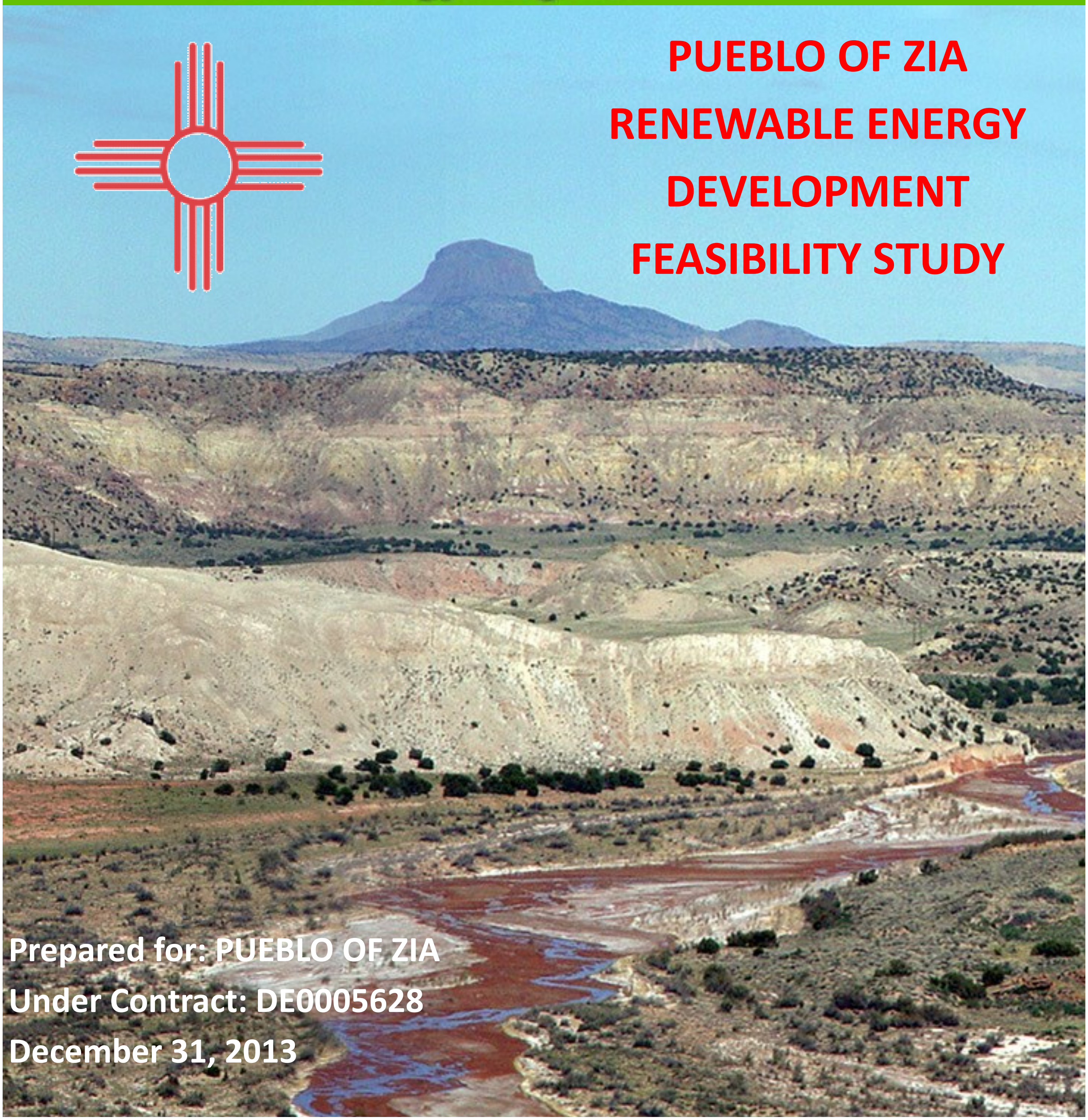
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Tribal Energy Program

# PUEBLO OF ZIA RENEWABLE ENERGY DEVELOPMENT FEASIBILITY STUDY



Prepared for: PUEBLO OF ZIA

Under Contract: DE0005628

December 31, 2013

Witcher and Associates

NEW MEXICO RETA renewable energy transmission authority

New Mexico Community Capital

Native Development Associates

Sustainable Engineering

Los Alamos National Laboratory

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## Prepared For:

Pueblo of Zia - Zia Pueblo, New Mexico, USA

Award No.: DE-EE0005628 - U.S. Dept. of Energy (DOE), Tribal Energy Program, Golden, CO

## Dates:

June 1, 2012 through December 31, 2013



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PUEBLO OF ZIA

The Pueblo of Zia and its Zia Renewable Energy Feasibility Study Team would like to most gratefully acknowledge the **U.S. Department of Energy Tribal Energy Program (TEP) and Office of Energy Efficiency and Renewable Energy (EERE)** for its ongoing efforts in providing critically needed financial and technical assistance for Native American tribes throughout the U.S., since 2002. Without such type of vision, expertise and funding it would not be possible for tribes such as Zia to develop their own renewable energy resources and reduce their carbon energy consumption through adopting of R-E technologies, education, training and green jobs development which all help to greatly strengthen our native communities. The Pueblo of Zia especially wishes to acknowledge the trusted guidance, expertise and valued partnership of Ms. Lizana Pierce (DOE TEP Project Manager), Mr. Kristopher Venema (CNJV) and entire TEP Project Team based in Golden, CO.

The Zia R/E Study Team would also like to thank the **Pueblo of Zia Tribal Administration and Staff** for its considerable efforts in the ongoing support of this project. This includes the Zia Tribal Governors who have honorably served over the three year course from project conception to completion, including, Governor Marcellus Medina, Governor Wilfred Shije and Governor Harold Reid.

**The Pueblo of Zia Renewable Energy Development Feasibility Study (DE5628)** is entirely dedicated to the proud generations of the Pueblo of Zia people, i.e., from the ever-present and guiding Ancestors, to the modern day Zia people, and for the many future generations of Zia people to come. May the Sacred Zia Sun Symbol and traditions continue to shine its abundant renewable wisdom, light and energy upon all.

Sincerely,

POZ R/E Study Team
December, 2013

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# I. EXECUTIVE SUMMARY

The Pueblo of Zia (pronounced,"*T'siya"* and also referred to as "Zia Pueblo" or "POZ") was awarded a grant to perform the "Pueblo of Zia Renewable Energy Development Feasibility Study", Award No. DE-EE0005628 by the Energy Efficiency & Renewable Energy, Golden Field Office, US Department of Energy (DOE). The period of performance was 6/1/2012-12/31/2013. POZ has conducted this comprehensive feasibility study for the best-use application(s) for development of renewable energy resources on its Tribal Trust lands (i.e., Trust Lands of Zia Indian Reservation). The feasibility study is essential for determining the technical and economic viability of a future renewable project(s) on POZ Tribal lands including the potential economic and environmental benefits for the Tribe.

To complete this study, the POZ has created a partnership with Los Alamos National Laboratories (G. Loren Tool, Principal Investigator); Native Development Associates (Jai Lakshman, Project Manager); Sustainable Engineering (Dan Hand, PE); Witcher and Associates (Jim Witcher, Geologist), ARES Corporation (Michael Emerson, Senior Vice President); NM Renewable Energy Transmission Authority and New Mexico Community Capital (Wendy Sandidge, Director of Operations). Together, this partnership collected, cataloged, mapped and analyzed data on POZ's renewable energy resource base and then matched resource attributes with the most suitable renewable technologies for Tribal energy consumption and need while addressing key impacts on the cultural and social values of POZ. This study looks at ways to:

- Provide a balanced local renewable power supply for POZ, its members, Tribal offices, schools and buildings, and businesses on Tribal lands;
- Provide a firm power supply for export and commercial market distribution; and,
- Provide economic development for the Tribe and its Tribal members, including job training and creation, each, in accordance with the goals and objectives as conveyed by the POZ Tribal Council and Tribal Administration.

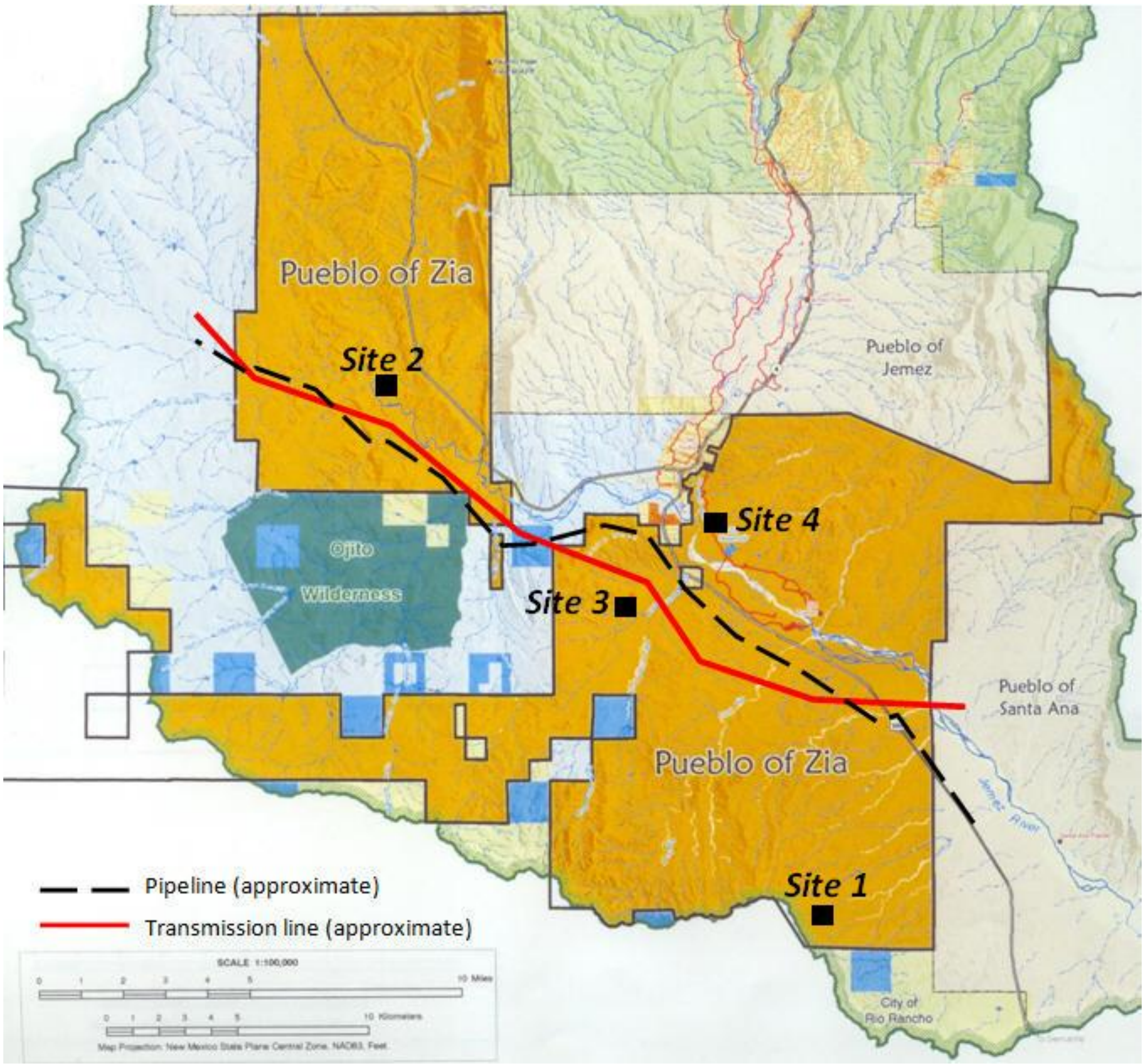
A key goal of the study is to analyze the integrated development of solar, geothermal, and wind renewable energy resources at POZ.

The feasibility study determined that ample solar, wind and geothermal resources exist at POZ to support the development of a generation project. A site down-select process was performed that indicated there is a capacity to generate between 27,000,000 kWh and 47,000,000 kWh at preferred sites using a combination of solar, wind and geothermal energy. The customer base and load exists to apply generated electricity toward Net Metering for POZ and/or Export back into the grid. A financial analysis was performed showing that Net Metering and Export options will produce a reasonable internal rate of return for an investor. The financial analysis evaluated the financial impact of tax incentives and various business structures POZ will need to consider.

The study recommends that all resources be pursued for development. Each of the resources have different attributes that cause the economic advantage to be somewhat difficult to compare. For example both solar and wind resources can be investigated to define the potential resource for a small investment, and the solar and wind plants can be built incrementally. Geothermal on the other hand requires a much larger initial investment, one cannot drill a portion of a well and expect to have investment data. Rather a well has to be drilled to total depth, which is a substantial cost ($ millions --

depending on depth, $12 million for POZ Site 1 for example). If the drilling confirms the resource, however the geothermal resource has a more attractive cost and economic advantage than the solar and wind. For purposes of this study the Project Team is therefore recommending that the Pueblo continue to pursue all resource options for potential income, i.e., offering projects that will attract all types of investors, small and large. Secondly all the resources could potentially share the cost of needed electrical upgrades, thus helping to reduce overall development costs.

**Figure 1.1 Developable Sites at Pueblo of POZ**



**Geothermal Energy Potential:** Site 1 presents the best potential geothermal site from a strictly geologic point of analysis. This site will require the highest up front drilling cost, and delivers the best economics at a levelized cost of $79.90/MWH. Site 3 is the second best site with a levelized cost of $106.20/MWH. Site 3 requires the second highest up front drilling cost. Sites 2 and 4 have similar economics $219.71/MWH and $187.13/MWH, respectively. All sites were held to the same Rate of Return of 7.5% by adjusting the levelized cost of power. Since the levelized cost of power is much higher than what the local market will support Sites 2 and 4 are not considered economic. The group also considered the POZ's long-term Economic Development Plans and while Site 3 is preferred over Site 1, development at either of the sites is acceptable.

**Wind Potential:** Site 3 presents the best wind site, based on metered wind resources, proximity to local Jemez Mountains Electrical Cooperative Inc. (JMEC) utility lines and scalability relative to POZ's electric demand. It delivers the best economics at a levelized cost of $105/MWH. All sites were held to the same Rate of Return of 7.5% by adjusting the levelized cost of power. Uncertainty exists regarding the likely annual energy capture possible at Site 1. This site was classified as a NREL Class 3 wind regime. Site 3 was classified as a NREL Class 4 wind regime with undetermined upslope wind losses along the north White Mesa boundary. Up to 15% additional wind energy capture is possible at Site 3 versus Site 1.

**Solar Potential:** Sites 3 and 4 offer the best solar photovoltaic sites, based on proximity to local JMEC utility lines, scalability relative to POZ's electric demand and available acreage. It delivers the best economics at a levelized cost of $165/MWH. All sites were held to the same Rate of Return of 7.5% by adjusting the levelized cost of power. Solar module prices may fall dramatically through 2020. This study assumes a value of $2.35 per peak watt or 60% lower than reported by U.S. Energy Information Administration (EIA) in 2012. The EIA study represents average pricing for various applications and different technology types which are unlikely to be representative of utility-scale module prices in the near future. Prices of $1.17 per peak watt are achievable if DOE's 2020 Sunshot program goals are met. Using this assumption a $120 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

Integrated development of renewable and other energy resources is a distinct possibility at POZ. Any of the resources jointly developed would distribute the cost of electric transmission upgrades and decrease the transmission portion of the cost. The study includes consideration of multiple resources at each site. They are supportive in the sense that solar and wind tend to occur at different times of the day and of course they all share the same transmission grid and local infrastructure. Geothermal is a baseload resource and natural gas fired generation could provide firming capacity for the wind and solar. We also considered a novel combination of Solar thermal and Geothermal combined at the thermal power plant level. The solar thermal provides the high temperature heating and the geothermal provides the low temperature heating. This solar-geothermal combination would share not only transmission but also the power plant (turbine, generator, and heat exchangers) and yield a power plant that is cheaper than solar alone, and has a 24/7 capability with a minimal requirement for thermal storage. Although this combination is more expensive than geothermal only, it is less expensive than other renewable energy development at $92/MWH. The solar geothermal combination would require the largest amount of capital investment and produce the largest amount of return for the POZ.

# II. BACKGROUND

The POZ has conducted this comprehensive feasibility study to determine best-use application(s) for development of renewable energy resources on its tribally held TRUST lands (i.e., Trust Lands of Zia Indian Reservation).

This feasibility study will be used to determine the technical and economic viability of future renewable project(s) on POZ Tribal lands including the potential economic and environmental benefits for the Tribe to:

a) Provide a balanced local renewable power supply for POZ, its members, Tribal offices, schools and buildings, and businesses on Tribal lands;
b) Provide a firm power supply for export and commercial market distribution; and,
c) Provide economic development for the Tribe and its Tribal members, including job training and creation, each, in accordance with the goals and objectives as conveyed by the POZ Tribal Council, the Zia Tribal Administration, and as outlined in, The Pueblo of Zia Comprehensive Plan, and Pueblo of Zia Enterprise Zone Master Plan.

## A. ZIA PUEBLO – LOCATION

The POZ is located within the flood plain of the Jemez River, and the Pajarito and Jemez Plateaus in Sandoval County, New Mexico, approximately 17 miles (27 km) northwest of Bernalillo, NM and 35 miles (56km) northwest of Albuquerque, NM. Current boundaries of the POZ Reservation Lands ("Trust Lands") extend approximately 261 square miles or 167,000 acres. The POZ main village is situated alongside the Jemez River atop a mesa that provides spectacular views of the surrounding Zia Pueblo lands and outlying areas. Lands of POZ range in elevation from 5,200 feet to over 9,000 feet and include a diverse range of  pine forest, red bluffs, white mesas, extensive cattle grazing lands and clear, unimpeded sight lines in each direction from the Pueblo.  South of the POZ lies the Nacimiento Mountains and the Pajarito and Jemez Plateaus.

## B. HISTORICAL BACKGROUND

The people of the POZ have continuously inhabited their current homelands since before 1250 A.D. The POZ is part of the Keres Indian Nation, with ancestral roots to the upper San Juan River basin and Mesa Verde region. The traditional language of Zia Pueblo is *Keresan*, which remains commonly spoken today. The POZ is the birthplace of the renowned historic "Zia Sun symbol" which displays sixteen stylized rays radiating in each of the traditional four directions from a central sun. In the 1920s the symbol was adopted by the State of New Mexico for use as its official State flag emblem.

## C. CONTEMPORARY LIFE

Today, the POZ's population of 875 Tribal members live in 178 housing units, of which 141 homes are owned by individual owners. Remaining structures are communal-type housing. A door-to-door income survey conducted in 2010 (in conjunction with USDA Rural Development) substantiates that the POZ remains well below the median household income (MHI) for the State of New Mexico and surrounding regions in all comparable Census categories. The total median income for combined 1-4 person households and 5-8 person households at the POZ is $23,440; the average household income combined is $28,616. As such, the POZ falls -31% and -16% (respectively) below 2010 Census figures for the State of New Mexico. The Pueblo falls -44% and -32% (respectively) below reported 2010 Census figures for the United States.

POZ Tribal members continue to speak and conduct traditional ceremonies in their Native language of *Keres*. The Tribe has elected to not develop any gaming related enterprise(s) on its lands. Rather, it has continued to utilize its longstanding practices of agriculture and traditional arts and crafts while pursuing other sustainable types of culturally appropriate economic development activities. Current economic development initiatives of the Tribe include: development of a mixed use town plaza retail & commercial center in the nearby town of Bernalillo, NM; development of a regional commercial, retail and light-industrial center known as the, "Zia Enterprise Zone" (ZEZ) located on POZ Tribal lands that includes a POZ Cultural Center and Museum, State of New Mexico - Zia Sun Symbol Visitors Center, retail shops, regional food cooperative farmer's market and grocery, restaurant, motel, native film offices/education center and development of sustainable light-industrial facilities. As well, the Zia Enterprise Zone has been designated by the Tribe as a key development site for its renewable-energy resources program.

The POZ is firmly committed to sustainable, culturally-appropriate economic development that will strengthen the Tribe's self-reliance through commercial and industrial employment opportunities, agricultural production and distribution, cultural tourism and renewable resources development. To help realize these goals the Pueblo has invested significant resources in land acquisition and enterprise planning. This Feasibility Study for Development of Renewable Energy Resources on POZ Tribal Lands is intended to help the Pueblo move forward with conceptual planning, project infrastructure design and securing financing and partnerships needed to support the POZ's economic development.

## D. THE ZIA SUN SYMBOL AND RENEWABLE ENERGY

For the Zia people, the Zia Sun symbol is a most ancient sacred design. It reflects the basic harmony of all things in the universe. As with most Native American Tribes, for POZ people four is a sacred number. It reflects the four directions, the four seasons, the sunrise, noon, evening and night phases of the day and the four stages of life: childhood, youth, adulthood and old age. The POZ also believe that man has four sacred obligations: to develop a strong body, a clear mind, a pure spirit and a devotion to the wellbeing of the people and the land. Accordingly, POZ has long maintained a fundamental interest in renewable energy, as its most sacred Tribal symbol speaks of energy, sustainability and life. Through development of its renewable energy resources the POZ seeks to provide a local renewable balanced power supply for its Tribal members, community, offices and businesses located on Tribal lands, and develop a balanced power supply for export and commercial market distribution. Such enterprise will also provide the type(s) of sustainable economic development that is needed for strengthening the self-reliance of the Tribe and its members, including job training and creation that is culturally appropriate and consistent with the Pueblo's longstanding practices and traditions. Development of renewable energy resources will provide economic and environmental benefits which, have been clearly defined by the POZ Tribal Council and pueblo elders as being in the highest and best sustainability interests of the POZ for the generations to come. Development of renewable energy resources at the POZ will also represent a 'coming full circle' with Zia's longstanding traditions of working in harmony and deepest respect with the land, skies, winds and all related natural sources.

## III. GOALS & OBJECTIVES

A key goal of the study is to analyze the integrated development of solar, geothermal, and wind energy resources at the POZ, with added potential to combine gas-fired generation to provide a firm power supply.  While the study did not directly assess the various uses of natural gas generation, it is widely recognized that natural gas is a significant part of the Country's energy mix and is addressed in this study in a preliminary manner as an additional source of possible generation.  Geothermal offers a base load source of energy, providing power continuously for end-users. Wind and solar offer intermediate and peaking sources of energy, which can be harvested throughout the day, with periods of variable but predicable output. Variability will be managed in an integrated manner, using the POZ's combined renewable resources to generate high quality power.

Tasks outlined in this proposal are intended to collect, catalog, map, and analyze data on the POZ's renewable energy resource base and then match resource attributes with the most suitable renewable technologies for Tribal energy consumption and needs.  Also, key impacts on cultural and social values of the POZ will be addressed.  Valuable technical and economic information will accrue from this study that may be applied to scale-up or scale-down the various power technology potential on the POZ for maximum benefit and best area(s) of application, project phasing and potential for future replicability and expansion.

Based on the results of the feasibility study the POZ intends to perform a feasibility analysis to assess the potential for a Tribal business venture. Options to be assessed include business forms such as a Tribal utility authority, partnership with private developers, or a separate Tribal entity, and the various market drivers to establish the level of demand such as renewable energy certificates (RECs), power purchase agreements (PPAs), Tribal set-asides, personnel requirements, and regulatory considerations necessary for establishing the venture.

# IV. FEASIBILITY STUDY COMPONENTS

## A. DOWN SELECT PROCESS

During Zia's energy development process[1], four development sites were identified (see Figure 1.1 above) as being potentially feasible on the basis of a comprehensive set of technical and cultural factors. Three renewable technologies were also identified as potentially developable (geothermal, wind and solar photovoltaic). Additional down select factors were outlined and a process was described which could be used to further reduce the number of possible site and technology combinations considered during this feasibility study. The goal of this effort was to focus attention on siting combinations i.e. sites and technologies which potentially offer more value to the Pueblo, in terms of a site's ability to score well on multiple siting criteria, maximize energy income and reduce impacts of development on the Pueblo. The full description of this process can be found in Appendix G.

Figure 4.1., shown below, outlines the proposed down select process to be used for solar PV. A similar process would be used for wind and geothermal.

