statement is joint funding by the Department of Energy and commercial partners of a 50 MW(e) geothermal well field, power plant, and transmission line at the Baca Location in Sandoval County, New Mexico. The power plant will utilize a single-flash steam separation system and mechanical-draft cooling towers and will use cooled geothermal fluid for cooling. The geothermal well field will initially consist of up to 17 wells producing fluid from an area of approximately 300 ha (746 acres), including up to 176 new wells to be added during the 30 years of operation.

A 115 kV transmission line will be constructed from the project site to the TA-3 substation near Los Alamos. The line will be capable of carrying up to 150 MW of capacity and will be approximately 30 km in length. The two routings proposed will traverse private land, portions of the Santa Fe National Forest, and the Los Alamos Scientific Laboratory. One of the proposed routes will cross the Bandelier National Monument.

The proposed plant is situated along the Redondo and Jaramillo Creeks graben within the Valles Caldera, a major Quaternary volcanic center superimposed upon the western margin of the Rio Grande rift, a first-order tectonic feature. Volcanic rocks and caldera fill material of Pleistocene age crop out at the surface overlying a sequence of perhaps 3800 m (12,400+ feet) of older Quaternary and Tertiary volcanics, Tertiary sands, Paleozoic sedimentary rocks, and a Precambrian granitic basement complex. Produced heat flow values at the site are high, exceeding $3 \mu\text{cal}/\text{cm}^2$. A gravity anomaly of 25 milligals is coincident with the project area. The closest known active fault zone, in Jemez, lies to the southwest of the Valles Caldera. No significant seismic events have been recorded near the project site.

The geothermal resources of the project area include both a liquid and a vapor-dominated reservoir. The calculated weight of fluid in place in the major, liquid-dominated reservoir is 1.8×10^{12} kg (4×10^{12} lb.). The average reservoir fluid temperature is in excess of 260°C (500°F). The main production and injection zone is the lower Bandelier Tuff; the upper Bandelier forms the caprock.

The principal effluents from the power plant are nonflashed, hot geothermal fluid, which will be injected, and geothermal vapor released to the atmosphere from the cooling towers. The liquid contains lightly concentrated dissolved solids, and the vapor contains small amounts of noncondensable gases, including hydrogen sulfide.

2.0

SUMMARY AND CONCLUSIONS

Releases of hydrogen sulfide during normal operation will result in increases of H_2S concentrations in the air of less than 2 ppb at the Baca boundary and less than 10 ppb at other locations within the Baca Location. Accidents or abnormal operation conditions may infrequently result in concentrations exceeding these values for infrequent intervals of up to several hours.

Induced subsidence of the land surface resulting from geothermal fluid production is not expected to be likely or measurable at the surface and may even be less significant than that occurring naturally. The proposed fluid injection pressures and temperatures are within a range not likely to initiate any significant earthquake activity as a result of hydraulic fracturing or thermal stress cracking of the reservoir rocks. Induced seismicity at the project site will probably be obscured by natural seismicity.

Potential impacts resulting from development of the 50 MW(e) geothermal well field, power plant, and transmission line are summarized in Table 1-1 included in the executive summary.

Comments on the DEIS were grouped into the major categories of (1) inadequate analysis of expansion beyond the Federal action, (2) inadequate treatment of American Indian religious impacts, (3) critiques of the technical methods of impact estimation, particularly for hydrology and air quality, (4) potential future public ownership of the Baca Ranch, and (5) transmission line alternative discussions. These comments have been included in Appendix I of the EIS, addressed generally in Section 12, and resulted in expanded discussion in appropriate sections of the EIS.

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Table 1.1. Summary of potential impacts of development of the 50-MW(e) geothermal well field, power plant, and transmission line at the Baca site^a

Ecology (Sects. 4.1.4, 4.2.4, and 4.4.1.2)	Land use (Sects. 4.1.1, 4.2.1, and 4.4.1.1)	Geology (Sect. 4.2.5)	Socioeconomics (Sects. 4.1.5 and 4.2.7)	Cultural resources (Sects. 4.1.5.2, 4.1.7, and 4.4.1.4)	Air (Sects. 4.1.3 and 4.2.3)	Water (Sects. 4.1.2 and 4.2.2)
<ul style="list-style-type: none"> Disturbance of important winter elk range 	<ul style="list-style-type: none"> Grazing and logging largely unaffected 	<ul style="list-style-type: none"> Induced subsidence and seismicity are very unlikely 	<ul style="list-style-type: none"> Minor effects of disassociation between costs of services and tax benefits 	<ul style="list-style-type: none"> Potential impact on identified archaeological sites 	<ul style="list-style-type: none"> Impact of release of approximately <8 grams/sec (50 lb/hr) of hydrogen sulfide during plant operation 	<ul style="list-style-type: none"> Consumptive water requirement of plant (107 kg/sec or 820,000 lb/hr) requires withdrawal of approximately 5.67 ha (14 acres) of land from irrigation over the 30 year life of the plant
<ul style="list-style-type: none"> Loss of habitat for Jemez Mountain Salamander (state endangered species) 	<ul style="list-style-type: none"> Major recreational resources affected (decreased accessibility and visual impact of transmission corridors) 		<ul style="list-style-type: none"> Potential impacts of increased traffic volumes on Indian Pueblos 	<ul style="list-style-type: none"> Potential disruption or desecration of Indian religious sites, sacred areas or sacred objects (plants, animals, water, etc.) 	<ul style="list-style-type: none"> Impact of release of approximately 0.22 kg/sec (1900 lb/hr) of cooling tower drift during plant operation 	<ul style="list-style-type: none"> Geothermal fluid withdrawal will reduce the flow in the Jemez River by approximately 0.78 liters/sec (12.38 gal/min)
<ul style="list-style-type: none"> Potential effects on rare plant species 	<ul style="list-style-type: none"> Potential threat to designated National Natural Landmark 			<ul style="list-style-type: none"> Potential interference with access to Indian religious sites, sacred areas, or collecting grounds for sacred objects 		
<ul style="list-style-type: none"> Increased stream sedimentation and possible damage to trout fishery 	<ul style="list-style-type: none"> Possible conflicts with future public acquisition of the Baca property Estimated land requirements are: disturbance for plant and wells: 18.2 ha (45 acres) transmission line right-of-way: corridor 1: 97.5-106.7 ha (approximately 241-264 acres) corridor 2: 112.8-126.5 ha (approximately 279-313 acres) 			<ul style="list-style-type: none"> Potential interference with Indian religious ceremonies Withdrawal of geothermal fluids may affect discharge of Indian sacred springs 		

^a Identification and quantification of the impacts of development of 150 MW(e) and 400 MW(e) is purely speculative and was not included in this table for that reason. The impacts which result from development to 150 MW(e) and 400 MW(e) will be similar to those presented in this table, however, their magnitude will differ. Discussions of the impacts of development of 150 MW(e) and 400 MW(e) are found in Sect. 4.5.