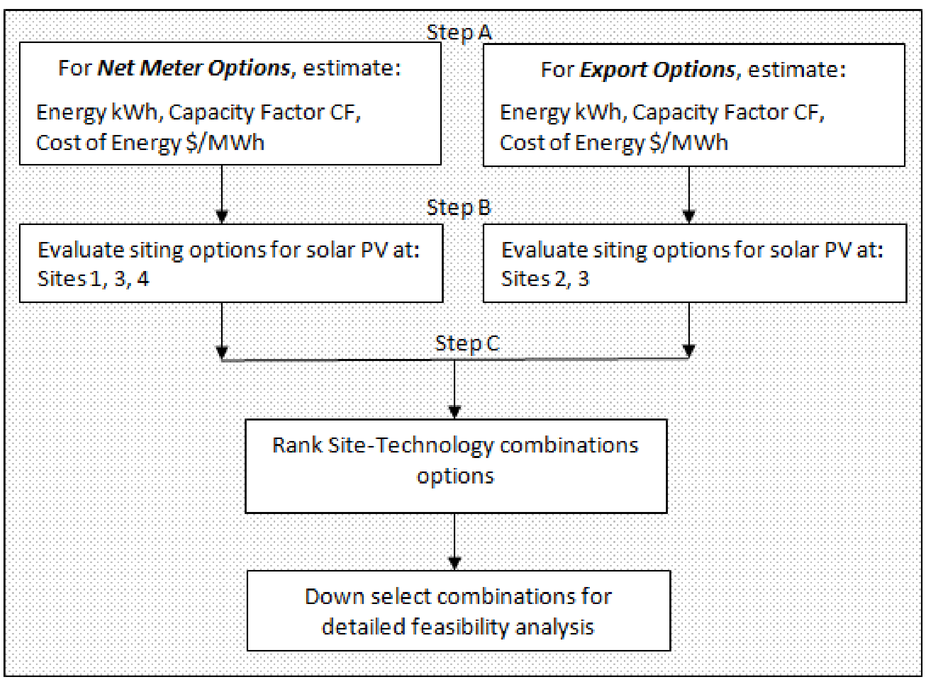



**Figure 4.1. Down Select Process: Zia Siting and Technology Options**

[1] During 2011, Los Alamos National Laboratory (LANL) developed a joint project proposal with the Pueblo of Zia serving as project lead. This effort successfully competed for feasibility study funds offered by DOE's Tribal Energy Program (TEP); funding formally occurred in July, 2012.

Siting combinations were tentatively identified as possible candidates for more detailed **Step B and Step C** evaluation. The Combined Siting Options shown below identify technology combinations by proposed site locations within each row evaluated for **Step A**. For example, one option includes simultaneous development of geothermal, solar PV and wind at various sites. Total installed capacity would equal approximately 7,200 kW. This combination would generate approximately 27.7 million kWh of electricity annually. Zia may also choose, on the basis of additional selection criteria, to consider only one siting option for one technology[2] rather than developing two sites. This choice will reduce installed kW for each option listed below. A map showing the location of all POZ sites described in this report is shown in Figure 1.1 in Section I above.

The developable sites at POZ include:

- **Site 1 - Roberts Tower:** located on southeastern pueblo land. Geothermal and solar PV resources can be interconnected to an existing JMEC 24 kV distribution line, then transported to ZEZ via a 24 kV distribution line extension. The latter configuration would allow net metering of energy consumed and produced. Net metering would reduce or eliminate nearly all commercial electricity consumed at ZEZ, and potentially results in a sale of up to 41.2 million kWh annually to JMEC.

- **Site 2 - Warm Springs:** located on northwestern pueblo land. Solar PV resources can be interconnected to an existing 115-kV transmission line for direct sellback of all energy produced. A sellback configuration potentially results in a net sale of approximately 7.0 million kWh annually to JMEC or another bulk purchaser of electricity.

- **Site 3 – San Ysidro Substation:** located on northwestern pueblo land. Solar PV and wind resources can be interconnected to an existing 115-kV substation for direct sellback of all energy produced. A sellback metering potentially results in a net sale of approximately 3.9 million kWh annually to JMEC or another bulk purchaser of electricity.

- **Site 4 - Zia Enterprise Zone (ZEZ):** located on northeastern POZ land along U.S. Hwy 550 near NM Hwy 4. This solar PV alternate site can be developed near the ZEZ commercial area to permit net metering i.e. no sellback kWh are likely. Approximately 1.8 million kWh could be generated annually.

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[2] For example, two geothermal sites are proposed for evaluation during Pueblo of Zia's study however one site may prove to be infeasible or uneconomic.

Table 4.A summarizes raw site scores recorded during the December 19, 2012 session.

**Table 4.A. Raw Site Scores**

| Combined Siting Options | Site Score | Score Variance |
|---|---|---|
| **Site 1 - Roberts Tower** | 227 | 69.7 |
| **Site 2 - Warm Springs** | 216 | 37.7 |
| **Site 3 - San Ysidro Substation** | 270 | 82.2 |
| **Site 4 - Zia Enterprise Zone** | 278 | 101.1 |

The scoring listed in Table 4.A. is based on individual scores for fifteen factors including environmental impact, financial cost and income, project risk, cultural and other Tribal concerns etc. A score variance is also listed; it indicates that evaluators agreed most consistently (lowest variance) on Site 2's score but agreed least consistently (highest variance) on Site 4's score.

The ultimate value of this exercise was to evaluate ***combinations*** of sites and technologies, not only individual sites. A variety of siting combinations were previously identified as being potentially capable of maximizing energy income for the Pueblo. When site scores are combined into siting combinations, the resulting scores provide an initial guide for detailed feasibility analysis.

After review of these results and discussions by POZ's project team two combinations were selected for analysis.

It was important to retain options for geothermal development at Site 1. Lack of significant transmission capacity at Site 1 will be a negative development factor; however this cost will be represented in feasibility analysis of geothermal options. Exposure of wind turbines on the ridge line at Site 1 is a negative development factor; also Zia's property boundary does not allow large setback distances from the ridge line at this site. Prior wind site assessments done in 2008-2010 by Duke Energy at Mesa Prieta near Site 3, plus access to transmission corridors, suggests heavier weight needs to be given to this site for wind development.

These combinations offer significantly different technology mixes and capacities, anchored by the location of geothermal development. Their main features are summarized below:

- If ***Geothermal-Wind-Solar (Combination A)*** is developed at Sites 1, 3 or 4, geothermal, solar, and wind capacity is installed; total nameplate capacity equals 3,000 kW.

- If ***Solar-Geothermal (Combination B)*** is developed at Sites 1, 3 and/or 4 geothermal and, solar capacity is installed wind capacity is not developed; total nameplate capacity equals 3,000 kW.

Notably both combinations are projected to generate nearly equal levels of Net Metered energy; however their annual capacity factors[3] differ substantially. This difference results from the embedded proportions of non-variable geothermal energy versus variable wind and solar energy.

## A. TECHNOLOGY OPTIONS

### WIND RESOURCES

In general, siting constraints imposed on larger Wind Energy Conversion System (WECS) arrays include the following:

- Wind conditions (statistic data concerning wind speed and wind direction)
- Topography: the site needs to be favorable, preferably with an extensive crest line and associated swale geometry
- Accessibility (existing roads)
- Environmental influence of the turbine array (e.g. shadow flickering, noise emission, RF interference, visual impact, water requirement)
- Distances between the individual turbines in an array
- Adequate transmission capacity is needed to inject wind power from the plant to the grid

San Ysidro Substation consists of two parcels that could be developed: acreage adjacent to the San Ysidro substation and a narrow crest line along White Mesa's western escarpment. Only Site 3's crest line received a "Favorable" feasibility rating for turbine siting, based on the six siting criteria. Differences in terrain, prevailing wind azimuth and seasonal wind speeds are the major factors to be considered in choosing sites for development. Site 1 offers marginal wind resources to support operation of turbine arrays. For many hours of the year, Site 1 can be classified as offering mid-range NREL Class 3 winds[4], with a substantial portion of hours during spring months possibly exceeding this level. Site 3 can be classified as offering NREL low-range Class 4 winds, with a minor portion of hours during spring months possibly exceeding this level. Turbulence U values have not been estimated, the degree to which wind energy can be effectively captured on the upper distribution still needs to be characterized.

Due to metering duration and level of accessible detail provided by the Duke Energy - Mesa Prieta dataset[5], the estimated 10-to-80 and 50-to-80 meter multipliers at lower bound is assumed for the height extrapolation; it is offered mainly for conservatism. Estimated seasonal average wind speeds obtained from this analysis are tabulated in Table 4.B.

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[3] Estimated capacity factors are Combination A, 55%; Combination B, 40% capacity factor equals actual energy generated divided by maximum energy potentially generated based on nameplate ratings; a lower capacity factor plant may require higher levels of firming to reduce variability, which incurs higher operating cost.

[4] Class 4 or greater are generally considered to be suitable for most wind turbine applications. Class 3 areas are potentially suitable for wind energy development using tall (e.g., 50 m hub height) turbines relative to blade span. Class 2 areas are marginal.

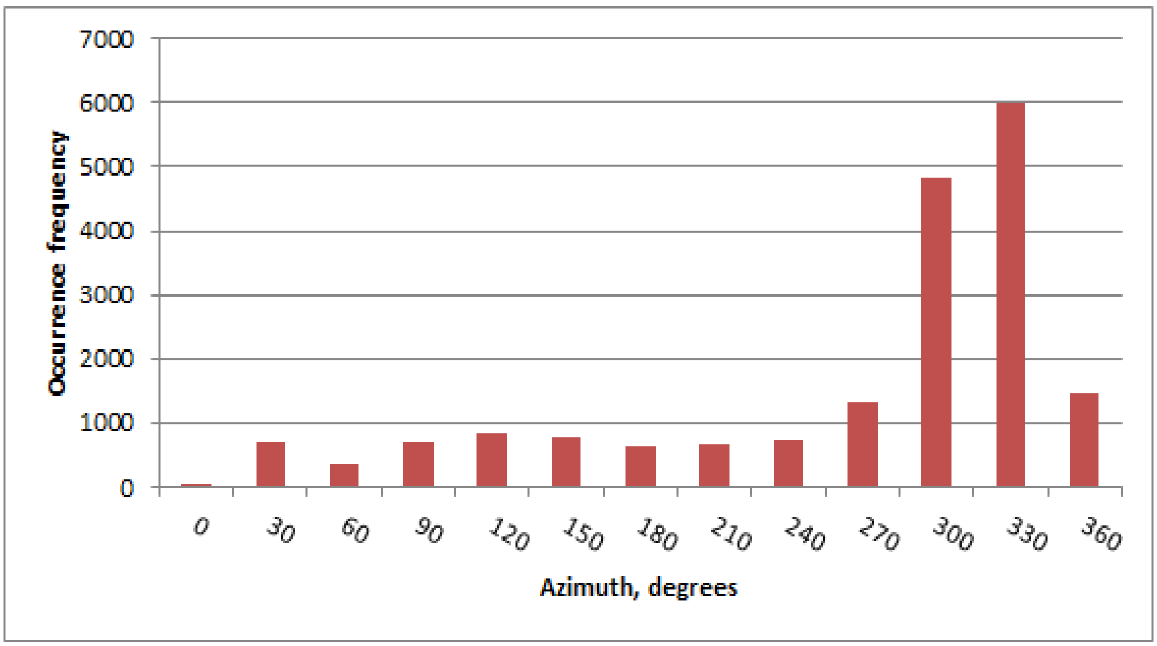
[5] Metered at Mesa Prieta. Collected by Duke Energy LLC. a multi-year dataset collected at Pueblo of Zia between October 2008 and September 2010. Wind speed and direction was metered at 10, 31 and 50 meters.

**Table 4.B. Estimated Seasonal Average Wind speeds: POZ Sites 1, 3**

| Period | Dates | Days | Site 1: Mph; M/s | Site 3: Mph; M/s |
|---|---|---|---|---|
| Spring | 03/01/09 to 05/31/09 | 93 | 14.1; 6.3 | 15.1; 6.8 |
| Summer | 06/01/09 to 08/31/09 | 92 | 10.5;4.7 | 16.9; 7.6 |
| Fall | 09/01/09 to 11/31/09 | 91 | 11.3; 5.1 | 14.9; 6.7 |
| Winter | 12/01/09 to 02/28/09 | 90 | 13.3; 6.0 | 13.8 ; 6.2 |

Table 4.B indicates a moderately variable average wind speed is likely during all seasons, with higher winds likely to occur during spring months. Figure 4.2 displays a histogram summary of the observed azimuthal wind pattern at POZ's Tribal Office.

**Figure 4.2. Summary of Observed Wind Azimuth**




A data series collected at POZ's Tribal Offices from November, 2012 to June, 2013 additionally indicates wind direction trends reliably along northwest azimuths (300-330 degrees) with some increasing scatter observed in transition months of April-June.

## SOLAR RESOURCES

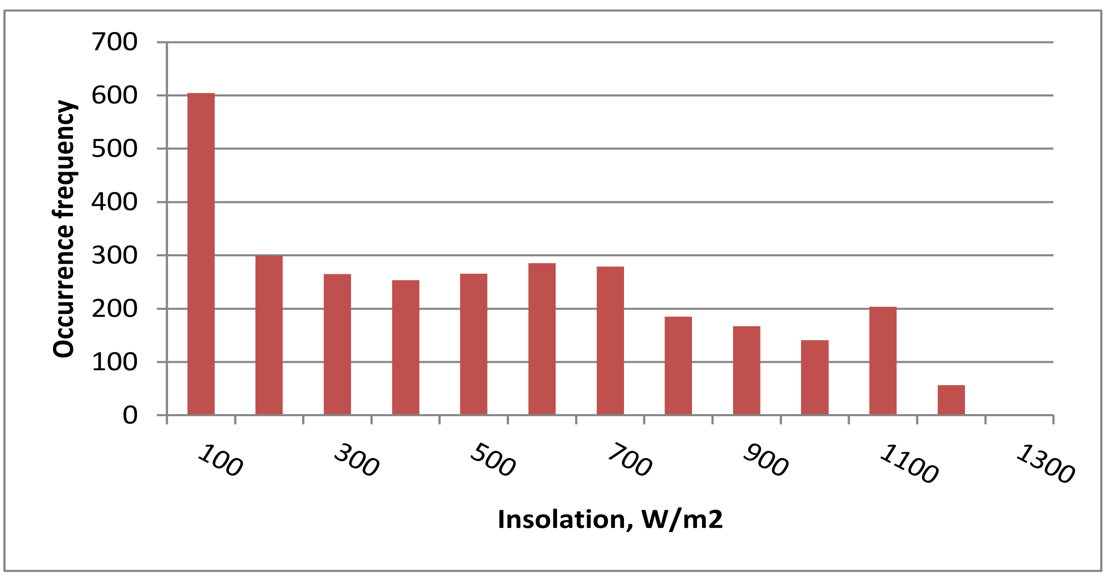
In general, siting constraints imposed on larger solar PV arrays include the following:

- Solar conditions (statistical data concerning daily and seasonal insolation)
- Topography: the site needs to be favorable, preferably unobstructed south facing location offering tilt equal to latitude minus 10 degrees as a good compromise tilt angle; Accessibility (existing roads)
- Avoid excessive wind loading; design for anchoring
- Environmental influence of the array (e.g. solar glare, grading and compaction of terrain, erosion, water requirement)
- Spacing the rows of solar panels to maximize energy harvest while preventing shading; inter-row separation should be about 2.5 times the row height
- Adequate transmission capacity is needed to inject solar power from the plant to the grid

All POZ solar PV sites received a “Favorable” feasibility rating, based on the six siting criteria. Differences in terrain, JMEC interconnection and wind loading are the major factors to be considered in choosing sites for development. No significant differences in ambient solar insolation levels are expected among these sites.

POZ offers sufficient solar resources to support operation of solar photovoltaic arrays. Figure 4.3. displays metered insolation recorded from November, 2012 to July, 2013.

**Figure 4.3. Histogram Summary of Metered Solar Insolation at Zia Tribal Offices**



This data series indicates that development sites at POZ potentially capture on average from 3.2 $kWh/m^2$ per day in December to 8.6 $kWh/m^2$ per day in June. A sample of solar data from this metering site is summarized in Table 4.C. below:

**Table 4.C. Binned Average Insolation: POZ Tribal Offices**

| Insolation Bin, $W/m^2$ | Hours in Range | Percent of Time in Range | Bin Average, $W/m^2$ | Standard Deviation, $W/m^2$ |
|---|---|---|---|---|
| >0-500 | 1,690 | 56.2 | 201 | 159 |
| >500-750 | 665 | 22.1 | 618 | 68 |
| >750-1,000 | 390 | 13.1 | 870 | 71 |
| >1,000 | 261 | 8.7 | 1,071 | 42 |

POZ's metered data indicates an average insolation of 510 $W/m^2$ was recorded over 3,007 daytime hours. Yearly electric output produced by a 4,000 kW array is estimated to equal or exceed 6,180 Mega-watt hours (MWh). PV array performance is largely proportional to the solar radiation received, which may vary from the long- term average by 30% monthly and 10% yearly. This data is based on long- term monthly values reported by NREL. Energy production values are valid only for crystalline silicon PV systems.

Up to 3,000 racks of solar cell panels[6] are proposed for installation at Site 3. The solar array is oriented approximately SW-NE, with all panels oriented towards due south. The plant occupies approximately 20 acres. The tie-in consists of a 24.9 kV step up station with DC to AC inverters (STA 4), connecting to a tap pole structure on JMEC's distribution line.

At Site 4, the plant extends along an existing JMEC line corridor for 2,700 feet and requires installation of 750 racks of solar cell panels. The plant tie-in consists of a 24.9 kV step up tie-in station including DC-AC inverters, connecting to the existing pole termination near the proposed primary development site at Zia Enterprise Zone ZEZ.

See Appendix C discussion of the likely range of monthly solar energy capture at POZ.

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[6] 240 watt crystalline silicon modules per panel with DC to AC conversion efficiency of 77% which provides 3,080 kW of AC power injected to JMEC's tie-in during hours of peak insolation.

Geothermal Power Plants can be divided into three categories 1) Steam, 2) Flash and 3) Binary. The categories exist because geothermal resources are not all created equal. A geothermal steam plant requires steam under pressure. The steam is fed directly into a turbine and power is produced. This type of resource is the least expensive to develop. The geysers in California are the best example of geothermal steam power plants. Minimum requirements for a steam plant are a gathering system (wells and pipe) for the steam and a turbine/generator set to produce power. Figure 4.4 shows the major components of a geothermal steam power plant. Note that this plant has a cooling tower, which is now included in Geothermal Steam Power Plants, so the steam can be condensed and re-injected into the reservoir. The cooling tower also helps lower the exhaust pressure at the turbine exit, which causes the turbine to make more power. The injection of the condensed steam back into the reservoir prolongs the life of the reservoir by recycling the fluid used to collect the heat.

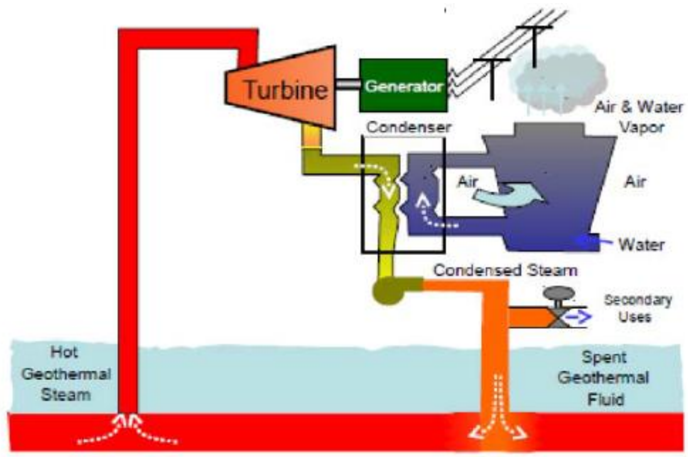


**Figure 4.4 Geothermal Steam Power Plant**

The next category of geothermal power plant is the Flash Plant, depicted in Figure 4.5. A flash plant requires a geothermal resource at 350°F or greater. The hot high pressure liquid is put in a "flash" tank where the pressure is reduced and some of the liquid boils off to steam. The steam is separated from the liquid (steam rises to the top and the liquid water remains on the bottom) and is used to spin a turbine and make shaft power. Obviously the steam from a flash plant is greatly reduced in mass flow as compared to the total flow and as such flash plants are typically smaller than steam plants. In order to get a sufficient fraction of steam to economically support a flash plant a resource temperature of 350°F is generally required. The minimal flash plant requires the addition of a steam separator to the before mentioned steam plant. Flash plants can also be found in the Geysers.

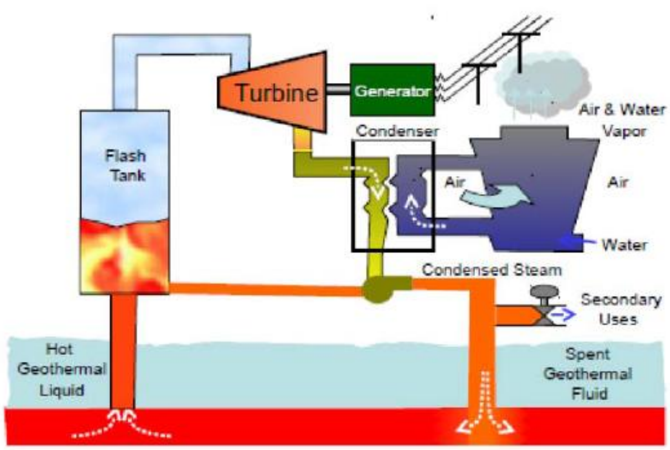


**Figure 4.5. Geothermal Flash Power Plant**

The last type of geothermal power plant, a binary plant, is a power plant that transfers the thermal energy of the geothermal fluid to another working fluid (Iso-propane, Iso-pentane, R245fa, R134a, etc.) that boils at a temperature lower than water. This second working fluid (the binary fluid) is boiled to a vapor that is used in the plant to produce power. The internal parts of the binary power plant are the same as for a steam power plant; they just use a different working fluid. A Binary Geothermal Plant is depicted in Figure 4.6.

A binary power plant has the same type machines (turbines, pumps, fans, generators) as the other type power plants. However, the binary fluid rather than water is used inside the power plant machines. Binary plants have become much more popular and widespread in the last decade. Although binary plants are more expensive than steam or flash plants, they are very similar to large vapor compression refrigeration machines and can be used on resource temperatures significantly less than the boiling point of water at atmospheric conditions.

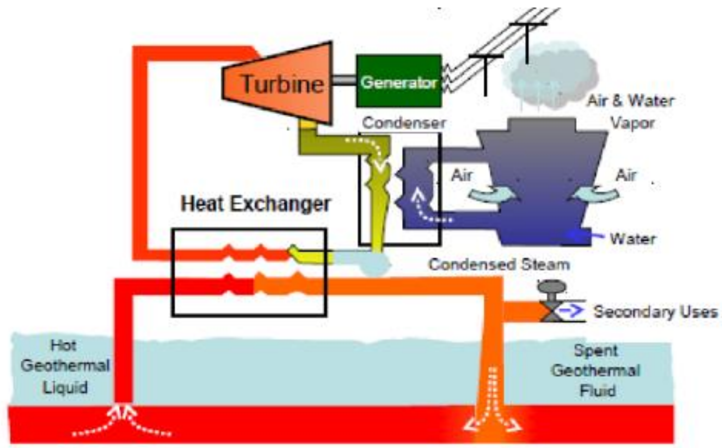

**Figure 4.6 Geothermal Binary Power Plant**

Binary geothermal power plants operate in a cycle. Figure 4.6. illustrates the major parts of the plant. The geothermal fluid heats the working fluid in a heat exchanger, which vaporizes under pressure. This heat exchanger is designed to withstand the corrosive nature of geothermal fluids and isolates the rest of the power plant from the geothermal fluid. One might also call the heat exchanger a boiler, as it serves the same function as a boiler in a traditional fossil fueled power plant. The high pressure high temperature vapor exits the heat exchanger and expands through the turbine which produces shaft power that spins a generator and produces electric power. When the vapor exits the turbine its pressure and temperature have been considerably reduced. Now the vapor is condensed back to a liquid. This is done via a cooling tower (normally by evaporating water). When the working fluid exits the cooling tower it is a low pressure and mild temperature liquid (about 60-90$^{o}$F). Then a pump pressurizes the liquid. The pressurized fluid is then heated with the geothermal fluid and process for the working fluid continues in this cycle.

The geothermal fluid is pumped from the production well to the heat exchanger (boiler) and then injected back into the geothermal reservoir where it maintains the pressure on the geothermal reservoir and is eventually reheated by the geothermal resource. While in the heat exchanger the geothermal fluid transfers some of its thermal energy to the working fluid, the two fluids do not mix and are not contaminated in any way by this process. In some cases the total dissolved solids in the geothermal fluid might limit how much the temperature of the geothermal fluid can be reduced to minimize precipitants from forming inside the heat exchanger. The spent geothermal fluid might also be sent to a secondary application to further use its remaining thermal energy, before the geothermal fluid is returned to the reservoir. What makes geothermal a sustainable resource is the heat from the earth is continually heating the water. When harnessed in harmony with Earth's natural heat, these systems can last for centuries and beyond.  The oldest geothermal power plant is in Italy and has been operating for more than a century.

Currently a binary power plant operates in Chena Hot Springs, AK that uses 167°F source water and 38°F cooling water.  The combination of cooling water and very expensive power prices make the Chena Hot Springs power plant economically feasible.  While one could theoretically build a geothermal binary power plant with a geothermal resource only slightly warmer than ambient temperature, the economics are not favorable.  Lower temperatures mean lower temperature differences (and pressures) between the working fluid and the geothermal source fluid and this requires larger and more expensive turbines and heat exchangers.  Although Binary Power Plants are more expensive than Steam or Flash Plants they require less maintenance since only the heat exchanger is exposed to the geothermal fluid.  The source of maintenance headache for steam and flash plants is the geothermal fluid that can be very corrosive and require special very expensive metal and metal treatments.  A binary power plant could be used on any geothermal resource of sufficient temperature to produce power, whereas the other types of power plants require either steam or a temperature of 350°F or higher.  Hence binary power plants have a more universal application.

Currently there are 43 Geothermal Binary power plants operating in the United States, with a nameplate capacity of 733 MWs.  These power plants range in size from the 280 kW plant at the Oregon Institute of Technology to several power plants over 40 MWs in size.  The first of these plants date to 1984 and during the last decade more than 400 MWs have been added.  The widespread application over several decades indicates a technology that has been proven and is in a state of application.  These plants are modular, go up very quickly after the geothermal field is proven and provide many years of reliable service.  Since the power plants operate at reduced temperature and pressure they tend to operate unattended and the machines last longer than other power plants where the metallurgic properties of materials are pushed to a greater degree.  Many of the plants are owned by utility companies or independent power producers and most of the plants are connected directly to an electrical grid.  Utilities like geothermal power because it's both "renewable" and baseload.  So the output is more predictable than other renewable forms of electricity and a geothermal plant of the same nameplate capacity will produce 3-4 times the output of a similar nameplate capacity wind or solar plant.  The increased output is valuable to utilities in meeting the required amount of electricity from renewable resources.  A complete listing of the 43 Plants in chronological order of start year is included at Appendix L.  The increasing number of binary plants is obvious since 1984.  This is due to the modular design and the fact that binary power plants can operate at much lower resource temperatures.

Development of the geothermal resource at the Pueblo of Zia supports the goals of the Pueblo by providing a reliable indigenous source of continuous power and thermal energy that is in harmony with the values of the Pueblo. Fully developed the geothermal resource would support the internal energy needs of the Pueblo and generate economic activity through the sale of electric energy and greenhouse or aquaculture products. Local jobs would be created through the electric power and secondary uses (greenhouse, aquaculture, direct heating). Most of the secondary jobs would build on skills innate to the Pueblo, such as farming, aquaculture, and direct heating. Through geothermal development, Zia would become a net exporter of energy and establish the Pueblo as energy independent. Developing this resource also emulates a core Zia value of living within a sustainable framework that supports natural processes, protects and prolongs the earth for future generations.

# V. TOP LEVEL DESCRIPTION OF POZ SITES 1-4

## A. SITE 1 - ROBERTS TOWER

### WIND RESOURCES – 6,000 KW WECS ARRAY

In terms of topography, Site 1 offers classic ridge-swale units which consist of bowl shaped depressions oriented, rising at gradients of approximately 20-40 feet per mile to broad crest lines[7]. Because this geometry can create potential acceleration of winds[8], a catalog of the approximate extent of each major swale unit was created. See Appendix D for a listing of ridge-swale units observed at Site 1[9].

Figure 5.1. below shows the proposed siting of three WECS turbines at Site 1.
An existing JMEC 24.9 kV distribution service drop is located 1.0 mile northeast of the proposed turbine tie-in location, as shown on Figure 5.1. The tie consists of a 24.9 kV step up station (STA 1), connecting to an existing pole termination at Site 1.

A potential issue related to operation of turbines at Site 1 is Radio Frequency (RF) interference. Antennas mounted at Roberts Tower are used for television, cell and microwave communications. Rotating turbine blade surfaces have created well-documented instances of multi-path RF distortion, fading and other forms of interference in similar situations. A mitigation strategy could involve use of radar absorbent coatings[10] on the blades which substantially prevents reflections but also reduces turbine efficiency. This issue should be evaluated during discussions with developers.

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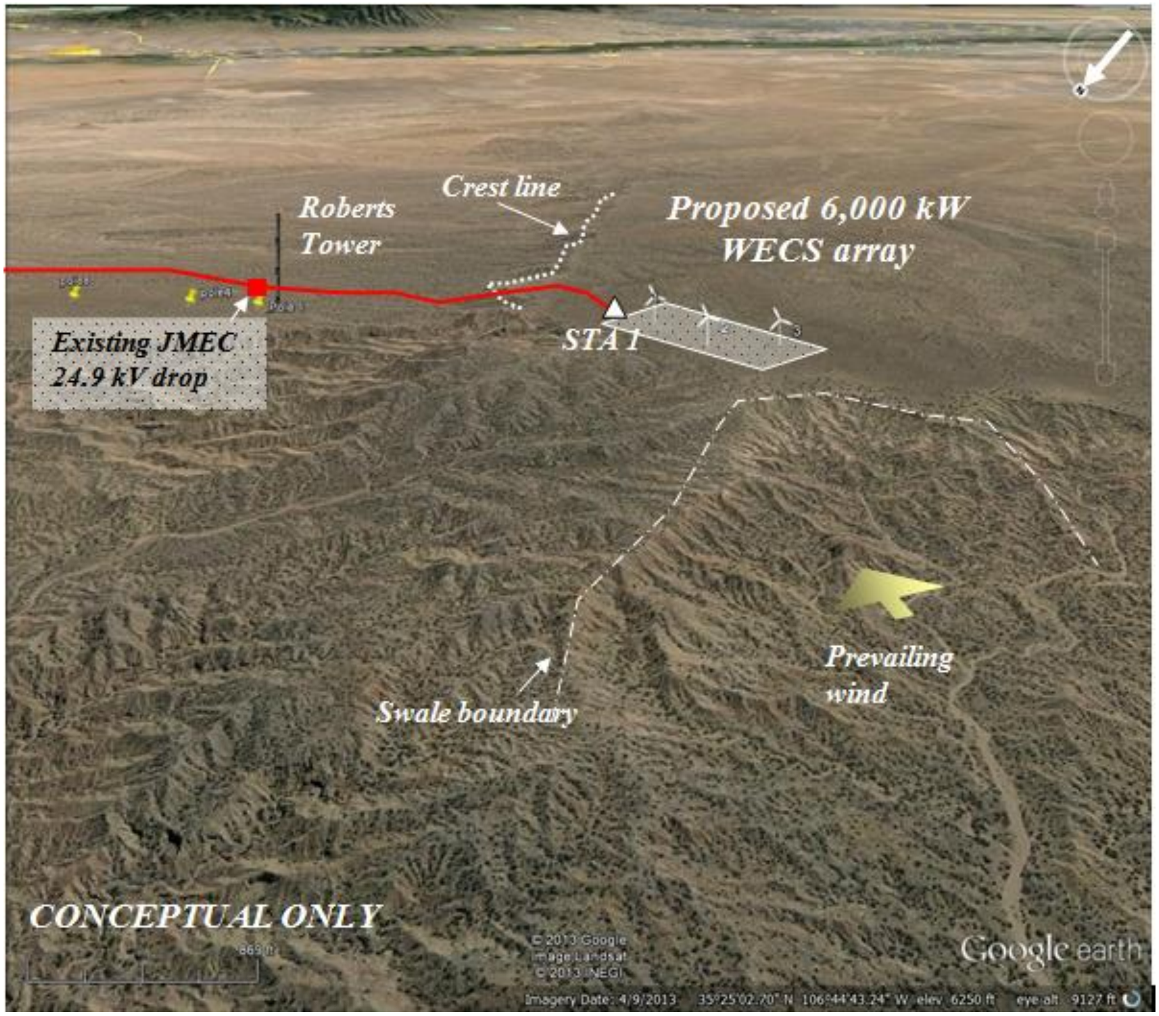
[7] Swale path dimensions: width 4,470 feet, baseline 3,630 feet, rise along baseline 530 feet.

[8] Due to up-slope compression of laminar wind flow; the geometry of swales oriented along Pueblo of Zia's prevailing wind directions is of economic interest for siting WECS arrays. Accelerations of wind speeds of 10% or more are possible depending on swale geometry.

[9] Siting turbines at the crest line may result in exposure to slope turbulence which could create a potentially damaging operating environment; therefore an alternate siting scheme is proposed.

[10] Radar-absorbent material, or RAM, is a class of materials used to reduce or eliminate RF interference; One of the most commonly known types of RAM is iron ball paint. It contains tiny spheres coated with carbonyl iron or ferrite.

**Figure 5.1. Wind WECS Array (Site 1)**



## Site 1: WECS Siting Issues

Two turbine sizes are listed for comparison, 1.6 MW and 2.0 MW which are mounted at hub heights of roughly 260 and 320 feet respectively.

**Table 5.A. WECS Array Size Parameters**

| Size Parameter | Plant: 1.6 MW Turbine | Plant: 2.0 MW Turbine |
|---|---|---|
| Total acres | 66 | 75 |
| Width E-W feet | 3,030 | 3,230 |
| Length N-S feet | 760 | 810 |
| No. Turbines | 3 @5 rotor diameters | 3 @ 5 rotor diameters |
| Daily output rating[11] | 4.5 MW (10.8 MWh) | 6.0 MW (14.4 MWh) |
| Water usage Gallons/year[12] | 20,800 | 25,600 |

For applications of this technology, turbines are sited at least four rotor diameters apart in the plane perpendicular to the prevailing wind direction, and at least six rotor diameters apart in the plane parallel to the prevailing wind direction. This prevents reduced wind speeds and increased turbulence due to adjacent turbines. Turbines are also placed at a distance twenty or more times the height of any man-made structure or vegetation upwind of the array. Turbulent wind flow created by a structure generally extends vertically to twice the height of the structure. It is important to avoid areas of steep slope. Wind on steep slopes tends to be turbulent and has a vertical component that can affect the turbine. Also, the construction costs for a steep slope are greatly increased. On ridgelines and hilltops, turbines are setback from the edge to avoid the impacts of the vertical component of the wind.

## SOLAR RESOURCES – 1,000 KW SOLAR PV ARRAY

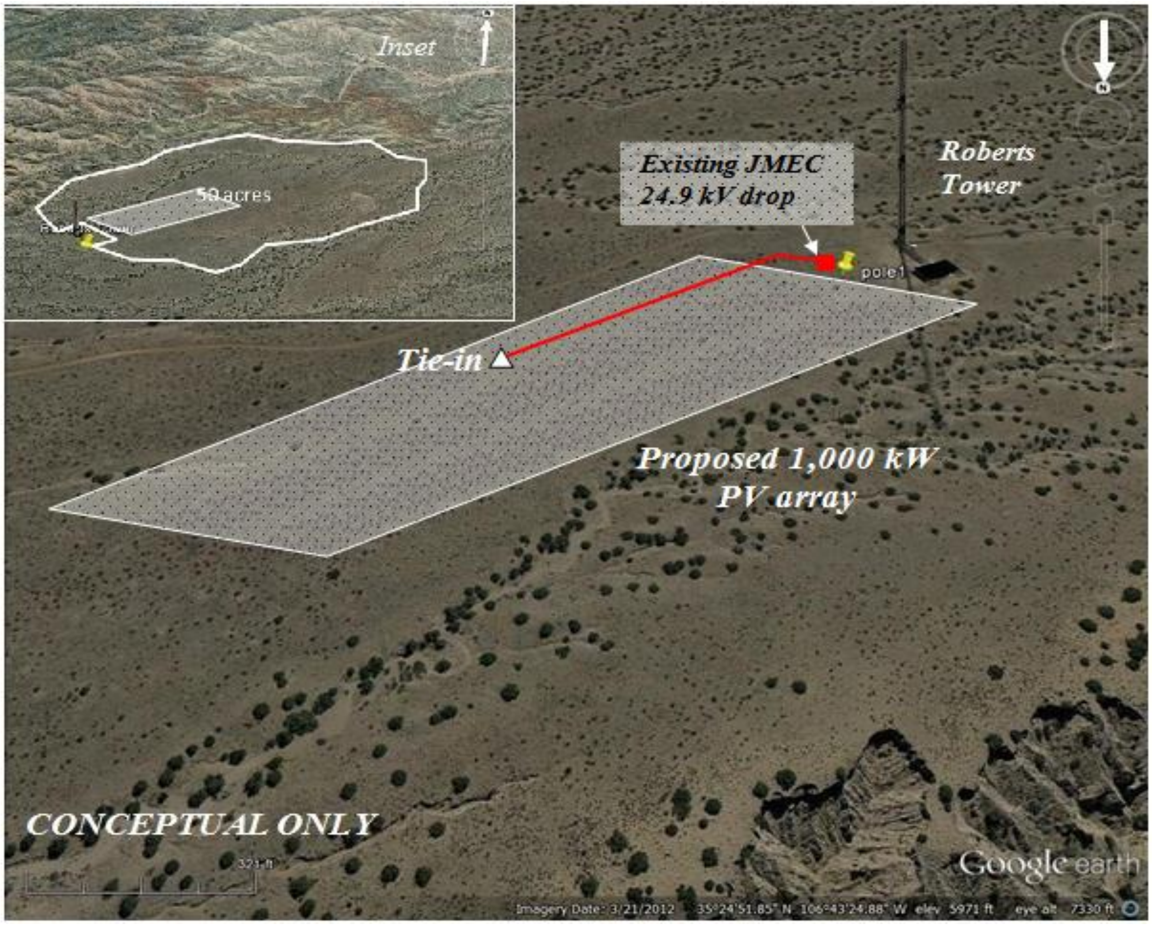
The inset below displays a view of the entire developable area which extends in a northeasterly direction from Site 1. The solar array is oriented approximately SW-NE, with all panels oriented towards due south. The plant extends down slope from JMEC's first pole near Roberts Tower for 2,700 feet and requires installation of 750 racks of solar cell panels[13]. A larger array cannot be economically sited at this location due to JMEC line capacity limitations.

The plant tie-in consists of a 24.9 kV step up tie-in station including DC-AC inverters, connecting to the existing pole termination at Roberts Tower.

Figure 5.2. below provides an overview of the proposed Solar PV array at Site 1.

[11] Turbine capacity based on GE'S 1.6 MW 1.6-77 WTG turbine, cut-in loss of 7.4% and forced outage rate of 3%.
[12] Assumes four blade cleanings per year are required to maintain array efficiency.
[13] 240 watt crystalline silicon SiC modules per panel with DC to AC conversion efficiency of 77% which provides 770 kW of AC power injected to JMEC's tie-in during hours of peak insolation.

**Figure 5.2. Solar PV Array (Site 1)**




## GEOTHERMAL ELECTRIC POWER POTENTIAL

The geothermal resource temperature at Site 1 is estimated at 280°F. At a flow rate of 1,250 GPM using standard Organic Rankine Cycle (ORC) Technology, about 4.6 MWs of power can be made. The most appropriate power plant for this temperature is a binary power plant. Binary Power Plants are similar to Steam Power Plants except that binary plants don't make steam, rather they use a secondary working fluid often called a refrigerant that follows the same process as water does in a combustion power plant; just at different temperatures and pressures.

**Figure 5.3. Geothermal Electric Power Plant (Site 1)**

The ORC typically uses a geothermal resource between 190 and 350°F. The geothermal resource heats a secondary working fluid in a heat exchanger and is then re-injected into the ground or used for some secondary process. The geothermal fluid is cooled by at least 30°F or to a temperature of 140-170°F. The amount of energy extracted by the secondary working fluid is a function of both energy availability and economics. The secondary working fluid absorbs the thermal energy in the heat exchanger from the geothermal fluid (see Figure 5.4.) and is transformed from a high pressure liquid to a high pressure vapor. In a normal power plant this is the function performed by the boiler and superheater (converting water into dry steam). The high pressure organic vapor then goes to the turbine where it pushes on the turbine blades to make shaft power. The shaft power is converted into electric energy via the generator and transmitted to the electric grid.

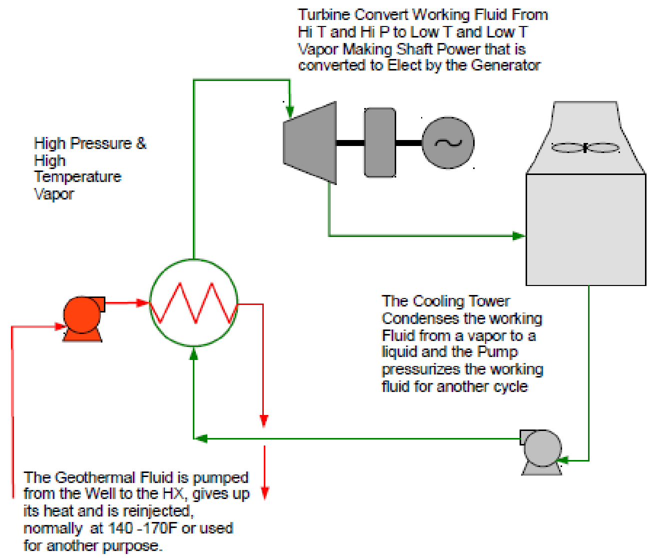



**Figure 5.4. Typical Geothermal Power Plant**

After exiting the turbine the organic fluid is at a lower pressure and temperature but still mostly in a vapor state. This vapor is then condensed back into a liquid using a cooling tower, which can be a wet or dry process. A wet process is shown in Figure 5.4. because it is more typical. After the fluid is condensed it enters a pump where its pressure is increased and it is ready to enter the heat exchanger where it absorbs more thermal energy, transforms into a vapor and repeats the cycle.

Water boils at 212°F at atmospheric pressure whereas R134a, a typical secondary working fluid boils at -15°F at atmospheric pressure. It is the boiling/condensing temperatures and pressures and other properties of the secondary working fluids that allow engineers to utilize relatively low temperature geothermal resources to make power. One needs about 125°F of temperature difference between the hot resource and cold resource to which heat is rejected to convert geothermal energy to electric power economically. The low temperature resource is usually the wet bulb temperature of the location (55-65°F). Any amount of temperature difference, no matter how small could be used to make power, however the cost of such an operation would make the power too expensive. Figure 5.5., shows the thermal efficiency that could be achieved theoretically given a resource hot temperature as shown on the horizontal axis and a cold or rejection temperature at 60°F. Although at temperatures around 2,000°F the efficiency approaches 80%, real power plants do not operate beyond about

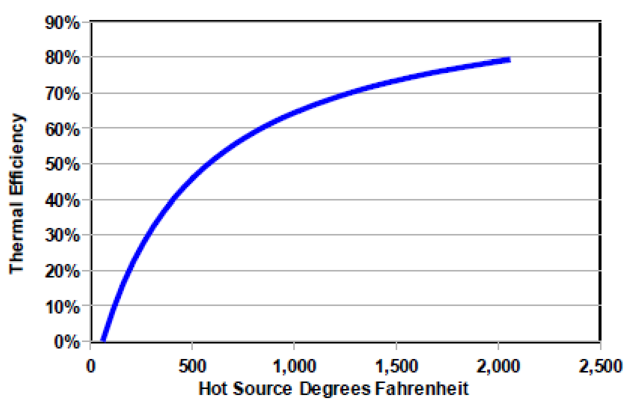



**Figure 5.5. Carnot or Theoretical Thermal Efficiency for A 60°F Rejection Temperature**

55%. The most efficient power plants use cascaded cycles with Gas Turbines as topping cycles and standard Rankine Cycles as bottoming cycles. This arrangement assures energy is added to the power cycle at the highest possible temperature and rejected at the lowest possible temperature, which is what one has to do to build the most efficient thermal power cycle. Temperature is to thermal power plants what the elevation head is to hydro power plants. The analogy is that one adds water at the highest possible elevation and rejects water at the lowest elevation and this provides a maximum head difference for making power as the water falls from a high elevation to a low elevation, just like the thermal energy "falls" from a higher to a lower temperature. In general lower temperature binary power plants can make about 20-50% of the power available by the Carnot Cycle. When the Carnot Efficiency Curve is shown in more detail for the temperatures available from typical geothermal resources (less than 350°F) the theoretical efficiencies are low, Figure 5.6. is a blow up of the Carnot Efficiency Curve for temperatures less than 350°F.

Most geothermal power plants operate at thermal efficiencies of less than 18%. This is not because geothermal power is less efficient, it's because the thermal energy is available at a lower temperature than other sources of thermal energy (combustion for example) and one has less available energy to convert to electric power.

For the resource expected at Site 1 at 1,250 GPM and 280°F, the Carnot Efficiency computation yields a Carnot Efficiency of 29%, a real power plant operating between 280°F and 65°F is capable of an efficiency of about 15%. Figure 5.6. is a simple ORC that could be used at Site 1.

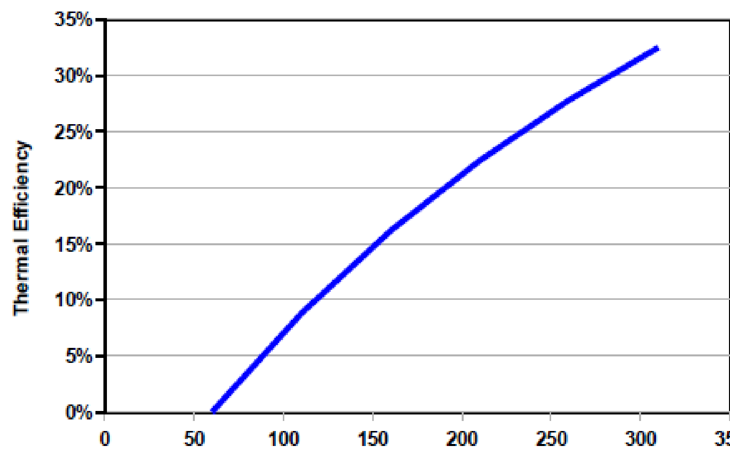


**Figure 5.6. Carnot or Theoretical Thermal Efficiency for a Hot Source less than 350°F and 60°F Rejection Temperature**

The geothermal fluid enters the cycle from the left and heats the working fluid to a vapor and is then is re-injected into the ground or used for a secondary purpose. The vapor then enters the turbine where it makes shaft power that is converted into electricity. After exiting the turbine the organic fluid, still a vapor, is condensed into a liquid. The liquid then enters the pump and is pumped to a high pressure liquid and sent to the evaporator or boiler where it absorbs the thermal energy from the geothermal resource and transforms into a vapor. This cycle is repeated indefinitely to make power.

Table 5.B. summarizes the output from a cycle of this type for Site 1.

| Parameter | Output |
|---|---|
| Geothermal Flow Rate, GPM | 1,250 GPM |
| Geothermal In Temperature | 280°F |
| Geothermal Out Temperature | 110°F |
| Working Fluid | R245fa or R134a |
| Working Fluid Hi Pressure (Pump Outlet) | 300 psia |
| Working Fluid Hi Temperature (Evaporator Out) | 255°F |
| Working Fluid Low Temperature (Cooling Tower Out) | 80°F |
| Working Fluid Low Pressure (Cooling Tower Outlet) | 24 psia |
| Power Out | 4.3 MW |
| Thermal Efficiency | 14.0% |
| Plant Cost | $27.6 Million |
| Annual Royalty Paid to POZ | $192,900 |
| Electric Revenue @ $0.080/kWH, Annual | $2.8 Million |
| Production Tax Credit, Annual | $0.71 Million |
| Production Tax Credit, New Mexico | $0 |
| Internal Rate of Return | 7.5% |

**Table 5.B. Site 1 Geothermal Output**

A more complete listing is included at Appendix H.

This simple organic Rankine cycle is profitable. The risk taken is that the resource might be deeper or have less flow and temperature than projected.

## GEOTHERMAL SOLAR COMBINED CYCLE (GSCC)

Solar Power is made with PhotoVoltaic Cells (PV) or by concentrating the Solar energy to raise the temperature of a working fluid. PhotoVoltaic Cells are not heat engines and therefore are not subject to the heat laws of thermodynamics. The best commercially available PV cells are about 15% efficient as measured by comparing the full energy in the sunlight incident to the PV surface to that amount converted to electric energy. PV could be combined with other forms of energy development in much the same way as wind energy, sharing transmission infrastructure. In fact a site in Nevada (Stillwater Geothermal Plant near Fallon, NV) has both PV and Geothermal and they do share transmission infrastructure. Since photovoltaic cells are not thermal and do not integrate with the thermal aspects of power production they will not be considered further in this report. Concentrating Solar Power (CSP) on the other hand is thermal and could be integrated with other forms of thermal power production. CSP has thermal power conversion efficiencies in the lower 30% range and the CSP market is moving towards larger plants with higher collection temperatures. We note that solar thermal power is about twice as efficient as typical geothermal power or photovoltaic.

There are several types of concentrating solar collectors, Parabolic, Fresnel Lens, Flat Plat (Towers), and Dish Collectors. The concentrating collectors focus sunlight onto smaller surfaces and multiply the energy per unit of area, similar to the way a magnifying glass works, but many times more concentrated. Generally the solar collectors have collection temperatures that start at about 700°F. The tower collectors can have a much greater collection temperature, often with the ability to exceed the temperature limits of the metal receivers. Tower collectors normally use flat mirrors focused on a receiver tower. Fresnel lens are special lens that concentrate light and achieve the same end state as other types of focus strategies. Fresnel Lens are very thin and take up little space, their cost and questionable durability have limited their use. Dish collectors are dish shaped and normally have a heat engine for each dish. Given many types of solar collection strategies our purpose is not to analyze or evaluate individual solar technologies, rather it is to pick an appropriate solar technology that can be combined with geothermal in a way that promotes both the geothermal and solar development. The obvious way to combine these technologies is to use them to heat a common working fluid that drives a power cycle.

The Parabolic Trough Collector has been in use since the early 1990s and Parabolic Trough Collectors are available from several manufacturers. Its durability, use, and performance have been validated (Prabhu, 2005 & Moss, 2010). What makes Parabolic Trough Collector and Geothermal Power suitable to integration are several factors:

1) both can use power plants that are modular;
2) the solar collection temperature is compatible with Geothermal power, in fact it can be used to boost both Solar and Geothermal Power; and,
3) most Parabolic Trough Collector plants are located in arid regions where geothermal is also located. The collection temperature of the Parabolic Trough Collector and the geothermal resource are keys to integrating the resources.

Most Parabolic Trough Collector plants today are designed for a collection temperature of 735°F, which is several hundred degrees higher than most geothermal power plants. This makes the most suitable integration a cascaded power cycle with at least two turbines. This allows the use of solar at its highest temperature for the top cycle and the geothermal to be used on the bottom cycle with waste heat from the upper cycle to boost its temperature and efficiency. Another way to integrate the two resources would be to use the solar heat to raise the temperature of the geothermal and use only a single cycle. While this would make the geothermal cycle slightly more efficient, it would also degrade the efficiency of the solar cycle. Moving high temperature energy into low temperature geothermal energy does not make more energy, rather it reduces the energy intensity of the solar (its temperature) and therefore less of the overall energy can be converted into electric power. In the power world this is called lost availability. The better way to combine the resources is to keep the solar making power at a higher temperature and use the geothermal on the lower temperature cycle to do the low temperature heating. By doing most of the low temperature heating on the bottom cycle with geothermal the solar can still be used to elevate the geothermal power cycle temperature and make more power.

This arrangement is called a Cascaded Power Cycle and a proposed cycle is shown at Figure 5.7. This cycle was modified from a cycle in the 2006 NREL report for Analyzing Using the Organic Rankine Cycle for small Parabolic Trough Collectors. The author analyzed several working fluids and combinations of cycles. The cycle chosen as best is a cascaded cycle using Toluene as a working fluid on top and Butane as the working fluid on the bottom cycle. The Top cycle has a maximum temperature and pressure of 725°F and 700 psia and the bottom cycle has a maximum temperature and pressure of 330°F and 550 psia.

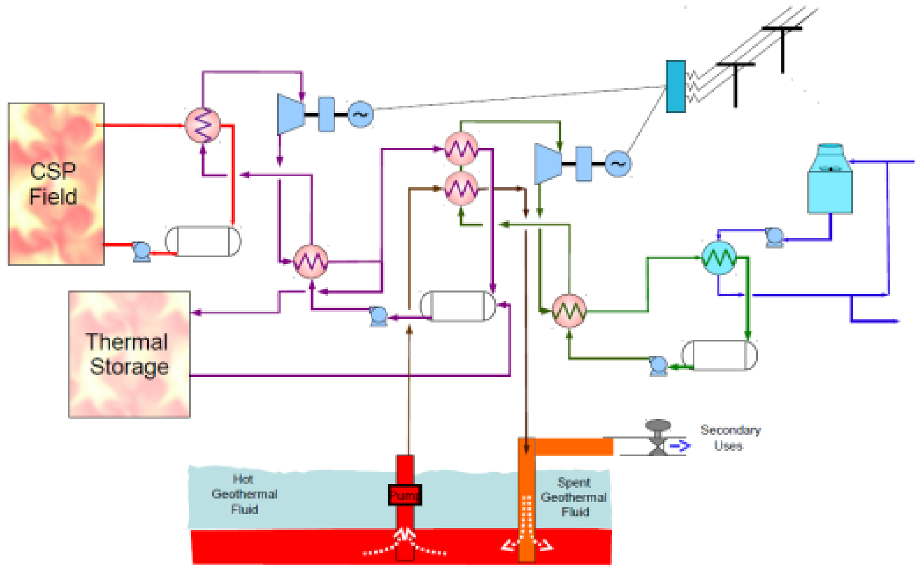


**Figure 5.7. Combined Geothermal and Solar Thermal Power Plant**

Using this cascaded power cycle, solar on top and geothermal on bottom, the overall conversion achieves efficiencies of 28%, which is a few points lower than possible but its simplicity, first cost, and lower maintenance costs make up this difference.

For the case herein, the combined plant still achieves a high efficiency and geothermal provides about two thirds of the plant output when the sun is not out. The author of the 2006 NREL study concludes that the Organic Rankine Cycle developed and used mainly at geothermal power plants, can be useful for harnessing Parabolic Trough Collector generated thermal energy. Its main advantages are the modular design, proven technology and low cost. In the work herein, the cycle is modified by adding geothermal energy to perform the heating of the lower cycle working fluid, butane, up to temperatures of 275°F, this is just over half the heating required on the lower cycle. The other half of the butane heating is provided by the Parabolic Trough Collector thermal energy. Since only half of the Parabolic Trough Collector energy is now used in the butane or lower cycle this energy is available for other purposes, specifically storage for running the lower cycle during non-sun times.

One of the serious drawbacks of solar energy is a lack of ability to produce power when the sun is not available. Typically this is addressed with storage, however many solar power plants do not have storage because of its expense. However with geothermal providing the low temperature heating portion of lower cycle, the Parabolic Trough Collector thermal energy is reduced by more than half. In this modification this energy is stored for use when the sun is not available, the storage temperature will be compatible with topping off the lower cycle. This storage strategy uses a lower storage temperature which reduces losses and since half or more of the lower cycle energy is provided by the geothermal resource the quantity of storage is also reduced. During periods when the sun is not available the stored energy is recycled through the bottom cycle, this is anticipated to occur every night and on some weather days. The bottom cycle operates the same whether it's drawing energy directly from the sun or energy that has been stored. The upper cycle does not operate when the sun is not available. This arrangement achieves two important measures, it makes power available 24/7 and uses the stored energy and geothermal energy in a way that reduces storage and improves cycle efficiency (raises the boiling temperature). This improves reliability, reduces the cost as compared to a 100% backup and improves solar economics. We note that the bottom cycle will operate at a higher efficiency than if it were only geothermal. Table 5.C. lists summary parameters from the combined Solar-Geothermal Power Cycle:

| Parameter | Output |
|---|---|
| Geothermal Flow Rate, GPM | 1,250 GPM |
| Geothermal In Temperature | 280$^{o}$F |
| Geothermal Out Temperature | 110$^{o}$F |
| High Temperature Fluid Circulated through Parabolic Trough Collector | Therminol 2 |
| Therminol 2 High Low Temperature | 735/685 |
| Working Fluid Upper Cycle/Lower Cycle | Toluene/Butane |
| Working Fluid Upper/Lower Cycle, Hi Pressure (Pump Outlet) | 755/605 psia |
| Working Fluid Hi Temperature Upper/Lower Cycle (Evaporator Out) | 725/330$^{o}$F |
| Working Fluid Low Temperature | 330/90$^{o}$F |
| Working Fluid Low Pressure Upper/Lower Cycle | 56/44 psia |
| Power Out | 14.7 MW |
| Thermal Efficiency | 22.4% |
| Plant Cost | $126.7 Million |
| Annual Royalty Paid to POZ | $740,300 |
| Electric Revenue @ $0.092/kWH | $10.6 Million |
| Production Tax Credit, Federal | $2.4 Million |
| Production Tax Credit, New Mexico | $1.9 Million |
| Internal Rate of Return | 7.5% |

**Table 5.C. Site 1, Combined Geothermal Solar Performance Summary**

A more complete listing of the Geothermal Solar Power Plant combination is included at Appendix I.

## B. SITE 2 - WARM SPRINGS

### SOLAR RESOURCES – 4,000 KW SOLAR PV ARRAY

The inset below displays a view of the entire developable area, offering construction grade terrain with 2% slope or less. An area of 100 acres is highlighted. Figure 5.7 shows the proposed siting of 3,000 racks of solar cell panels[14] at Site 2. The solar array is oriented approximately SW-NE, with all panels oriented towards due south. The plant occupies approximately 20 acres.

Given this site's location adjacent to a large dry wash on the south boundary associated with mesa drainage, an additional review of the potential for flooding is needed. Elevation contours indicate a general trend towards lower elevations from north to south which drain into the wash.
An existing Tri-State 115 kV transmission line corridor is located 0.7 mile south of the proposed array tie-in location, as shown on Figure 5.8. The tie-in consists of a 24.9 kV step up station with DC to AC inverters (STA 2), connecting to a tap pole structure on Tri-State's line.

Figure 5.8. provides an overview of the proposed PV array at Site 2.

[14] 240 watt crystalline silicon modules per panel with DC to AC conversion efficiency of 77% which provides 3,080 kW of AC power injected to JMEC's tie-in during hours of peak insolation.

**Figure 5.8. Solar PV Array (Site 2)**


## GEOTHERMAL ELECTRIC POWER POTENTIAL

The POZ Site 2 resource has a flowing spring with a measured temperature of 129°F. Estimates of maximum temperature are up to 176°F, with flows estimated at 1,500 to 2,000 gpm. Drilling depths are estimated to be 2,000 feet or less. The maximum temperature prediction is based on geochemistry and requires drilling into the source reservoir to achieve the maximum temperature. Given the low geothermal temperature predicted geothermal electric production is not likely to be economic. The possibilities are described below. We note that the integration of Solar and Geothermal is also possible at this site, however compared to Site 1, more of the low temperature heating must be done with the solar collected thermal energy. This will cause the economics of a geothermal solar combination to be financially less attractive than Site 1 since more solar heat is required and solar heat is more expensive than geothermal. At site one about half the energy (54%) for the lower pressure cycle was geo-thermally supplied, the remaining being supplied by solar-thermal energy, either from storage or direct isolation. At site two the maximum expected temperature is only 176°F versus the 280°F at Site 1, this lower temperature means that only 18% of the thermal energy could be supplied from the geothermal source, which will place more dependence on solar thermal energy which is significantly more expensive and puts this option beyond economic consideration. Therefore in the interest of being concise a geothermal and solar option for Site 2 is not presented.

**Figure 5.9. Geothermal Electric Power Plant (Sites 2 & 4)**


Since the predicted maximum temperature of the Site 2 Resource is 176°F, a binary plant should be considered. The cold sink temperature at Site 2 is the wet bulb temperature, 60°F. The wet bulb temperature provides a temperature differential between the hot resource and the cold sink (the atmosphere, or wet bulb temperature) of about 176-60 = 116°F. This is very marginal for electric power production and will require larger than normal heat exchangers and turbine blades. To illustrate the reduced potential consider the small geothermal power plant in Klamath Falls, Oregon commissioned in 2010 at Oregon Institute of Technology (OIT). This small power plant is a reasonable estimate of the power that might be available from a low temperature resource such as the one at Site 2. The OIT resource temperature is 197°F and it rejects to a 70°F wet bulb, making its temperature differential 127°F, between the geothermal source fluid and the heat sink or cold source. The flow rates of the geothermal resource at OIT are 624 GPM and cooling water at 1309 GPM. The OIT plant, a nominal 280 kW Pure Cycle Unit by Pratt and Whitney, nets about 226 kW of power, not considering the well pumps. When the well pumps are considered (two for a total 148 kW) the net power drops to 78 kW. The thermal efficiency of the OIT system is reported to be about 8%, however this 8% number does not account for the two well pumps. When the well pumps are deducted from the net power the thermal efficiency drops to 2.8%. These relatively high flow rates and low temperatures cause most of the power produced to be consumed in the power production process. The overall efficiency of the OIT resource considering only electric production is very low at 2.8%, however when one considers the secondary uses of the geothermal fluid for direct heating the overall efficiency jumps to 83% making the total application economically feasible. Indeed OIT has saved hundreds of thousands of dollars through use of the direct heat. The point here is to illustrate that a power system using an ORC machine cannot expect to achieve a thermal efficiency much better than what OIT has demonstrated and that other uses of the geothermal fluid might be used to make development economically attractive. The POZ may want to consider direct uses for agriculture or aquaculture to help this site achieve economic viability.

The Binary Geothermal Power Plant at OIT achieves an efficiency of 8% without considering the well pumps. Since the water at Site two flows naturally we shall assume that only minimal head is required for pumping the water. With a total pumping power of 122 kW (which assumes 17 feet of head at the well head versus 300' for the OIT wells), the efficiency of converting the thermal energy to electric energy is 2.5%, which is optimistic considering the temperature differential between the geothermal resource and the heat sink at Site 2 is more than 20 degrees Fahrenheit less than at OIT.

A computer program was used with these parameters to calculate the power output and compute flow rates of water. The table below summarizes the output:

| Property | Value/Units |
|---|---|
| Geothermal fluid Flow Rate, GPM | 1,500 GPM |
| Brine Temperature Hot | 176°F |
| Brine Temperature Rejected | 110°F |
| Power Plant Efficiency | 2.5% |
| Gross Power Plant Rating | 529 kW |
| Power Plant Output | 358 kW |
| Electric Energy Produced Per Year | 2,672 MWH |
| Number of Days Plant Assumed Down for Maintenance/Outages | 17 Days |
| Thermal Efficiency | 2.5% |
| Plant Cost | $5.4 Million |
| Annual Royalty Paid to POZ | $41,700 |
| Electric Revenue @ $0.220/kWH | $596 Thousand |
| Production Tax Credit, Federal | $58 Thousand |
| Production Tax Credit, New Mexico | $ |
| Internal Rate of Return | 7.5% |

**Table 5.D. Site 2, POZ Geothermal Electric Performance Summary**

Plant power output estimates take into consideration the local weather, and assume cooling water is available. A transmission loss of 4.5% is also assumed. The computer output is presented in more detail at Appendix J.

The largest single cost factor in the estimate is the cost of drilling the production and injection well pair at 2 million dollars. This is followed by the cost of the power plant equipment at $1.2 million. These two costs are the preponderance of the investment. The drilling cost is more at risk, since one could drill and fail to find the resource, but one would not start power plant procurement without first confirming the resource through drilling. If the resource is located at a more modest depth, then the drilling costs will be reduced. The geologic information is not such that a depth can be predicted with reasonable confidence; we therefore assume a reasonable case depth and base the economic estimate on a drilling cost of 2 million dollars. We expect to drill two wells, one producer and one injector. Estimates for the cost of the power plant equipment is based on recent bids from manufacturers of binary equipment. Only a few competitors are making binary power plant equipment. The best price for a packaged power plant (including cooling tower, electrical generation equipment, and interface controls for the power plant and electric grid connection) is about $3.1 million per MW. The 3.1 million per MW is based on a higher temperature than the resource we expect at site two, so in this estimate a cost close to what OIT paid for its equipment was used to estimate the cost of power plant equipment for this resource.  A higher temperature would make the cost per MW decrease and a lower temperature would cause the cost per MW to increase.

The binary equipment selected for this application operates independently of operator interface, would have the ability to shut down when conditions require it, and could also automatically start itself.  The major maintenance function is performed routinely, and that is to check on the equipment via electronic monitoring and physically checking the equipment.  Annual maintenance depends on the chemistry of the produced water and involves the critical parts of the plant such as the heat exchanger, the bearings, and heat rejection equipment.  Annual maintenance is scheduled and usually done in a one or two week outage, during times when clients can be served from other sources of generation.

The estimate (see Appendix J) is at $10,293 per kW for developing geothermal electric power at Zia Site 2.  As an example the plant at Oregon Institute of Technology in Klamath Falls cost approximately $4,400 per kW, however this cost included only power plant equipment and installation, as the wells, well pumps and other infrastructure were already in place.  When only the work associated with the power plant equipment (no well work, no well testing, no transmission), then the cost at POZ Site 2 is $4,800 per kW which is within 9% of the OIT cost.  Given this installation was three years in the past, this seems like a reasonable estimation.  The clear risk at Site 2 is the drilling cost.

## C. SITE 3 - SAN YSIDRO SUBSTATION/WHITE MESA

### WIND RESOURCES – 6,000 KW WECS ARRAY

In terms of topography, Site 3 offers an abrupt mesa boundary, rising at gradients of approximately 600 feet per mile to a narrow crest line. This site is co-located within an operating gypsum mine, which creates additional constraints on siting. Notably turbine setbacks will be limited to 400 feet or less. Due to potential upslope turbulence from the mesa scarp, setbacks of at least twice the average rise will be required to avoid creating a damaging operating environment.

Figure 5.10. shows the proposed siting of three WECS turbines at Site 3.

**Figure 5.10. Wind WECS Array (Site 3)**


A broad swale formation[15] is oriented along prevailing wind azimuth at Site 3. This geometry can create potential acceleration of winds; see Appendix D for a listing of ridge-swale units observed at Site 3.

JMEC's 24.9 kV distribution line extension would be located along a 2.2 mile corridor southeast of the proposed turbine tie-in location, as shown on Figure 5.8. The tie consists of a 24.9 kV step up station (STA 3), connecting to an existing pole termination at San Ysidro substation.

[15] Swale path dimensions: width 4,470 feet, baseline 3,630 feet, rise along baseline 530 feet.

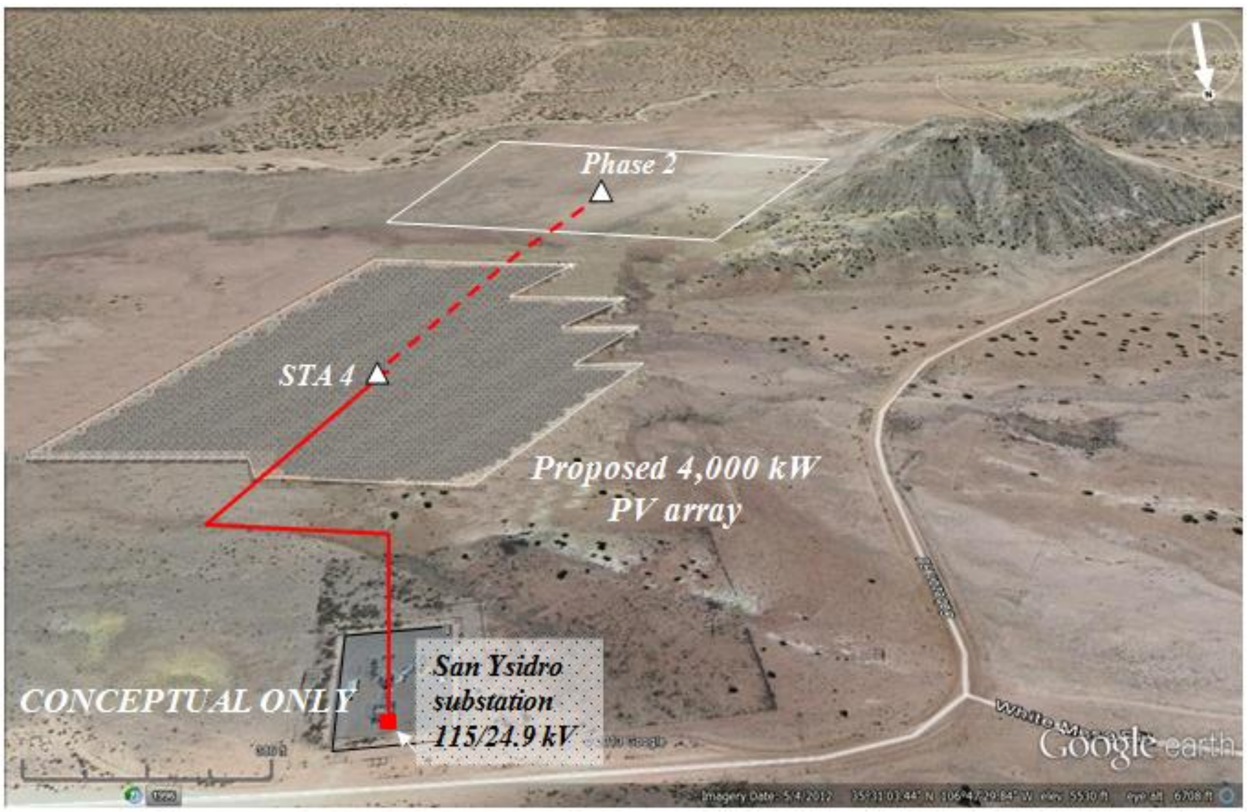
## SOLAR RESOURCES – 4,000 KW SOLAR PV ARRAY

An area of 60 acres is highlighted. Figure 5.11 shows the proposed siting of 3,000 racks of solar cell panels[16] at Site 3. The solar array is oriented approximately SW-NE, with all panels oriented towards due south. The plant occupies approximately 20 acres. This site offers additional acreage for development, as shown in Figure 5.11. below, consisting of an adjacent 5 acres.

Tri-State's 115/60/24.9 kV substation is located 0.4 mile north of the proposed array tie-in location, as shown on Figure 5.11. The tie-in consists of a 24.9 kV step up station with DC to AC inverters (STA 4), connecting to a tap pole structure on JMEC's distribution line.

Figure 5.11 provides an overview of the proposed PV array at Site 3.

**Figure 5.11. Solar PV Array (Site 3)**




[16] 240 watt crystalline silicon modules per panel with DC to AC conversion efficiency of 77% which provides 3,080 kW of AC power injected to JMEC's tie-in during hours of peak insolation.

## GEOTHERMAL ELECTRIC POWER POTENTIAL

The POZ Site 3 resource is estimated to be between 7,500 and 8,000 feet, at a temperature of 234°F and flow rate of 1,250 GPM. With this temperature and flow a binary cycle would be the appropriate power system. This type of equipment has been discussed in the applications at Site 1 and 2, and the discussion will not be duplicated here. We do point out that the since the temperature is projected to be higher the efficiency jumps from 2.5% to 8.0% and this significantly increases the power output and revenue generated. This is somewhat balanced by the requirement to drill deeper, however the improvement in temperature more than offsets the added drilling costs and this site is very close to the local electric market pricing. Lastly we mention that Site 3 development fits better with the POZ's Zia Enterprise Zone (ZEZ) preferred development plan.

**Figure 5.12. Geothermal Electric Power Plant (Site 3)**

A computer program was used with these parameters to calculate the power output and flow rates of water. The table below summarizes the output:

| Property | Value/Units |
|---|---|
| Geothermal fluid Flow Rate, GPM | 1,250 GPM |
| Brine Temperature Hot | 234°F |
| Brine Temperature Rejected | 110°F |
| Power Plant Efficiency | 8.0% |
| Gross Power Plant Rating | 2.0 MW |
| Power Plant Output | 1.8 MW |
| Electric Energy Produced Per Year | 13,020 MWH |
| Number of Days Plant Assumed Down for Maintenance/Outages | 17 Days |
| Plant Cost | $14.5 Million |
| Annual Royalty Paid to POZ | $105,900 |
| Electric Revenue @ $0.106/kWH | $1.5 Million |
| Production Tax Credit, Federal | $299 Thousand |
| Production Tax Credit, New Mexico | $0 |
| Internal Rate of Return | 7.5% |

**Table 5.E., Site 3, Geothermal Electric Performance Summary**

Plant power output estimates take into consideration the local weather, and assume cooling water is available. A transmission loss of 4.5% is also assumed. The computer output is presented in more detail at Appendix K.

Similar to Site 2, the drilling cost is the largest single cost, followed closely by the power plant equipment cost. Since the temperature is projected to be 234$^{o}$F, this site makes more power and is economically more desirable.

Site 3 supports other infrastructure (transmission, roads/accessibility , water, agriculture and mining) being developed within the Zia Enterprise Zone, therefore, Site 3 presents an attractive Geothermal Electric opportunity for further exploration as the POZ continues to develop its renewable energy options.

## D. SITE 4 - ZIA ENTERPRISE ZONE (ZEZ)

### SOLAR RESOURCES – 1,000 KW SOLAR PV ARRAY

The solar array is oriented approximately SW-NE, with all panels oriented towards due south. The plant extends along an existing JMEC line corridor for 2,700 feet and requires installation of 750 racks of solar cell panels. The plant tie-in consists of a 24.9 kV step up tie-in station including DC-AC inverters, connecting to the existing pole termination near the proposed primary development site at Zia Enterprise Zone (ZEZ).

Figure 5.13. provides an overview of the proposed Solar PV array at Site 4.

**Figure 5.13. Solar PV Array (Site 4)[17]**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[17] The Jemez Springs 69 kV substation serves as a distribution delivery point for POZ. It is also labeled JMEC substation since it is the key utility asset of interest in this study.

# GEOTHERMAL ELECTRIC POWER POTENTIAL

The POZ Site 4 resource is the same resource as Site 2. The main difference is that the drilling depth is estimated to be 1600 feet, which will be slightly less expensive than Site 2 where the drilling depth is estimated to be up to 2000 feet. Still this site is not economically attractive for geothermal electric production.

Table 5.F. summarizes output for this site. Since this site is so similar to Site 2 an Appendix with all the specific values has not be included.

| Property | Value/Units |
|---|---|
| Geothermal fluid Flow Rate, GPM | 1,500 GPM |
| Brine Temperature Hot | 176°F |
| Brine Temperature Rejected | 110°F |
| Power Plant Efficiency | 2.5% |
| Gross Power Plant Rating | 529 kW |
| Power Plant Output | 360 kW |
| Electric Energy Produced Per Year | 2,672 MWH |
| Number of Days Plant Assumed Down for Maintenance/Outages | 17 Days |
| Plant Cost | $4.8 Million |
| Annual Royalty Paid to POZ | $36,900 |
| Electric Revenue @ $0.187/kWH | $527 Thousand |
| Production Tax Credit, Federal | $61 Thousand |
| Production Tax Credit, New Mexico | $0 |
| Internal Rate of Return | 7.5% |

**Table 5.F. POZ Summary Geothermal Electric Output Site 4**

# VI. PUEBLO OF ZIA NET METER VERSUS EXPORT ANALYSIS

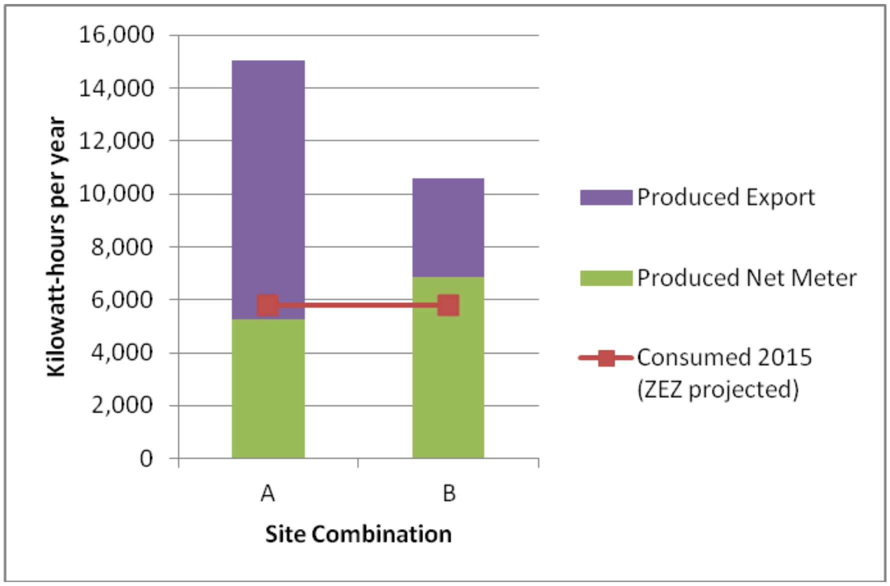
This feasibility study considered the financial impacts of both Net Metering and Export of electricity via a Power Purchase Agreement (PPA). In the case of Net Metering, the electricity produced by a renewable energy generation project would be used directly by the POZ to offset its demand for power purchased from Jemez Mountain Electric Cooperative, Inc. (JMEC). The term "Net" refers to the amount of electricity purchased after deducting that which is produced by the renewable energy generation project. Modern electrical meters have the ability to run "forward" when electricity is being consumed by the customer and "backward" when the customer is generating more electricity than is being consumed at that moment. Therefore, the amount of "Net" electrical use is documented and results in a significant reduction in the amount of electricity required to be purchased. This, in turn, reduces the utility cost for the POZ. In practical terms, JMEC will apply a credit for every excess kWh produced which is equal to the purchased price of a kWh. (Ref. http://www.jemezcoop.org/Energy/net_meter.cfm ).

While Net Metering clearly provides a benefit to POZ in the form of reduced electrical costs, it does not provide for the selling of commercial scale electricity generated from renewable energy by POZ. For POZ to receive payments, the electricity would need to be "exported" to customers beyond the POZ via the electrical transmission grid. In an export scenario, the developer (Seller) of the renewable energy project would enter into a Power Purchase Agreement (PPA) with a utility or other large-scale user (Buyer) of electricity to supply a specified amount of electricity at specified pricing. Through a PPA, a Buyer can ensure a reliable, long-term, cost-competitive supply of electricity. Therefore, PPAs contain detailed incentive and penalties for the Seller and guarantees for the Buyer. They are legally binding contracts and are subject to state and federal regulation.

Currently, POZ's peak electric demand equals or exceeds 0.4 Megawatts (MW), requiring over 2.5 million kilowatts-hours (kWh) of energy to be delivered annually to the Pueblo village and several commercial operations located on POZ Tribal lands. Potential increases in electric demand due to growth at the Zia Enterprise Zone (ZEZ) is expected to occur between 2015-2018. The initial build out estimated in 2015 could add approximately 0.7 MW of electric demand, requiring delivery of an additional 3.3 million kWh of energy annually.

Due to the potential for commercial scale renewable energy projects at POZ, it is likely that there will be excess electricity generated to export or "sellback." With this in mind, the down-selected site combinations discussed in Section IV.A were evaluated for their relative amounts of electricity which could be Net Metered or Sold (Sellback). The results of this evaluation are presented in Figure 6.1.

**Figure 6.1. Zia Sellback versus Net meter Options**




NOTES:

FUTURE ELECTRICITY "CONSUMED 2015" IS BASED ON PROJECTED ZIA ENTERPRISE ZONE DEVELOPMENT AND PHASED BUILD-OUT AT SITES A, C PLUS EXISTING CONSUMPTION AT THE WHITE MESA MINE AND MESA VERDE RESOURCES OPERATIONS, AND ZIA VILLAGE (SEE APPENDIX N FOR ZEZ SITE PLAN).

NET METER LOCATION IS AT ZEZ.

ANY EXCESS NET METER KWH (ABOVE THE RED LINE) BECOMES SELLBACK, AND DOES NOT OFFSET ZIA'S CONSUMPTION BEHIND THE ZEZ METER.

## A. POTENTIAL ENERGY PURCHASERS

Potential purchasers of commercial-scale POZ renewable energy generated electricity include utilities, utilities co-ops, and large users of electricity. For the purpose of this feasibility study, buyers within the state of New Mexico will be considered. The state of New Mexico has mandated a Renewable Portfolio Standard (RPS) requiring utilities to produce a specific fraction of their electricity via renewable sources (wind, solar, geothermal or biomass). The New Mexico RPS mandates are presented in Figures 6.2. and 6.3.

Figure 6.2. New Mexico RPS Requirements

| | 2006 | 2007-2010 | 2011-2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|
| Investor Owned Utilities | 5% | 6% | 10% | 15% | 15% | 15% | 15% | 15% | 20% |
| Rural Cooperatives | | | | 5% | 6% | 7% | 8% | 9% | 10% |

Source: http://www.instituteforenergyresearch.org/renewable-mandates/new-mexico-renewable-electricity-mandate-status/

**Figure 6.3. New Mexico Diversity Requirements as % of total RPS Requirement**

No less than 30% Wind
No less than 20% Solar
No less than 5% Other Technologies
No less than 1.5% Distributed Generation (2011-2014) and 3% Distributed Generation by 2015

Source: http://www.nmprc.state.nm.us/utilities/renewable-energy.html

In the case of POZ, potential purchasers of renewable electricity may include, but are not limited to:

Investor Owned Utilities

- Public Service Company of New Mexico (PNM)

Rural Cooperatives

- Jemez Mountain Electric Cooperative, Inc. (JMEC)
- Tri-State Generation and Transmission Association (Tri-State)

Large-Scale Users

- Los Alamos Department of Public Utilities (DOE-LANL is biggest user)

The developer of a POZ renewable energy project would need to enter into a PPA as discussed in Section VI to sell the electricity generated.

It is possible that, depending on the size and type of R/E development by POZ, electricity could be "wheeled" to other utilities in the region.  Wheeling involves using the transmission grid to move electricity to and between various users based on supply and demand needs.

## B. POWER QUALITY AND FIRMING OPTIONS

Supplying adequate power quality[18] for both Export and Net Metering is a potential concern for developers. POZ's renewable capacity would be primarily affected by weather, estimated to cause daily, hourly and second-to-second variations in energy capture on a short-term basis due to normal range of variations. However, fast-ramping natural gas-fired capacity may will required to stabilize output capability during periods of higher wind or solar variability, depending on a utility's capacity mix. During periods of maximum plant output, ramping rate requirements could exceed approximately +/- 15 MW per minute or the equivalent rate provided by a non-regenerating gas turbine plant.

The assumed firming plant for this analysis is one or more General Electric LM 2500 turbines, which are a derivative of the General Electric CF6 aircraft engine. The LM 2500 it delivers 24 MW of electricity at 60 Hz with a thermal efficiency of 36 percent at ISO conditions. Approximately 9,660 SCF[19] of gas must be burned to yield 1 Megawatt-hour MWh of electric energy output.

Gas turbines used for firming can be located far from the actual development site, if controlled in a coordinated, remote manner. In general the firming turbine and wind/solar plant must be connected to a common transmission circuit unless firming is conducted at system level. An example of system level firming can be found in the "Ancillary Services AS" program in Texas, which has existed since 2005[20]. Summary information posted by ERCOT indicates that AS prices have varied from $5 to $35 per MWh, with a majority of months averaging $5 to 10 per MWh. The value of firming is estimated to equal approximately $5 per MWh.  This value represents a future open market price, which might be achieved in New Mexico with a program similar to ERCOT's AS procedures. It also represents the potential income gained by owner-operators who self-firm as opposed to paying utilities to perform the same service at system-level. While these two examples i.e. site versus system-level firming are not strictly equal in terms of firming value, they represent value range that can be used for estimation.

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[18] In this report "power quality" refers to the likely short-term variability of available wind and solar resources, it does not include issue such as harmonic content, synchronization of voltage or phase, or continuity of service,
[19] SCF Standard Cubic Foot, measure of gas volume
[20] See www.ercot.com/content/meetings/wms/keydocs/2010/0217/14 for a summary of this program.

**Simulated Wind/Solar Variability**

"Delta (Δ) Standard Deviation" abbreviated D_StDev is used to measure plant output variability and is defined as follows: The difference between successive data points in the plant output series, or period-to- period ramp rate. The standard deviation of the deltas is a good indication of how much the wind output series changes from period-to- period, therefore ***standard deviation of the deltas is used as a measure of output variability in this study.***[21] A firming strategy can be applied in one of two ways:

- Firming can be used to fill periods of low plant output
- Firming can be used to extend periods of plant output

The first strategy "A" is used mainly to offset prolonged output reductions over several hours following a period of sustained high output. The occurrence frequency of this event is likely to occur at approximately daily intervals. The second strategy "B" is used to lengthen periods during which low plant output can be maintained especially when wind is approaching or is declining relative to the mid-day peak. The occurrence frequency of this event also has not been determined but it is likely to occur more frequently than the "A" set of events i.e. hours per day. A subset of output variations in this simulation are not affected by a firming strategy. In this case, incomplete information relating to short-term wind or solar forecasts could prevent an effective strategy from being used, resulting in higher values of D_StDev. This event typically occurs during highest periods of sustained plant output. A more effective (but potentially costly) firming strategy could be devised to reduce output variability during these periods.

**Net Load Variability**

Wind generation in Texas exhibits a diurnal (daily) component of variation that tends to be "anti-correlated" with the daily load curve[22]. Wind generation output is often greatest at night and least in the daytime, with wind generation tending to drop sharply in the morning when load is rising quickly, and increase sharply in the evening when load is dropping. This effect appears to be stronger in the summer. Winter afternoon load rise tends to coincide with a general increase in wind production, but there are times when wind is also ramping down in this period. In general, New Mexico will exhibit the same pattern of correlation.

[21] If the deltas are normally distributed then sigma relates to the proportion of deltas within a certain distance of the mean ; adapted from "Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements", GE Energy Report to ERCOT, March 21, 2008.

[22] See http://www.uwig.org/AttchA-ERCOT_A-S_Study_Exec_Sum.pdf; March 2008, GE Energy report, Attachment A. Exec Summary;

GE Energy has proposed the following metric: the variability of ***Net Load*** (utility load minus wind generation) may often be less than the sum of the variability's of load and wind or solar generation considered separately. In order to investigate these differences, three data series were analyzed:

- Seasonal Public Service of New Mexico's load data for winter, summer, fall and spring; each season is represented by a typical week's load series (average hourly values)[23]

- November 2012-July 2013 metered wind and solar data from Pueblo of Zia's Tribal Office tower (average hourly values)

- A capacity mix of 40% wind, 60% solar was chosen to minimize hour-to-hour variability and maximize monthly capacity factor. Table 1 lists trial results which identified this capacity mix

**Table 6.1. Summary of Pueblo of Zia site firming strategies**

| Month | Wind/Solar Fraction | Capacity Factor | Variability 1/StDev | Figure of Merit |
|---|---|---|---|---|
| April | 0.00 | 0.28 | 9.23 | 18.46 |
| April | 0.20 | 0.28 | 10.72 | 21.44 |
| April | 0.40 | 0.29 | 11.49 | 22.98 |
| April | 0.60 | 0.27 | 10.93 | 21.86 |
| April | 0.80 | 0.23 | 9.49 | 18.99 |
| April | 1.00 | 0.20 | 7.98 | 15.95 |
| | | | | |
| July | 0.00 | 0.31 | 8.72 | 17.45 |
| July | 0.10 | 0.31 | 9.35 | 18.70 |
| July | 0.20 | 0.32 | 9.93 | 19.85 |
| July | 0.40 | 0.32 | 10.60 | 21.19 |
| July | 0.60 | 0.32 | 10.30 | 20.61 |
| July | 0.80 | 0.31 | 9.25 | 18.49 |
| July | 1.00 | 0.30 | 7.98 | 15.95 |

Table 6.1. is organized as a list of different wind/solar mixes (fraction) for two sample months. For each mix e.g. a wind/solar fraction of 0.20 indicates 20% wind, 80% solar, monthly capacity factor and variability were estimated. Also, a Figure of Merit FOM was estimated which equals the sum of capacity factor and 1/Standard Deviation. By maximizing FOM, an optimal capacity mix can be identified. In both months, a capacity mix of 40% wind, 60% solar yields the highest FOM.

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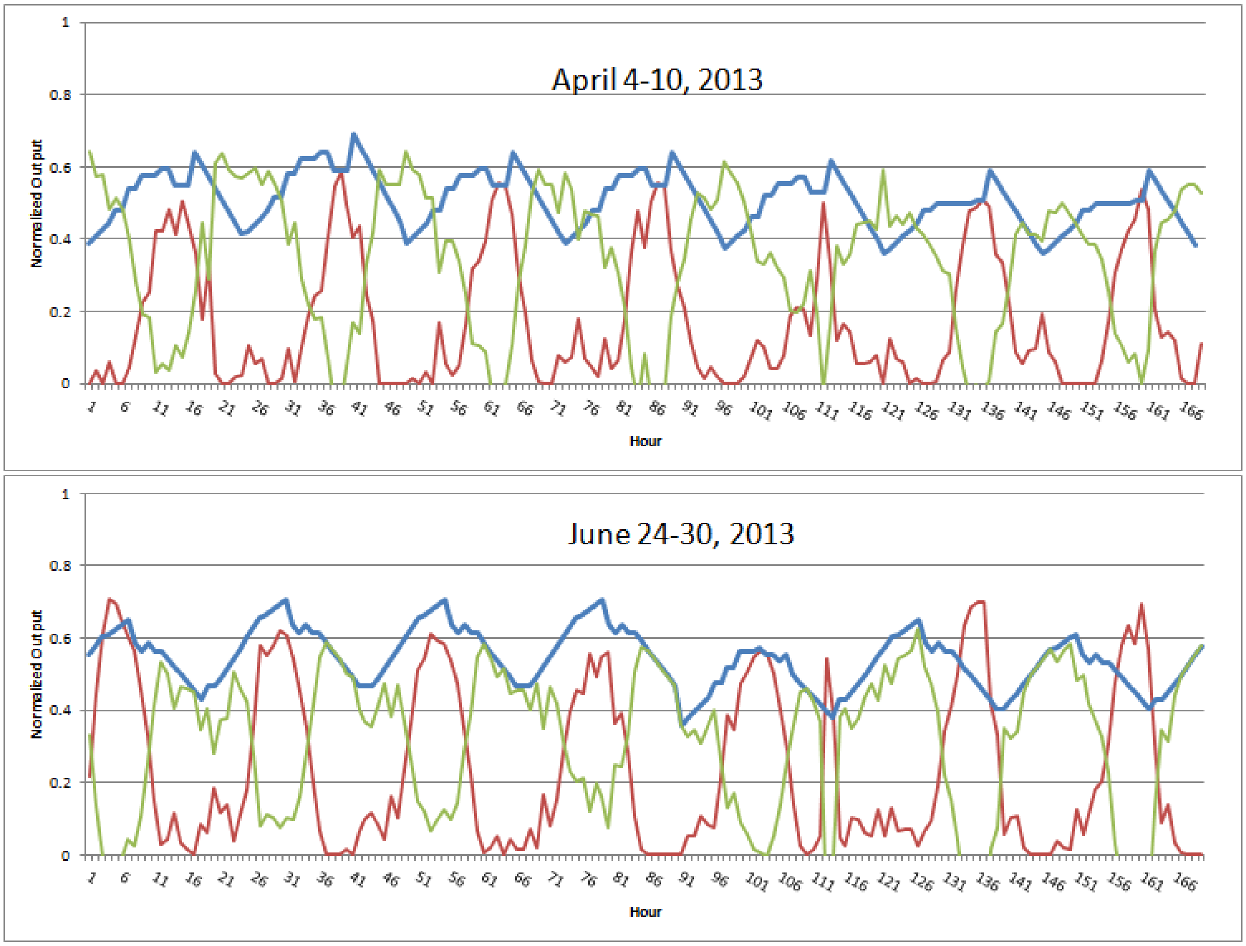
[23] See Appendix B in PNM's IRP report located at http://www.swenergy.org/news/news/documents/file/PNM_IRP_2011-

Net load variability has been observed to increase with renewable capacity. Wind generation tends to have a greater overall impact on variability in the summer, late spring and early fall, but variations in winter and early spring tend to be more operationally significant due to the low net load levels. With the same wind generating capacity, incremental variability due to wind increases as the time span becomes longer, but appears to taper off, and appears to stabilize at longer time spans.

D_StDev values listed in Table 6.1. indicate firming can reduce Pueblo of Zia's impact on PNM's load variability by 50% or more but annual gas costs exceeding $3 Million will be incurred. Costs are approximate; they are mainly useful for comparing cases, not estimating total costs of firming operation. Net load variability will also be reduced during periods in which wind variability changes in opposite patterns to load variability without incurring additional firming cost. This effect should be treated as a "variability credit" by PNM, however it may be difficult to meter and validate. This analysis does not reflect short-term power output variability of concern to developers[24] but it provides a measure of the degree to which firming may be required. Figure 6.4. shows the result of simulations for a typical weekly plant output cycle at Pueblo of Zia's site in April and June.

[24] Usually calculated as mean divided by standard deviation for periods of less thirty seconds; the wind data used for this study represents hourly average values.

**Figure 6.4. Simulated Pueblo of Zia Weekly Plant Output Cycle (40% Wind, 60% Solar)**




Blue: PNM system demand; Red: Solar/Wind output; Green: Net demand (PNM-Zia)

As shown the general outcome of combining Zia output with PNM's demand profile is to shift daily peaks to later time periods in April and July. Also, daily peak demand is lowered over 10% in July on four of seven weekdays. Without wind/solar or firming PNM's load curve in June exhibits a load variability of 0.026; however Zia Pueblo's Net load curve exhibits a load variability of 0.089 after wind/solar plant is added (assuming no firming). This result suggests firming will be needed to reduce potential hour-to-hour variability on PNM's system to acceptable levels.

# VII. FINANCIAL IMPACT

## A. BUSINESS ANALYSIS

As described in Sections IV thru VI (above), all POZ renewable energy options considered in the Down Select process are capable of producing exportable electricity. Three sites (Roberts Tower, San Ysidro substation and ZEZ) are located such that they can produce electricity for Net Metering. This provides POZ with flexibility in meeting its electricity demands as well as being prepared to sell electricity back into the grid. Successful implementation of any generation option requires the proper business structure and partnerships to ensure financing and development support are available and provided in a timely fashion.

## B. EXPORT MARKET

During the course of this feasibility study, the project team surveyed the potential energy purchasers, described in Section VI above, to determine their ability and desire to purchase electricity from POZ. To differing degrees the potential purchasers continue to seek renewable energy options and the possibility exists for them to purchase electricity from POZ. To properly position POZ to capture this market, it is important to understand the process by which electricity is purchased, which is described herein.

**Request for Proposal**
Due to the current ample market supply of renewable energy generated electricity sources, purchasers will typically release a request for proposal (RFP) to provide electricity and ask for responses within 90 days. The RFP will specify parameters such as the type of electricity (wind, solar, other), firmed or non-firmed, amount of MWh desired, peak power, duration, etc. They may give advance notice that an RFP release is imminent, but it is not a requirement.

Upon receipt of proposals, purchasers will typically choose the lowest priced provider that meets the generation and delivery requirements. While there is some limited data about the prices of PPAs, the price terms of most agreements signed with purchasers are kept strictly confidential. In Section VII.F, the projected PPA pricing for generation options will be discussed.

To be successful in the Power Purchase Agreement RFP process (PPA-RFP), POZ will need to establish a business structure capable of developing a renewable energy project well before the RFP is released. To determine the correct type of business structure it will be essential to consider tax incentives provided by federal and state governments. Since typical RFPs require the production of electricity within 18 months of the PPA award, it is also important for POZ to partner with a credible developer who has a demonstrated installation and generation track record. The need to partner with a developer is important because based upon investigation conducted by the POZ study team, no instances were found whereby any tribes have successfully entered into PPAs with utilities. This observation was confirmed by EERE staff at the Indian Energy Workshop held at NREL in September 2013.

**Tax Incentives**

Like other emerging technology industries, federal and state tax policy has been modified to incentivize renewable energy developers by making their return on investment (ROI) more attractive. In some cases, these tax incentives are necessary to make the project financially viable.

As seen in Figure 7.1. there are three types of federal tax incentives (source: DOE OFFICE OF INDIAN ENERGY Renewable Energy Project Development: Advanced Financing Process and Structures, 2013).

**Figure 7.1. Comparison of Tax Incentives**

| | PTC | ITC | Accelerated Depreciation |
|---|---|---|---|
| **Value** | Tax credit of 2.3¢/kWh or 1.1 ¢/kWh, depending on tech | Tax credit of 10% or 30% of project costs, depending on tech | Depreciation of eligible costs (not all project costs qualify) |
| **Select Qualifying Technologies** | • Wind<br>• Geothermal<br>• Biomass<br>• Hydro | • Solar<br>• Fuel cells<br>• Small wind<br>• Geothermal | Depreciation can be taken with either PTC or ITC |
| **Basis** | Energy produced over 10-year period. Can be combined with depreciation, but not ITC | Eligible project cost. Credit taken once the project is placed in service. Can be combined with depreciation, but not PTC | MACRS: 5-year depreciation schedule<br>Bonus: 50% first year accelerated depreciation on equipment |
| **Expiration** | Start construction before 1/1/2014 | Placed in service before 1/1/2017 | MACRS: None<br>Bonus: 1/1/2014 |

These incentives include the Production Tax Credit (PTC), Investment Tax Credit (ITC) and accelerated depreciation through Modified Accelerated Cost-Recovery System (MACRS). A renewable energy developer may apply for the MACRS and PTC or ITC, however only the PTC or ITC is granted on a single project. Through these incentives, the costs of a renewable energy project can be effectively reduced by up to 50%. In New Mexico, the federal PTC is available for eligible power production of all qualified energy generators to 2,000,000 megawatt-hours per year. (Source: http://www.nmcpr.state.nm.us/nmac/parts/title03/03.013.0019.htm) During the course of this feasibility study, the 2,000,000 megawatt-hour limit was reached and the federal PTC was no longer available. Also, given the uncertainty in the federal PTC's extension in 2014, it was decided to eliminate the PTC from the financial analysis of generation options.

In addition to the Federal tax incentives, the State of New Mexico provides for a corporate PTC for solar and wind as follows:

- Solar PTC: $27 per MWh
- Wind PTC: $10 per MWh

The corporate PTC for wind has the same 2,000,000 MWh/yr limit, thus the corporate PTC is no longer available (Source: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NM02F ). It is not included in the financial model.

## C. PROJECT FINANCING AND BUSINESS STRUCTURE OPTIONS

To benefit from tax incentives the project investor/developer needs to be a tax-paying entity with significant tax liabilities that can be offset by the tax credits. Since Native American Tribes do not pay federal income taxes, this presents a challenge in the development of Tribal renewable energy projects. One way a Tribe can benefit from these tax incentives is to create a tax-equity partnership. This approach is supported by a recent IRS ruling (March 8, 2013 IRS Private Letter Ruling-111532-11) that determined an Indian Tribal government is not considered a “governmental unit” or “tax-exempt organization” for purposes of renewable energy tax subsidies (Source: http://www.irs.gov/pub/irs-wd/1310001.pdf ). Therefore, Tribes should be able to enter into tax-equity partnerships just as any tax-paying entity would. As with any IRS matters, Tribes are encouraged to obtain legal counsel to determine if this approach is appropriate for them.

The general premise of the tax-equity partnership is that the Tribe partners with an investor who is able to finance the renewable energy project and obtain the tax credits. The Tribe, in turn, benefits from having lowered electricity rates and, in some cases, receiving royalty payments. The three types of tax-equity partnerships are presented in Figure 7.1. and are compared to the option of direct Tribal ownership (Source: DOE OFFICE OF INDIAN ENERGY Renewable Energy Project Development: Advanced Financing Process and Structures, 2013). The most commonly used tax-equity partnership is a sale lease back and it is the option assumed in the financial model.

**Figure 7.2. Financing Structures and Tribal Implications**

| | Direct Ownership | Partnership Flip | Sale Leaseback | Inverted Lease/Lease Pass-Through |
|---|---|---|---|---|
| **Financing** | User self-finances system and consumes power on-site | Investor can provide up to 99% financing. Debt can also be part of capital stack. | Investor provides 100% financing. Debt can also be part of capital stack, commonly at developer level. | Investor provides partial financing. Debt is a common part of capital stack. |
| **Up-front Tribal Capital Req.** | $$$$ | $ | $, potentially $0 | $$–$$$ |
| **Ownership** | User-owned | Co-ownership by developer and investor | Developer has option to purchase assets at lease term | Assets revert to developer at the lease term |
| **Tax Credit** | NA | PTC or ITC | ITC | ITC |
| **Investor Preference** | Certain firms have preferences for/familiarity with particular structures and/or technologies. Project specifics may also dictate financial structure selected. | | | |

The sale lease back option is attractive because POZ does not need to raise the money to fund the project. Due to the significant up-front costs required by a development project, a sale lease back greatly reduces the risks to a Tribe. Possible tax-equity partners include individual investors, corporations with an interest in renewable energy investing, and renewable energy developers who possess their own financing instruments. It is important to note that the tax-equity partner is considered the majority owner until such time that ownership of the project reverts to or is purchased by the Tribe. This means the partnership is **not** a Tribal- majority business.

It is certainly appropriate for POZ to directly own and develop a renewable energy project or be the majority owner of a partnership (e.g. 51 % / 49% split ownership), but that means the Tribe will have to also provide the bulk of the financing for the project either from its reserves or debt. Since a Tribe or majority-Tribal business is a tax-exempt entity, the project will not be financially sustainable unless it is set up through a tax-paying corporation as discussed below. If project financing is not an issue, the benefit for POZ being a majority owner is that POZ will have control over the development. This will allow POZ to better address its electricity needs in its community, Tribal facilities, industrial sites and at ZEZ.

In addition to determining the type of tax-equity partnership to pursue POZ must consider the proper business structure to support the partnership. There are seven (7) ways a Tribe can structure a business to support the development of a renewable energy project as seen in Figure 7.3. (Source: DOE OFFICE OF INDIAN ENERGY Renewable Energy Project Development: Advanced Financing Process and Structures, 2013).

**Figure 7.3. Business Structure Options**

| Business Structure Option | Simplicity and Quick Formation | Shield Tribal Assets from Business Liabilities | Avoid Federal Income Taxes | Separate Business from Tribal Control | Ability to Secure Financing |
|---|---|---|---|---|---|
| Tribal Instrumentality | ● | | ● | | |
| Political Subdivision | | | ● | | |
| Section 17 Corporation | | ● | ● | ● | |
| Tribal Law Corporation | | ● | | ● | |
| State Law Corporation | | ● | | ● | ● |
| LLCs/Joint Venture | | ● | | ● | ● |
| LLC (only if Tribe is sole member) | | | ● | | |

Again, it must be emphasized that the POZ must obtain business and legal counsel to determine the best option for its interests and members. Significant resources will be invested in the establishment and operation of any business structure.

## D. DOE INDIAN TRIBAL PREFERENCE

As discussed in Section 4, the potential purchasers for a POZ renewable energy project include the Los Alamos Department of Public Utilities (DPU) and LANL. As a DOE facility, LANL has the discretion to purchase electricity from Tribal businesses. The guidance is provided in a Memorandum for Senior Procurement Executives, from (Former) Secretary Steven Chu, Subject: Department of Energy Procurement Guidance – Purchase of Electricity, Energy Products and Energy By-Products from Indian Tribes, December 4, 2012, which states:

> *"This statutory procurement preference provides Federal agencies with discretion to give Tribal majority owned business organizations preferred access to the Federal government marketplace for electricity, energy, and energy by-products."* The memo allows DOE sites to conduct limited competition that only includes Tribes and Tribal businesses. At the same time it states "*the DOE purchaser would need to ensure that it pays no more than prevailing market rate for any purchases resulting from the limited competition."* This last instruction is in keeping with FAR Part 41, Acquisition of Utility Services (http://www.acquisition.gov/far/html/FARTOCP41.html).

While this recent DOE Indian preference guidance is a welcome change, it does present significant challenges for Tribes because of the stipulation that awards go to Tribal-majority businesses. This is generally in conflict with the guidance provided by DOE to Tribes seeking to sell into the utility market by creating tax-equity partnerships (Source: Renewable Energy Development in Indian Country, A Handbook for Tribes, NREL/SR-7A4-48078, 2010, Pages 80-88). As discussed previously in this section, it would be advantageous for the POZ to partner with non-Tribal businesses which will shoulder the financing and reap the tax benefits. Therefore, the POZ will need to consult with its legal counsel to determine if it is possible to structure a Tribal-majority business which can also create a tax-equity partnership as described above.

## E. SUMMARY PRO FORMA

Tables 7.A. and 7.B. present summary pro-formas based on the analyses presented in Section IV and in detail in Appendices F, H, I, J, K. The results are provided for the down selected combinations as described in Section IV and assume a 3000 kW firm capacity (5130 kW installed capacity) for both Net Metering and Export scenarios. Combination A includes geothermal, wind, and solar development while Combination B involves wind and solar. Any actual development project may produce different amounts of electricity, use different technology mixes, and benefit from lower equipment costs. Therefore, these financial results are meant to allow POZ to understand the costs and benefits of a representative renewable energy project.

**Table 7.A. Export PPA -3000 kW Firm Capacity**

**Summary of Capacity and Costs by Unit Type**

| | **Unit Capacity** | **Install Cost** | **O&M Cost** | **Interconnect** | **Plant Output** | |
|---|---|---|---|---|---|---|
| Unit Type | Peak kW | $000s per MW | $000s per MW | 000s | Annual CF% | Annual MWh |
| Geothermal | 1,300 | 6,800 | 100 | 1,600 | 90 | 10,250 |
| Solar 1 | 330 | 2,700 | 20 | 50 | 20 | 580 |
| Solar 2 | 2,130 | 2,700 | 20 | 360 | 20 | 3,730 |
| Wind | 1,370 | 2,200 | 28 | 640 | 30 | 3,600 |

**Summary of Capacity, Costs, Return by Site Combination**

| | **Combination A** | | | **Combination B** | | |
|---|---|---|---|---|---|---|
| Factor | Net Meter | Export | Total | Net Meter | Export | Total |
| Capacity MW | 0.0 | 3.0 | 3.0 | 0.0 | 3.0 | 3.0 |
| Install $000s | $0 | $15,035 | $15,035 | $0 | $13,634 | $13,634 |
| O&M $000s | $0 | $8,614 | $8,614 | $0 | $10,695 | $10,695 |
| Annual CF % | 55% | 55% | - | 40% | 40% | - |
| Annual MWh | 0 | 14,430 | 14,430 | 0 | 10,600 | 10,600 |
| Capacity Fraction | 0% | 100% | 100% | 0% | 100% | 100% |
| Produced $/MWh | -$74 | | | -$94 | | |
| Estimated IRR | 7.5% | | | 7.5% | | |

Assumptions: Combination A PPA $91/MWh; Combination B PPA $117/MWh

**Table 7.B. Net Meter- 3000 kW Firm Capacity**

**Summary of Capacity and Costs by Unit Type**

| | **Unit Capacity** | **Install Cost** | **O&M Cost** | **Interconnect** | **Plant Output** | |
|---|---|---|---|---|---|---|
| Unit Type | Peak kW | $000s per MW | $000s per MW | 000s | Annual CF% | Annual MWh |
| Geothermal | 1,300 | 6,800 | 100 | 1,600 | 90 | 10,250 |
| Solar 1 | 330 | 2,700 | 20 | 50 | 20 | 580 |
| Solar 2 | 2,130 | 2,700 | 20 | 360 | 20 | 3,730 |
| Wind | 1,370 | 2,200 | 28 | 640 | 30 | 3,600 |

**Summary of Capacity, Costs, Return by Site Combination**

| | **Combination A** | | | **Combination B** | | |
|---|---|---|---|---|---|---|
| Factor | Net Meter | Export | Total | Net Meter | Export | Total |
| Capacity MW | 3.0 | 0.0 | 3.0 | 3.0 | 0.0 | 3.0 |
| Install $000s | $15,035 | $0 | $15,035 | $13,634 | $0 | $13,634 |
| O&M $000s | $8,614 | $0 | $8,614 | $10,695 | $0 | $10,695 |
| Annual CF % | 55% | 55% | - | 40% | 40% | - |
| Annual MWh | 14,430 | 0 | 14,430 | 10,600 | 0 | 10,600 |
| Capacity Fraction | 100% | 0% | 100% | 100% | 0% | 100% |
| Produced $/MWh | -$71 | | | -$80 | | |
| Estimated IRR | 6.4% | | | 1.9% | | |

Assumptions: Combination A PPA $85/MWh; Combination B PPA $85/MWh

In the Export model, the internal rate of return (IRR) for the investor was set to an industry standard of 7.5% and the PPA rate was calculated in the model to be in the range of $110/MWh and $123/MWh. (See Appendix F). The model assumes the investor is a tax-paying corporation and, therefore, entitled to the ITC.

These development options would require between approximately $6,000,000 and $10,000,000 in installation costs and $4,000,000 to $5,500,000 in O&M costs. Even with a modest output capacity of 3 MW, this example shows the significant amount of financing required to undertake this type of project and show the benefit of creating a tax-equity partnership.

The PPA prices required to produce an acceptable IRR are much higher than the current rate POZ pays to JMEC, which is approximately $85/MWh. With this in mind, the financial impacts of Net Metering with JMEC were analyzed as seen in Table 7.B. The installation and O&M costs are the same as in the Export model and the ITC is applied. In this case, the investor still benefits, albeit at a lower IRR. POZ would benefit from reduced electricity costs.

Both models show that with the proper business structure and a tax-equity partnership, a renewable energy project can be developed by POZ and provide an investor with a reasonable IRR.

## F. REGULATORY AND PERMITTING

The POZ team met with BIA Regional representative on August 28, 2013 and in subsequent meetings to confirm that all regulatory and permitting requirement can be met in a timely fashion. The following is a summary of the significant requirements.

### LEASES

The U.S. Bureau of Indian Affairs (BIA) has responsibility for approving surface leases on Tribal land. A renewable energy project at POZ will require such a lease because it involves construction on and use of a prescribed section of Tribal land. The lease will be required regardless of what entity is developing the project, e.g. non-Tribal developer or Tribal-owned entity. The lease is between the POZ and the developer and is approved by BIA. BIA encourages discussions to occur concurrently between the Tribe, developer and BIA.

### ENVIRONMENTAL ANALYSIS

While there are numerous laws and regulations that may apply to a renewable energy project development (see attached), the BIA will determine the level of National Environmental Policy Act (NEPA) analysis and compliance required after the lease application is submitted. Depending on the location and condition of the tract of land being considered this can mean a minimum of a Categorical Exclusion (CATEX) Checklist to a maximum of an Environmental Impact Statement (EIS). Most likely, the project will require a less extensive Environment Assessment (EA). An EIS is prohibitively expensive and time consuming and should be avoided by choosing land according.

The POZ or its developer will be responsible for hiring an outside consultant to perform the EA. The BIA Environmental Coordinator will interface with the outside consultant to ensure the EA conforms to BIA's standards and will be the ultimate authority approving the EA.

### SURVEYS

The POZ will need to hire a professional surveyor to produce a survey of the leased area. The survey will be sent to the BIA Division of Real Estate Services and Land Surveyor's Offices (Regional) for approval.

### TRANSMISSION

If new transmission lines are required for the project, the developer will work through POZ and the BIA to get the lines and right of way approved.

## NATURAL GAS LINES

If new or additional natural gas lines are required for a POZ  Renewable Energy project, a service line agreement will be needed.  This is typically a one page document.  A natural gas pipeline located near San Ysidro substation is 36 inches diameter, approximately 0.6 miles northeast of the substation. This pipeline is owned by Kinder Morgan which operates the line as a high-capacity trunk extension from the Texas border near Hobbs, New Mexico. It terminates in Farmington, New Mexico. Data currently available cannot identify other major (20 inches or greater) natural gas pipelines in close proximity to POZ. A 10 inch diameter natural gas pipeline distribution line owned by Public Service Company of New Mexico is located approximately 4.5 miles west of the substation.

## ACCESS ROADS

If additional or improved access roads on POZ Tribal lands for a Renewable Energy project are required, this will be included in the surveyor's plat and will be addressed in the lease document.

## BOUNDARY FENCE

Any security fences required for POZ Renewable Energy operations would be located within the surface lease footprint.

## APPROVAL TIMING

The BIA has streamlined the approval process through the recent Residential, Business, and Wind & Solar Resource and Leasing on Indian Land Final Rule (November, 2012).  Starting with BIA early in the development phase will help.  After approval, the EA must go through a 30-day public comment period.

## LEASE COMPLIANCE

Once project development is complete, the BIA will conduct quarterly lease compliance inspections of the site to ensure all regulations are being followed.

## GEOTHERMAL COMPLIANCE

Geothermal projects require a considerably more involved leasing process than solar and wind projects. There will be a surface lease EA encompassing all aspects previously discussed and a site-specific analysis for each well site including, but not limited to, the following components:

- Geothermal wells
- Injection wells
- Power plant equipment
- Associated buildings

The company hired by POZ to develop the geothermal plant will produce an Environmental Assessment and plan that will be reviewed and approved by BLM.  There are two options:

1) Exploration Plan – Plan for exploratory well to validate the geothermal resource
2) Operation and Reclamation Plan – Plan for operation of the plant and eventual reclamation of the site

It is expected that the developer will work closely with BIA and BLM early in the process and during the review and approval phase.   An exploration plan can be approved in 1-3 months.  An operation and reclamation plan will take 6-8 months.

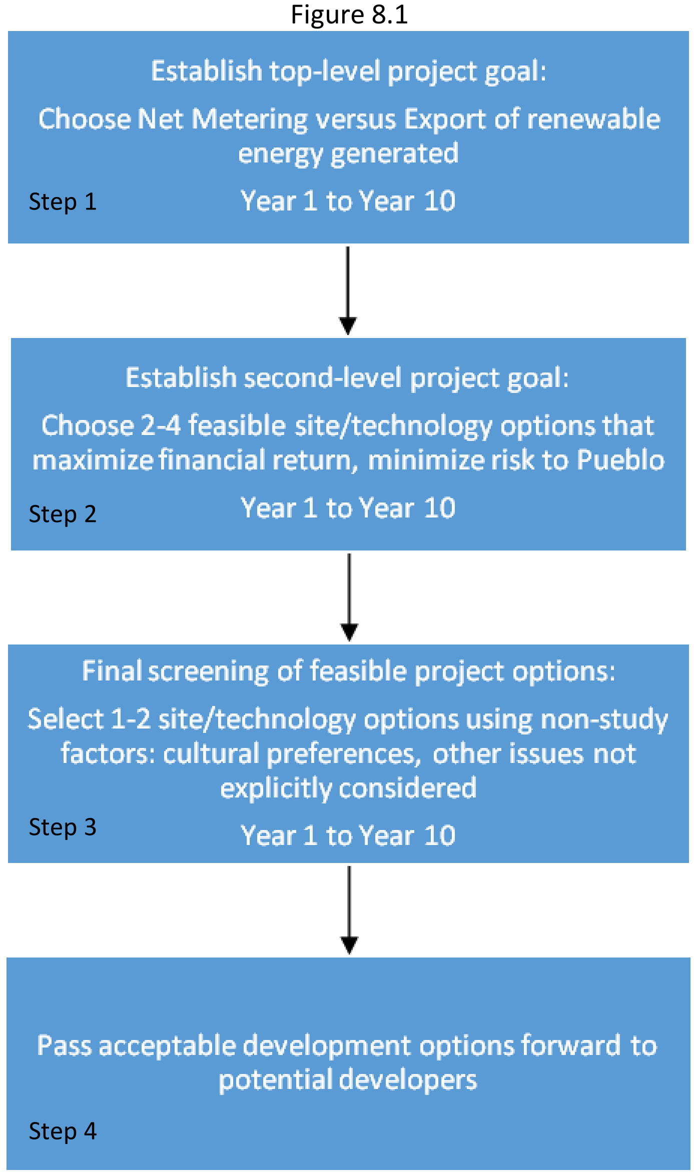
# VIII. RECOMMENDATIONS

Based upon the findings of all resources, technologies, electricity demands, cost information and applications assessed over the 18 month project study period, the Pueblo of Zia Renewable Energy Development Feasibility Study Team recommends the following decision process and path forward for the Pueblo of Zia:

## A. PROPOSED PROJECT DECISION PROCESS

A decision process for POZ's project development is outlined in Figure 8.1.

Figure 8.1



The decision outcome from each step should be completed before proceeding to the following step, to avoid creating potential conflicting goals later-on in POZ's decision process. The first three steps in Figure 8.1 list a timeline (Year 1 to Year 10) which indicates that the decision involved in these steps requires consideration of the top-level goal or option ***plus*** specifying the timeframe in which each step is completed. Certain steps could result in more than one goal or option being developed over time. For example, the Step 1 sets goals for Net Metering or Export of generated power; POZ could decide to develop Net Metering during Years 1-5 and Export during Years 6-10.

This process is intended to achieve incremental, steady business development for the Pueblo, but it will be affected by a variety of unknown risk factors that cannot be determined with high accuracy when each decision is made. The list of factors could include some or all of the items listed below:

- Changes in JMEC's regulated retail electricity rates or market-based PPA rates;
- Availability of future purchase power RFPs such as a Green Power procurement proposed for Los Alamos Laboratory;
- Changes in key cost factors e.g. solar cell module pricing falls more quickly than assumed;
- Growth at ZEZ creates a need for power that is more competitive than JMEC's retail rate;
- Changes in natural gas prices and availability that affect regional energy supply; and,
- New, more lucrative business structures that could be proposed by a potential developer.

Above all, the process is not intended to lead to a "Point A to Point B" development plan. If Steps 1 and 2 are completed by incorporating POZ's major business risk factors, then Step 3 identifies at least a Primary and Alternate development plan that could involve multiple sites and multiple technologies as options. This approach is similar to many business portfolios that are designed to diversify risk across a variety of investments. POZ could select the Primary plan to proceed with potential developers in Step 4. Or, the Primary and Alternate plans could be designed to achieve different business goals and different developer interactions depending on how one or more risk factors affects the project.

Another desirable project feature to explore during this process is ***phased development***, i.e., that is no site is developed to full capacity over a short period using the same technology. This allows POZ to gain operating experience at smaller scale and also allows the market to continue to develop more cost-effective or more reliable technologies that could be installed in a later phase. Older technology could eventually be retrofitted with new technology at a site, if economics justify the expense. Phased projects also allow POZ to limit financial exposure to smaller scale development until the project is proven.

## B. CONTEXT OF NET METER AND POSSIBLE IMPACT FOR THE TRIBE OVER 1-10 YEARS

In considering the resources, technologies, electricity demands, and costs, the feasibility study team recommends that POZ establish a top-level project goal of Net Metering with a secondary goal of expanding production to provide Export power in the 6-10 year time frame. As discussed in Section VI, a Net Metering development would offset POZ's demand for power purchased from JMEC and, in turn, significantly reduce POZ's utility expenses. Entering into a Net Metering agreement is much simpler than pursuing an Export PPA; therefore, POZ would be able to develop and operate the project relatively quickly. This would in turn provide POZ valuable experience in the operation and maintenance of a generation facility. It would also allow POZ to gain credibility with the utility and Export market as development of Export capacity is planned. The end result of these developments is that over a 10 year period, POZ goes from paying over $1,000,000/yr for electricity, to initially lowering its electricity payments, to ultimately producing revenue through export PPAs. In the process, POZ gains a sustainable business structure that can serve the Tribe and its members for decades.

# IX. APPENDICES

The following Appendices are attached to this report:

- Appendix A - Glossary of Terms Used
- Appendix B - Project Risk Factors
- Appendix C - Method of Resource Estimation
- Appendix D – Ridge-Swale Topography
- Appendix E – Power Flow Summary – Alternate Interconnection Options
- Appendix F - Financial Summary Sheets
- Appendix G - Site Down Select Findings
- Appendix H - Geothermal Electric Plant Site 1: Output & Estimates
- Appendix I - Solar and Geothermal Plant Site 1: Output & Estimates
- Appendix J - Geothermal Electric Plant Site 2: Output & Estimates
- Appendix K – Geothermal Electric Plant Site 3: Output & Estimates
- Appendix L – US Geothermal Binary Plants in Operation
- Appendix M – Geothermal Technical Report
- Appendix N – Zia Enterprise Zone Map
- Appendix O - Site A, Zia Enterprise Zone Master Plan
- Appendix P – Project Pictures
- Appendix R - References

# APPENDIX A: GLOSSARY OF TERMS USED

**CF:** Capacity factor; A measure of plant output variability; equals the quantity (Average energy output/Peak energy output). Values are always between 0 and 1.

**D_StDev** Used as a measure of plant output variability in this report; equals the difference between successive data points in a series, or period-to-period ramp rate.

**DOE** Department of Energy; DOE's Office of Tribal Energy provided funding for this study.

**EIA** Energy Information Administration source of national-level statistics regarding cost and usage of electricity.

**FOA** Forced Oil-Air rating of a transformer, used to determine the upper limit of operation.

**IRR:** Internal rate of return IRR of an investment is the interest rate at which the costs of the investment lead to the benefits of the investment. This means that all gains from the investment are inherent to the time value of money and that the investment has a zero net present value at this interest rate.

**ITC:** Investment Tax Credit reduces federal income taxes for qualified tax-paying owners based on capital investment in renewable energy projects.

**JMEC** Jemez Mountain Electric Cooperative, the current service provider for Pueblo of Zia.

**LANL** Primary author of this report.

**MVA** Mega-Volt-Amperes, a measure of total power injected into the utility grid.

**MW:** Megawatt; a measure of instantaneous electric demand; a megawatt of capacity will produce electricity that equates to about the same amount of electricity consumed by 150 to 200 New Mexico homes in a year.

**MWh:** Megawatt-hours, a measure of energy consumed over a specific period of time; calculated as the sum of all energy consumed during the billing period usually a month.

**PNM** Public Service of New Mexico, an Investor-Owned Utility IOU.

**PPA** Purchase Power Agreement.

**PTC:** Production tax credit offered by either state or Federal governments.

**PV** Photovoltaic (solar cell)

**SiC** Silicon crystalline solar module, a typical design used in larger arrays.

**TCUL** Tap Changing Under Load (transformer); this device is used to regulate voltage on distribution feeder circuits.

**WECS:** Wind energy conversion system, a common acronym for WECS.

# APPENDIX B: PROJECT RISK FACTORS

Numeric values are used to represent risk as a quick and succinct reference. The number values used have the following meaning: ***"1"*** is not preferred, unacceptable or too much risk; ***"2"*** is acceptable, possibly favorable, some risk; ***"3"*** is very favorable, little or no risk, preferred.

The following categories are rated numerically during this process:
***Financial***- Does this site create higher or lower risk (exposure to financial factors such as uncertainty in interest rates, cost of hardware etc), for Zia?

***Resource Availability***- Is the expected yearly availability of wind and solar resources at this Zia site adequate to support the size of proposed capacity?

***Technology***- Does this site create higher or lower risk (potential for hardware failure, use of untested designs etc) due to the technology planned for development at Zia?

***Regulatory*** *impact*- Does development at this site create significant impacts under regulations, or potentially cause a lengthy delay in development due to regulations?

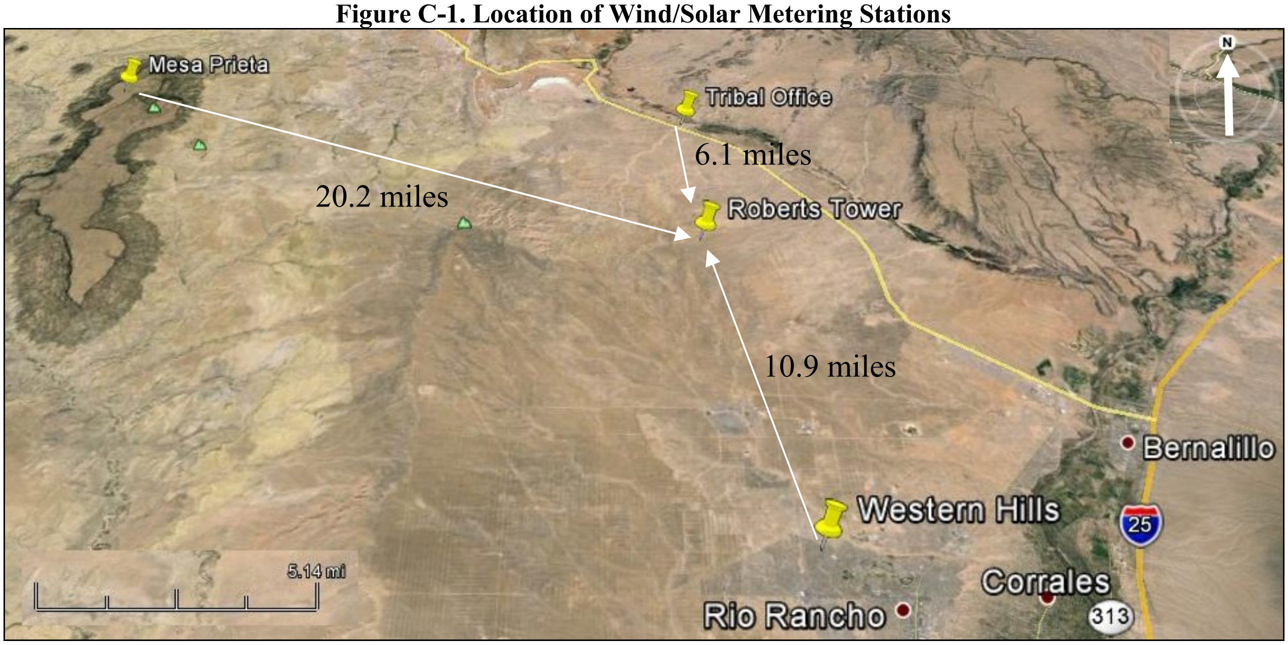
***Water*** *use*- Does this site's potential water usage benefit or threaten Pueblo of Zia's environmental security?

***Emissions, waste****, disposal*- Do the proposed technologies at this site create unacceptable air, water or solid waste disposal/exposure issues for Zia? Includes temporary and permanent construction.

# APPENDIX C: METHOD OF RESOURCE ESTIMATION

**Wind Resources**
Figure C-1 shows the locations of each metering station.

**Figure C-1. Location of Wind/Solar Metering Stations**




Los Alamos obtained access to a multi-year dataset collected at Pueblo of Zia between October 2008 and September 2010[1]. Wind speed and direction was metered at 10, 31 and 50 meters. Table C-1 summarizes findings related to variation in height multipliers versus metered height.

**Table C-1. Mesa Prieta Height Multipliers**

| Quantity | 31 meter | 50 meter | 80 meter |
|---|---|---|---|
| Average multiplier | 1.3342 | 1.4997 | 1.6365 |
| Standard deviation | 0.0664 | 0.1013 | 0.1536 |
| Skewness | 0.8402 | 0.7300 | 0.5646 |

The quantity titled "Average multiplier" in Table 2 represents a cumulative value estimated for the 10 meter to 31/50 meter height extrapolations. The quantities listed less than 80 meters were estimated by regression fits to Mesa Prieta's 30/50 meter data. Note that the latter value indicates the sites' average multiplier is estimated to equal 1.6365, (+/- 0.1536 range within one sigma variation)[2]. This implies within a 68% range of confidence that the multiplier value will not be lower than 1.4829[3].

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[1] Metered at Mesa Prieta. Collected by Duke Energy LLC. This site is located approximately 20 miles northwest of Site 1.The difference in elevation is 840 feet, Site 1 is located at lower elevation and therefore higher air density. NREL's guideline (see http://rredc.nrel.gov/wind/pubs/atlas/tables/1-1T.html) adjustment is 5% per 5,000 feet which equates to an 0.8% upward adjustment in wind speed at Site 1, relative to Mesa Prieta.

[2] If the wind data distribution is approximately normal then about 68 percent of the data values are within one standard deviation of the mean; skewness values shown in Table C-1 indicate that this dataset approaches normality as height increases.

If metered wind speed data series is sorted in rank order from highest to lowest daily average values, a "wind duration" curve[4] is obtained, as shown in Figure C-2.

**Figure C-2. Monthly Wind Duration Pueblo of Zia**

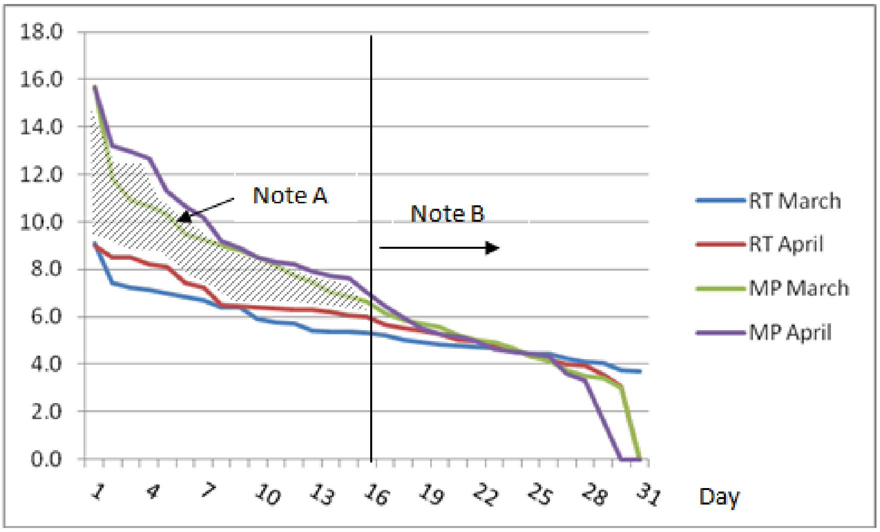


Figure C-2 display a total of 61 days of data, displayed for two months and two metering sites: Mesa Prieta and Roberts Tower. Features are: (Note A) Mesa Prieta reports more wind energy shown in the cross hatch area for 29 of 61 days and (Note B) sites are similar for 32 of 61 days. Conclusion: Mesa Prieta reports 25% higher daily average speeds for 29 of 61 days, or potential for more than 90% higher energy capture during these days.

A statistical procedure was applied to Mesa Prieta's data to approximate the yearly wind duration curve at Site 1. First, Mesa Prieta's 50 meter data was adjusted by a scalar to force the sum of March and April wind speeds metered at Site 1 to be consistent at both sites. The residual error was 5.3% low. This insures that the two metered months of interest represent a similar wind pattern. Second, a uniform layer of energy was removed from the Mesa Prieta curve, to reduce annual capacity factor. About 14% of annual energy was removed from the curve in this step. Third, Mesa Prieta's monthly shear exponents were applied to the curve to extrapolate wind speeds from 50 to 80 meters. The resulting curves are plotted in Figure C-3.

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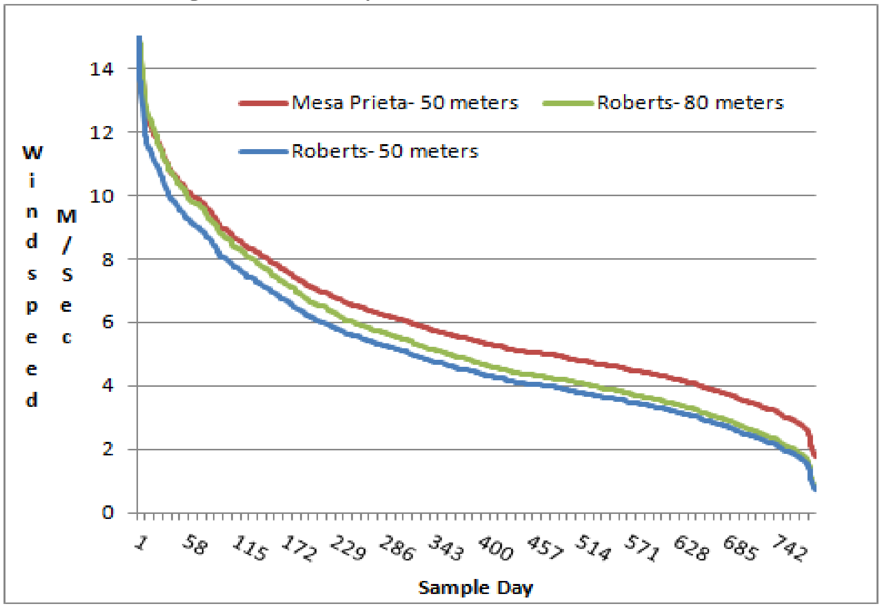
[3] The shear exponent for Mesa Prieta's 30 meter to 50 meter data interval equals approximately 0.22 in comparison to NMSU's previously referenced 0.29 value.

[4] Wind duration curve WDC: if the wind data series is sorted in rank order from highest to lowest hourly values, a WDC can be estimated. A duration curve is useful for displaying patterns of wind resources over long periods such as a year.

**Figure C-3. Yearly Wind Duration Pueblo of Zia**




The curve labeled "Roberts- 80 meters" shown in Figure C-3 differs from Mesa Prieta's curve in one important aspect i.e. annual capacity factor is 28.5% versus 33.2% metered at Mesa Prieta. This result was based strictly on LANL's technical judgment, it is possible that Roberts would exhibit a lower annual capacity factor than estimated. Since only two of twelve months' data is available from Roberts as of July 2013, this issue will remain unresolved until more data comparisons can be completed. For the purposes of this study, two bounding values of annual turbine capacity factor are assumed at Site 1: 25% and 30%.

**Solar Resources**

See Figure C-4's plot of two solar data series representative of Pueblo of Zia's probable monthly solar insolation.

**Figure 4. 2012-2013 Monthly Average Solar Insolation Pueblo of Zia**

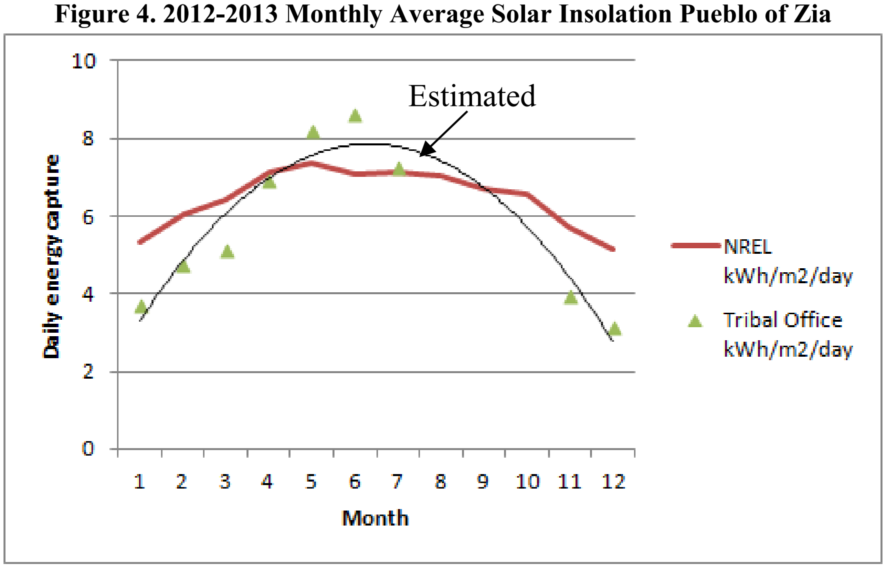


Figure C-4 plots NREL's projected monthly solar insolation values reported by PVWATT[5]; metered values metered at Zia' Tribal Office from October 2012 to July 2013; and a polynomial fit to the metered values, labeled as "Estimated". This comparison indicates that PVWATT reports a total yearly energy capture approximately 34% higher than metered at Pueblo of Zia's Tribal Office. This difference could be attributed to short-term variations due to cloud cover, however the actual cause has not been determined.

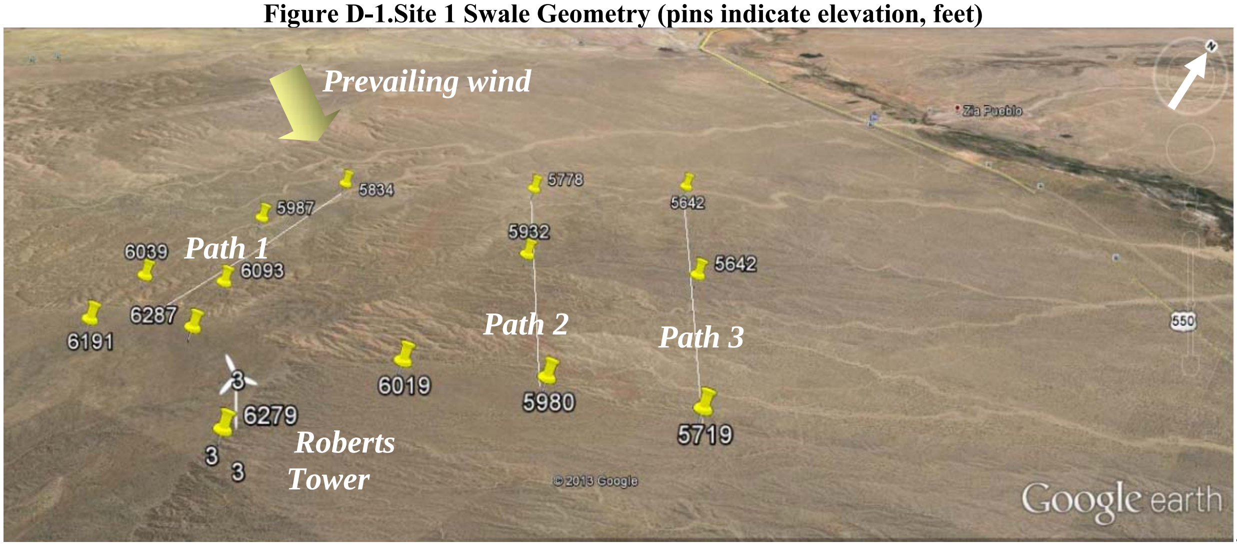
Figure C-4 displays data reported by NREL's TMY3 solar resource map[6]. Yearly electric output produced by a 1,000 kW array is estimated to equal or exceed 1,680 Mega-watt hours (MWh).

[5] See http://rredc.nrel.gov/solar/calculators/pvwatts/version1/ ; this calculator is useful for estimating electric energy generated by PV arrays.
[6] Available at http://www.nrel.gov/rredc/pvwatts/site_specific.html

# APPENDIX D: RIDGE-SWALE TOPOGRAPHY

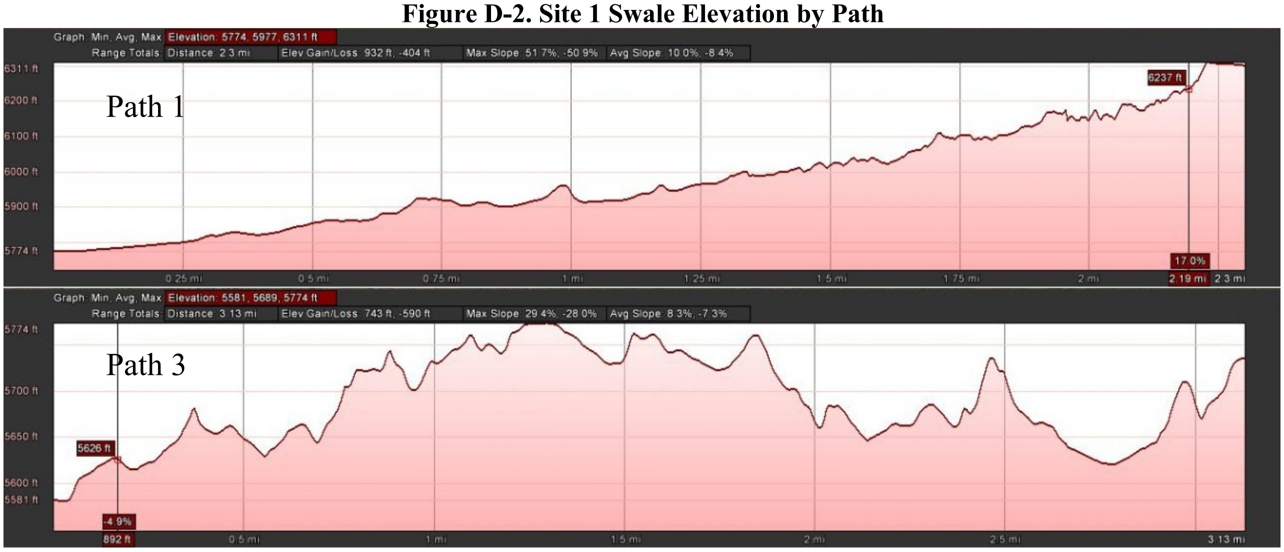
The following methodology was used to identify potential WECS locations at Sites 1 and 3. The overall goal was to maximize the power generation by utilizing specific terrain features that enhance local wind speed. Figure D-1 outlines placement of the swale baselines at Site 1.

**Figure D-1.Site 1 Swale Geometry (pins indicate elevation, feet)**




Initially, relative high and low elevations at the site were identified and labeled. The high points of interest were generally found along ridgelines. Nearby swales (low elevation areas) with gradually increasing elevation towards the ridgeline were located. Particular attention was paid to swales identified with an orientation perpendicular to the ridgeline and parallel with typical recorded wind directions. Terrain smoothness is also an important consideration, elevation maps are shown for each path in Figure D-2.

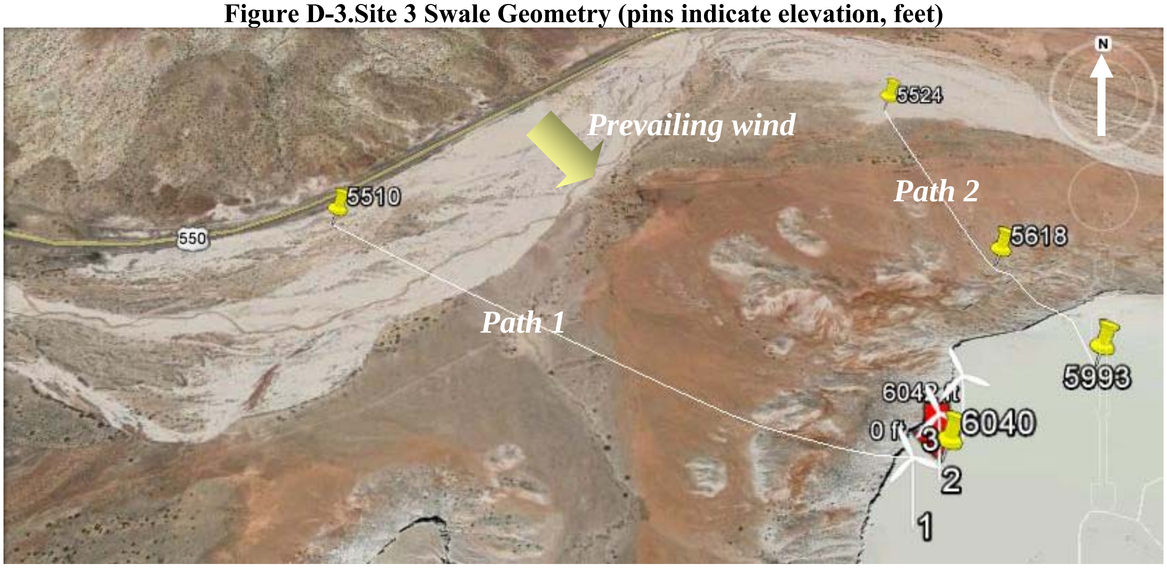
**Figure D-2. Site 1 Swale Elevation by Path**




In Figure D-2, the proposed ridgeline for turbine siting is located at right.

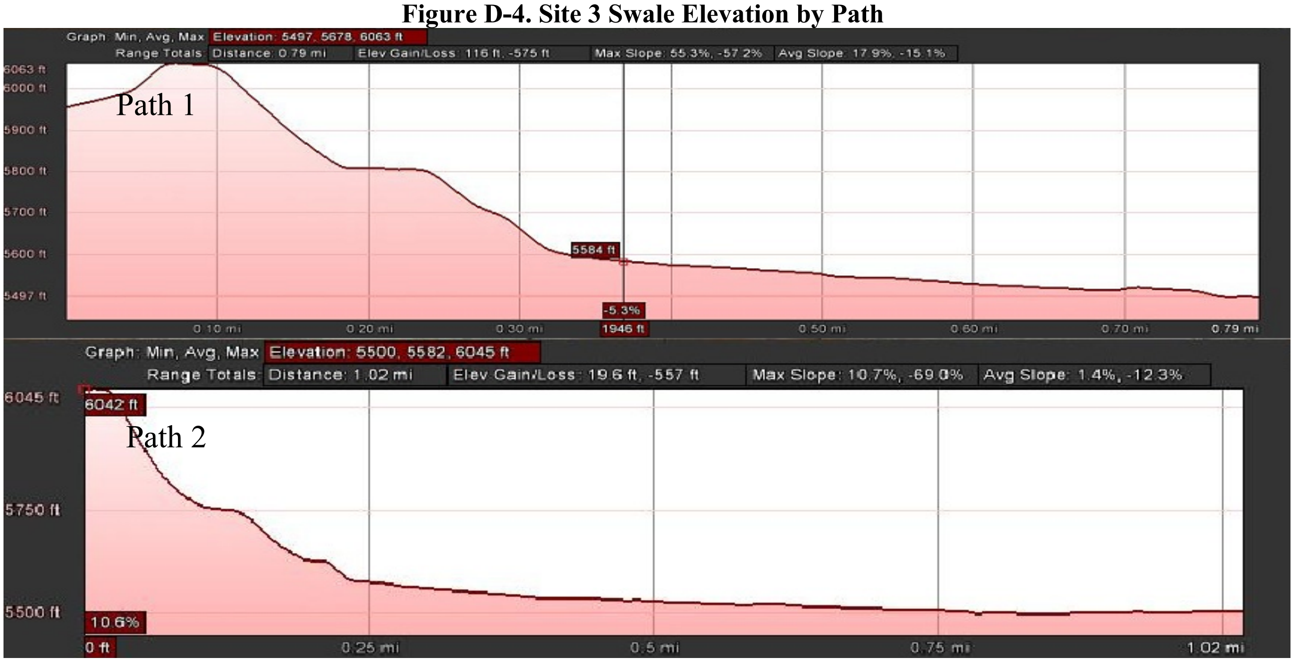
An “aspect ratio” was estimated for three observed swales[7] which could offer more suitable siting geometry for wind turbines. At Site 1, values range from 0.014 (Path 3) to 0.033 (Path 1), with higher values offering potentially larger amounts of wind acceleration. Higher aspect ratios are observed at Site 1 for swales exhibiting narrowest widths which create more favorable siting for turbine arrays along Path 1. Figure D-3 outlines placement of the swale baselines at Site 3.

**Figure D-3.Site 3 Swale Geometry (pins indicate elevation, feet)**




Terrain smoothness is also an important consideration, elevation maps are shown for each Paths 1 and 2 in Figure D-4.

**Figure D-4. Site 3 Swale Elevation by Path**

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[7] Aspect ratio is calculated to be equal to (Crest height above swale base/Length of swale baseline).

In Figure D-4, the proposed ridgeline for turbine siting is located at left.

At Site 3, aspect ratio values range from 0.146 (Path 1) to 0.109 (Path 2), with higher values offering potentially larger amounts of wind acceleration. Swale width is also a determinant of wind acceleration, with narrow swales potentially capable of channeling higher wind flows depending on orientation and surface roughness. Higher aspect ratios are observed at Site 3 for swales exhibiting narrowest widths which create more favorable siting for turbine arrays along Path 1.

The area of the swales identified at Sites 1 and 3 varied from 0.9 $mi^2$ to 2.2 $mi^2$.

# APPENDIX E: POWER FLOW SUMMARY: ALTERNATE INTERCONNECTION OPTIONS

All of the power flow cases described in this Appendix are based on WECC's 2010-11 Heavy Summer demand planning model. Tables E-1, E-2 and E-3 display columns labeled "PU" or "MW/MVAR". The PU column refers to per-unit voltage (1.0=100% nominal voltage)[8] observed at each voltage monitoring point shown in Figure 8. The "MW/MVAR" column refers to line flows (MW=Megawatts, MVAR=Megavars) along each monitored segment shown in Figure 8. Negative flows indicate flow out of the downstream node, positive flows indicate flow into the node. The following abbreviations are used:

- RT= Roberts Tower 24.9 kV
- ZIA= Zia Village 24.9 kV
- SUB=San Ysidro substation 69/115 kV
- JMEC= Jemez Springs substation 69 kV
- ZEZ= Zia Enterprise Zone 69 kV
- LJ=LaJara substation 115 kV
- ALG= Algodones substation 115 kV

The Base Case is shown for comparison to represent current circuit and demand configuration on JMEC's 69/24.9 kV network. To account for future load growth, the model includes 1,400 kW/900 kVAR load connected to ZEZ.

Table E-1 summarizes operation expected  for a 24.9 kV interconnection at Roberts Tower (Site 1).

**Table E-1. Estimated Line Flows, Interconnection Site 1**

| | | | *Voltage PU* | | | | | *Flow MW/MVAR* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Generating Option** | **Sites** | **Capacity** | **RT** | **ZIA** | **SUB** | **JMEC** | **ZEZ** | **RT to ZIA** | **ZIA to SUB** | **LJ to SUB** | **SUB to ALG** |
| Base Case- no generation | N/A | 0 | 0.986 | 0.987 | 0.991 | 0.988 | 0.989 | 0.2/0.1 | 0.6/0.3 | 7.2/-1.4 | -2.0/0.8 |
| (1) 1000 PV | Roberts Tower | 1,000 | 0.996 | 0.992 | 0.992 | 0.989 | 0.991 | -0.8/0.1 | -0.4/0.3 | 7.2/-1.4 | -3.0/0.8 |
| (1) 6000 WEC+ 1000 PV | Roberts Tower | 7,000 | 0.985 | 0.972 | 0.975 | 0.972 | 0.974 | -6.8/2.9 | -6.4/3.4 | 6.7/-1.1 | -8.4/3.6 |
| (1) 6000 WEC+ 1000 PV+ 5000 GEO | Roberts Tower | 12,000 | 0.963 | 0.943 | 0.953 | 0.949 | 0.951 | -11.8/5.5 | -11.4/6.8 | 6.3/-0.6 | -13.0/7.1 |

Three siting cases are listed in Table E-1 with capacity additions of 1000, 7000, and 12000 kW. All generating options are connected to JMEC's existing 24.9 kV service to Roberts Tower. The AC criterion used to determine the extent of reportable problems was a minimum of 0.93 voltage with a decrease of 0.02 or greater from the Base Case per-unit voltage for the unacceptable operating voltage limit. As shown, only the last case (12000 kW) indicates potential voltage regulation problems, which can be corrected relatively cheaply through static capacitor compensation. Line

[8] Per-unit is the expression of system quantities as fractions of a defined base unit quantity. Calculations are simplified because quantities expressed as per-unit are the same regardless of the voltage level.

flows are all within normal limits; notably flow from San Ysidro to Algodones substation is observed to increase in direct proportion to the amount of generating capacity added which suggests export energy sales will occur through this node.

Table E-2 summarizes operation expected for a 115 kV interconnection at Hot Springs (Site 2).

**Table E-2. Estimated Line Flows, Interconnection Site 2**

| | | | *Voltage PU* | | | | | *Flow MW/MVAR* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Generating Option** | **Sites** | **Capacity** | **RT** | **ZIA** | **SUB** | **JMEC** | **ZEZ** | **RT to ZIA** | **ZIA to SUB** | **LJ to SUB** | **SUB to ALG** |
| Base Case- no generation | N/A | 0 | 0.986 | 0.987 | 0.991 | 0.988 | 0.989 | 0.2/0.1 | 0.6/0.3 | 7.2/-1.4 | -2.0/0.8 |
| 4000 PV 115 | Hot Springs | 4,000 | 0.981 | 0.982 | 0.988 | 0.983 | 0.987 | 0.2/0.1 | 0.6/0.3 | 6.5/-1.6 | -1.3/3.0 |

No voltage regulation problems are observed. Line flows are all within normal limits, flow from San Ysidro to Algodones substations indicates most of the generated power is used locally to displace inflow to Pueblo of Zia and San Ysidro, not exported.

Table E-3 summarizes operation expected for a 69/24.9 kV interconnection at ZEZ/White Mesa/San Ysidro substation (Site 3,4).

**Table E-3. Estimated Line Flows, Interconnection Sites 3,4**

| | | | PU | PU | PU | PU | PU | MW/MV | MW/MV | MW/MV | MW/MV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Generating Option** | **Sites** | **Capacity** | **RT** | **ZIA** | **SUB** | **JMEC** | **ZEZ** | **RT to ZIA** | **ZIA to SUB** | **LJ to SUB** | **SUB to ALG** |
| Base Case- no generation | N/A | 0 | 0.986 | 0.987 | 0.991 | 0.988 | 0.989 | 0.2/0.1 | 0.6/0.3 | 7.2/-1.4 | -2.0/0.8 |
| (3) 4000 PV 24.9 kV + (4) | Substation, ZEZ | 5,000 | 0.992 | 0.993 | 0.997 | 0.994 | 0.992 | 0.2/0.1 | 0.6/0.3 | 6.9/-1.4 | -6.6/0.8 |
| (4) 1000 PV + (2) 4000 PV | ZEZ, Hot Springs | 5,000 | 0.982 | 0.983 | 0.986 | 0.984 | 0.980 | 0.2/0.1 | 0.6/0.3 | 6.4/-1.6 | -2.2/2.9 |
| (3) 6000 WEC+ (4) 1000 PV | Substation, White Mesa | 7,000 | 0.976 | 0.977 | 0.984 | 0.981 | 0.983 | 0.2/0.1 | 0.6/0.3 | 6.7/-1.2 | -8.5/2.6 |
| (3) 6000 WEC+ (3) 4000 PV+ (3) 5000 GEO | Substation | 15,000 | 0.967 | 0.968 | 0.975 | 0.971 | 0.969 | 0.2/0.1 | 0.6/0.3 | 6.0/-0.8 | -15.7/5.2 |

No voltage regulation problems are observed. Line flows are all within normal limits; notably flow from San Ysidro to Algodones substations is observed to increase in direct proportion to the amount of generating capacity added which suggests export energy sales will occur through this node. Flow from LaJara to San Ysidro substations is also reduced up to 17%.

The 115/69 kV tap-changing (TCUL) transformer used for voltage regulation at San Ysidro substation is rated at 7.5 MVA. When backflow on 69 kV circuits exceeds approximately 5000 kW, this unit is overloaded. Therefore a replacement transformer must costed against all generating options which exceed this level of capacity at Site 3.

# APPENDIX F: FINANCIAL SUMMARY SHEETS/REFERENCES

**F-1 Project:** Site 1 Solar PV Array 1,000 kW (Roberts Tower)
Financial factors:

- Project financial assessment extends from 2015 to 2035 (20 years)
- Federal tax rate 37%; New Mexico tax rate 5%
- Renewable Energy Credit $10 per MWh
- Federal Production Tax Credit $0 per MWh or alternately 30% Investment Tax Credit available until 2016
- New Mexico Production Tax Credit $27 per MWh, escalating $0 per MWh yearly
- New Mexico Capital Tax Credit 6% up to $60 million
- 20-Year straight line depreciation on plant
- Project is organized as a flow-through entity for tax purposes[9]

Operating factors

- Rated plant capacity at minimum 30% or higher daily capacity factor guaranteed from 10:00 am to 3:00 pm daily
- Energy sales 1,750 MWh annually
- Annual outage rate 10 days per year

Pueblo of Zia's project analysis resulted in the following conclusions:

- Construction costs will equal or exceed $2.2 million [Ref. 1] with additional operating expenses of $0.6 million ex depreciation [Ref. 1, 3]
- Estimated revenue is $7.6 million gross (before Federal and NM tax)
- Taxable income, after expenses and depreciation, is estimated to be $4.9 million
- Federal and state taxes levied will total $1.9 million, however, due to federal and state tax benefits renewable resource production, the project will receive an estimated $1.6 million in tax credits
- Cumulative royalty/lease payment to Pueblo of Zia is estimated be $0.3 million; assumes 3% royalty rate and $150 per acre lease fee
- $210 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%

Key Financial Issues:

- SiC module prices may fall dramatically through 2020 [Ref 2]. This study assumes a value of $2.10 per peak watt or 45% lower than reported by EIA in 2012 [Ref. 1]. The EIA study represents average pricing for various applications and different technology types which are unlikely to be representative of utility-scale module prices in the near future. Prices of $1.17 per peak watt are achievable if DOE's 2020 Sunshot program goals are met. Using this assumption a $105 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

[9] Such as LLC, LLP, etc. In this case investors will use the flow-through losses and credits against other income. For example, if Google became an investor in Zia's project other corporate income would offset potential tax losses and credits from renewable energy projects.

**F-2 Project:** Site 1 WECS Array 6,000 kW (Robert Tower)
Financial factors:

- Project financial assessment extends from 2015 to 2035 (20 years)
- Federal tax rate 37%; New Mexico tax rate 7%
- Renewable Energy Credit $5 per MWh
- Federal Production Tax Credit $23 per MWh or alternately 30% Investment Tax Credit available until 2016
- New Mexico Production Tax Credit $10 per MWh, escalating $0 per MWh yearly
- New Mexico Capital Tax Credit 6% up to $60 million
- 20-Year straight line depreciation on plant
- Project is organized as a flow-through entity for tax purposes

Operating factors

- Rated plant capacity at minimum 25% or higher daily capacity factor is not guaranteed; energy only non-firm sales
- Energy sales 13,140 MWh annually
- Annual outage rate 35 days per year

Pueblo of Zia's project analysis resulted in the following conclusions:

- Construction costs will equal or exceed $10.3 million [Ref. 1] with additional operating expenses of $3.1 million ex depreciation [Ref. 1, 4]
- Estimated revenue is $42.8 million gross (before Federal and NM tax)
- Taxable income, after expenses and depreciation, is estimated to be $27.9 million
- Federal and state taxes levied will total $11.2 million, however, due to federal and state tax benefits renewable resource production, the project will receive an estimated $5.6 million in tax credits
- Cumulative royalty/lease payment to Pueblo of Zia is estimated be $1.5 million; assumes 3% royalty rate and $150 per acre lease fee
- $155 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%

Key Financial Issues:

- As discussed in Appendix C, uncertainty exists regarding the likely annual energy capture possible at Site 1. This site was classified as a NREL Class 3 wind regime which can be exceeded if unmeterable wind speed gains from swale acceleration provide extra capture, or ongoing metering at Roberts Tower indicates higher peak winds than estimated from Mesa Prieta's data fits. Assuming a modest 5% increase in capacity factor results in 20% additional energy capture at Site 1, $120 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.
- Without Federal PTC tax credits but 5% increase in capacity factor, $150 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

**F-3 Project:** Site 2 Solar PV Array 4,000 kW (Hot Springs)
Financial factors:

- Project financial assessment extends from 2015 to 2035 (20 years)
- Federal tax rate 37%; New Mexico tax rate 7%
- Renewable Energy Credit $10 per MWh
- Federal Production Tax Credit $0 per MWh or alternately 30% Investment Tax Credit available until 2016
- New Mexico Production Tax Credit $27 per MWh, escalating $0 per MWh yearly
- New Mexico Capital Tax Credit 6% up to $60 million
- 20-Year straight line depreciation on plant
- Project is organized as a flow-through entity for tax purposes

Operating factors

- Rated plant capacity at minimum 30% or higher daily capacity factor guaranteed from 10:00 am to 3:00 pm daily
- Energy sales 7,010 MWh annually
- Annual outage rate 10 days per year

Pueblo of Zia's project analysis resulted in the following conclusions:

- Construction costs will equal or exceed $9.1 million [Ref. 1] with additional operating expenses of $2.6 million ex depreciation [Ref. 1, 3]
- Estimated revenue is $32.5 million gross (before Federal and NM tax)
- Taxable income, after expenses and depreciation, is estimated to be $21.2 million
- Federal and state taxes levied will total $8.5 million, however, due to federal and state tax benefits renewable resource production, the project will receive an estimated $6.5 million in tax credits
- Cumulative royalty/lease payment to Pueblo of Zia is estimated be $1.0 million; assumes 3% royalty rate and $150 per acre lease fee
- 225 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%

Key Financial Issues:

- SiC module prices may fall dramatically through 2020 [Ref 2]. This study assumes a value of 3.20 per peak watt or 16% lower than reported by EIA in 2012 [Ref. 1]. The EIA study represents average pricing for various applications and different technology types which are unlikely to be representative of utility-scale module prices in the near future. Prices of $1.17 per peak watt are achievable if DOE's 2020 Sunshot program goals are met. Using this assumption a $120 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

**F-4 Project:** Site 4 Solar PV Array 1,000 kW (Zia Enterprise Zone)
Financial factors:

- Project financial assessment extends from 2015 to 2035 (20 years)
- Federal tax rate 37%; New Mexico tax rate 7%
- Renewable Energy Credit $10 per MWh
- Federal Production Tax Credit $0 per MWh or alternately 30% Investment Tax Credit available until 2016
- New Mexico Production Tax Credit $27 per MWh, escalating $0 per MWh yearly
- New Mexico Capital Tax Credit 6% up to $60 million
- 20-Year straight line depreciation on plant
- Project is organized as a flow-through entity for tax purposes

Operating factors

- Rated plant capacity at minimum 30% or higher daily capacity factor guaranteed from 10:00 am to 3:00 pm daily
- Energy sales 2,800 MWh annually
- Annual outage rate 10 days per year

Pueblo of Zia's project analysis resulted in the following conclusions:

- Construction costs will equal or exceed $2.2 million [Ref. 1] with additional operating expenses of $0.6 million ex depreciation [Ref. 1, 3]
- Estimated revenue is $7.6 million gross (before Federal and NM tax)
- Taxable income, after expenses and depreciation, is estimated to be $4.9 million
- Federal and state taxes levied will total $1.9 million, however, due to federal and state tax benefits  renewable resource production, the project will receive an estimated $1.6 million in tax credits
- Cumulative royalty/lease payment to Pueblo of Zia is estimated be $0.3 million; assumes 3% royalty rate and $150 per acre lease fee
- $210 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%

Key Financial Issues:

- SiC module prices may fall dramatically through 2020 [Ref 2]. This study assumes a value of $2.10 per peak watt or 45% lower than reported by EIA in 2012 [Ref. 1]. The EIA study represents average pricing for various applications and different technology types which are unlikely to be representative of utility-scale module prices in the near future. Prices of $1.17 per peak watt are achievable if DOE's 2020 Sunshot program goals are met. Using this assumption a $120 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

**F-5 Project:** Site 3 WECS Array 6,000 kW (White Mesa)
Financial factors:

- Project financial assessment extends from 2015 to 2035 (20 years)
- Federal tax rate 357%; New Mexico tax rate 7%
- Renewable Energy Credit $10 per MWh
- Federal Production Tax Credit $0 per MWh or alternately 30% Investment Tax Credit available until 2016
- New Mexico Production Tax Credit $27 per MWh, escalating $0 per MWh yearly
- New Mexico Capital Tax Credit 6% up to $60 million
- 20-Year straight line depreciation on plant
- Project is organized as a flow-through entity for tax purposes

Operating factors

- Rated plant capacity at minimum 30% or higher daily capacity factor is not guaranteed; energy only non-firm sales
- Energy sales 15,770 MWh annually
- Annual outage rate 35 days per year

Pueblo of Zia's project analysis resulted in the following conclusions:

- Construction costs will equal or exceed $9.3 million [Ref. 1] with additional operating expenses of $3.1 million ex depreciation [Ref. 1, 4]
- Estimated revenue is $35.8 million gross (before Federal and NM tax)
- Taxable income, after expenses and depreciation, is estimated to be $22.1 million
- Federal and state taxes levied will total $8.8 million, however, due to federal and state tax benefits renewable resource production, the project will receive an estimated $6.7 million in tax credits
- Cumulative royalty/lease payment to Pueblo of Zia is estimated be $1.3 million; assumes 3% royalty rate and $150 per acre lease fee
- $105 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%

Key Financial Issues:

- As discussed in Appendix C, uncertainty exists regarding the likely annual energy capture possible at Site 3. This site was classified as a NREL Class 4 wind regime with undetermined upslope wind losses along the north mesa boundary. Assuming a modest 5% increase in capacity factor results in 15% additional energy capture at Site 3, $85 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

**F-6 Project:** Site 3 Solar PV Array 4,000 kW (San Ysidro substation)
Financial factors:

- Project financial assessment extends from 2015 to 2035 (20 years)
- Federal tax rate 37%; New Mexico tax rate 7%
- Renewable Energy Credit $10 per MWh
- Federal Production Tax Credit $0 per MWh or alternately 30% Investment Tax Credit available until 2016
- New Mexico Production Tax Credit $27 per MWh, escalating $0 per MWh yearly
- New Mexico Capital Tax Credit 6% up to $60 million
- 20-Year straight line depreciation on plant
- Project is organized as a flow-through entity for tax purposes

Operating factors

- Rated plant capacity at minimum 30% or higher daily capacity factor guaranteed from 10:00 am to 3:00 pm daily
- Energy sales 7,100 MWh annually
- Annual outage rate 10 days per year

Pueblo of Zia's project analysis resulted in the following conclusions:

- Construction costs will equal or exceed $8.8 million [Ref. 1] with additional operating expenses of $2.6 million ex depreciation [Ref. 1, 3]
- Estimated revenue is $31.1 million gross (before Federal and NM tax)
- Taxable income, after expenses and depreciation, is estimated to be $21.2 million
- Federal and state taxes levied will total $8.1 million, however, due to federal and state tax benefits renewable resource production, the project will receive an estimated $6.4 million in tax credits
- Cumulative royalty/lease payment to Pueblo of Zia is estimated be $0.9 million; assumes 3% royalty rate and $150 per acre lease fee
- 215 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%

Key Financial Issues:

- SiC module prices may fall dramatically through 2020 [Ref 2]. This study assumes a value of $2.10 per peak watt or 45% lower than reported by EIA in 2012 [Ref. 1]. The EIA study represents average pricing for various applications and different technology types which are unlikely to be representative of utility-scale module prices in the near future. Prices of $1.17 per peak watt are achievable if DOE's 2020 Sunshot program goals are met. Using this assumption a $110 per MWh PPA contract price with no escalation yields an IRR equal to 7.5%.

# APPENDIX G: SITE DOWNSELECT FINDINGS

During Zia's energy development process, at least four development sites were identified as being potentially feasible on the basis of a limited set of technical and cultural factors. Three renewable technologies were also identified (geothermal, wind and solar photovoltaic). Additional down select factors were outlined and a process was described which could be used to further reduce the number of possible site and technology combinations considered during a detailed feasibility study. The goal of this effort was to focus attention on siting combinations i.e. sites and technologies which potentially offer more value to the Pueblo, in terms of a site's ability to score well on multiple siting criteria, maximize energy income and reduce impacts of development on the Pueblo.

Figure 1 shown below outlines the proposed down select process to be used for solar PV. A similar process would be used for wind and geothermal.

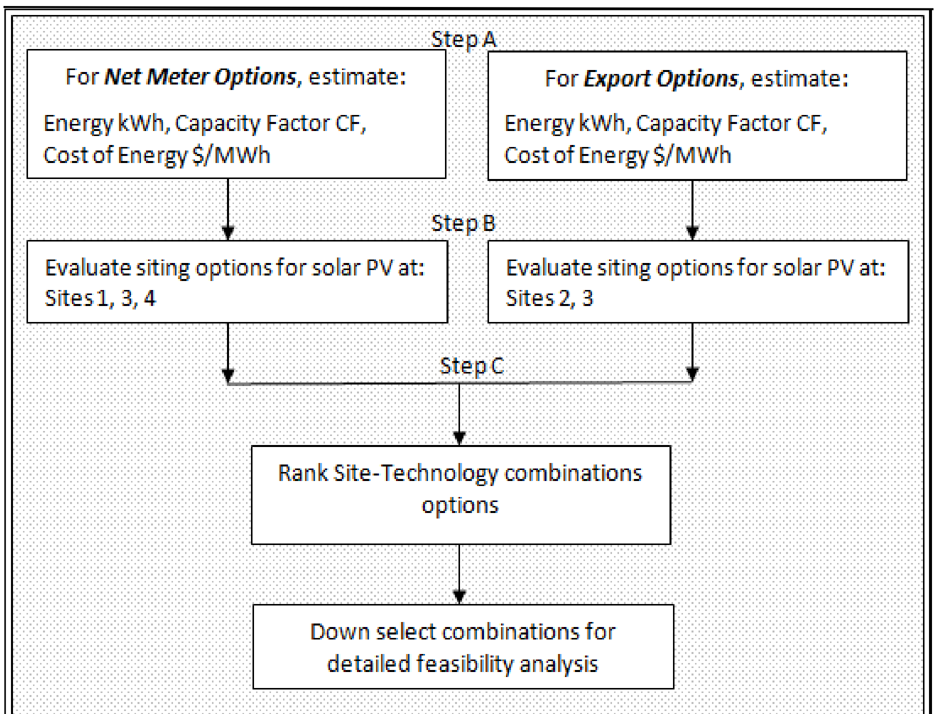


**Figure 1. Down Select Process: Zia Siting and Technology Options**

Six siting combinations were tentatively identified as possible candidates for more detailed **Step B and Step C** evaluation. 'Combined Siting Options' shown below in Table 1 identifies technology combinations by proposed site locations within each row evaluated for **Step A**. For example, Option 1 includes development of geothermal, solar PV and wind. Total installed capacity equals approximately 7,200 kW. Option 1 will generate approximately 27,700,000 kWh of electricity annually. Zia may also choose, on the basis of additional selection criteria, to consider only one siting option for one technology[1] rather than developing two sites. This choice will reduce installed kW for each option listed in the table.

**Table 1. Zia Site/Technology Combinations Identified in Step A[2]**

| Combined Siting Options | Geothermal 2000 kW | Solar PV 1000 kW | Solar PV 8800 kW | Wind 4200 kW | Installed kW | Annual kWh (x1000) |
|---|---|---|---|---|---|---|
| **1** | Site 2 | Site 1 | N/A | Site 2 | 7,200 | 27,000 |
| **2** | Sites 1, 2 | Site 1 | N/A | Site 2 | 9,200 | 42,600 |
| **3** | Sites 1, 2 | N/A | Site 2 or 4 | N/A | 12,800 | 45,200 |
| **4** | Sites 1, 2 | N/A | Site 2 or 3 | N/A | 12,800 | 45,200 |
| **5** | Sites 1, 2 | Site 1 | Site 2 or 4 | N/A | 13,800 | 47,000 |
| **6** | Sites 1, 2 | Site 1 | Site 2 or 3 | N/A | 13,800 | 47,000 |

These combinations were highlighted during Zia's proposal process because the technologies and capacities proposed at each site offered the potential for higher annual energy production and higher capacity factors; these characteristics also raise the likelihood of higher purchase power (PPA) prices being paid for energy generated for sellback purposes.

This report includes a down select matrix of the candidate commercial technologies with additional performance and siting characteristics for the Zia's sites such as:

- Technology maturity
- Relevant size or capacity
- Efficiency or capacity factors
- Operational requirements such as water supply, personnel, and land
- Emissions
- Capital costs
- Operations and Maintenance costs
- Levelized costs (as $/kWh or $/MMBtu)
- Natural gas assist (firming)
- Fossil fuel reduction

For all proposed renewable generation sites, a variety of land use factors will be relevant to this study including: all current and future connections to electric distribution lines, operating voltage kV; road access to remote sections of site; location of playas, arroyos, swales and other major topographic features; how the site is currently being used i.e., cattle are restricted

[1] For example, two geothermal sites are proposed for evaluation during this study however one site may prove to be infeasible or uneconomic.

[2] "1, 2" means Sites 1 and 2 are developed using this technology; "2 or 4" means Sites 2 or 4 are developed; "N/A" means the site will not be developed using this technology.

to specific parcels, etc; access to natural gas wells or commercial gas pipelines, mmcf per year capacity; pending changes of land ownership or legal status; and, tribal views on large-scale project development, business goals, and expected outcomes for renewable projects..

## 3. SITE SCORING PROCESS

An interactive scoring process intended to be used by Zia's project development team was outlined in early December, 2012. Blank scoring sheets are shown in Appendix A. The selection criteria were subdivided into three major categories: Scoring; Cost/Income; and Environment. A total of fifteen factors were considered for each site. To ensure standardized responses, the following scoring guidelines were issued to all evaluators prior to the actual work session[3]:

- First, review the site overview shown in Appendix B. All sites are shown as Google Earth images, a rough footprint is outlined for each proposed project area. For Sites 1 and 2, crest lines are highlighted for proposed wind turbine siting.
- The Scoring worksheet summarizes all top-level site factors to be scored. Some of these such as "Business structure", "Cultural impact" and "Tribal capacity" need to be defined, so we all understand this in an identical way. Appendix C contains a discussion of factors for reference.
- The Cost/Income worksheet provides background on the technologies that our proposal assumed. We can use this to score project costs and income, so there are columns listed for scoring. We transfer total scores from this sheet to page 1. So, we should probably start with page 2 then move to page 3.
- The Environment worksheet provides background on a variety of environmental impacts. There are two columns at the left especially acres footprint- these are the only factors that can be easily assigned number values at this point. Again, we'll transfer total scores from this sheet to page 1.
- Note the 1-2-3 scoring scale described at the top of each sheet. We need to use it consistently as values are entered, you can choose fractional values if necessary ex. 2.5 not 2 or 3, but I recommend that we try to use whole numbers if possible. Also I recommend that "0" values be entered under any factors you aren't qualified to address, instead of trying to rate the factor. Disqualify yourself from all four sites, if you choose to not score any factors.

## 4. SITE SCORING/OTHER KEY FINDINGS

A list of key questions to be answered for each scoring factor are shown in Appendix C. This material was presented for consideration by all evaluators during the December 19$^{th}$ work session. It was important that each evaluator maintain ***generality*** i.e. questions highlight general

[3] A total of ten evaluators participated in this process including Zia's Governor and Business Administrator held at Zia's Tribal Office on December 19$^{th}$. Two evaluators combined scores with other evaluators, resulting in eight distinct scores.

concerns related to each siting factor. The scoring process did not require examples such as specific regulations for environmental controls to be considered. Instead it was necessary to abstract a general idea of how each factor could impact a site. If possible evaluators were asked to score sites on a "binary" basis, which indicates only high or low impact is likely for a given factor. Some factors could not be scored in a binary fashion, since the range of possible impacts was too large. Reducing this range would require more detailed feasibility analysis which defeats the purpose of conducting a preliminary site down select. If any issues were identified that could be significant concerns during a later phase of the project they were documented. Table 2 summarizes raw site scores recorded during the December 19th session.

**Table 2. Raw Site Scores- Tribal versus Non Tribal**

| Combined Siting Options | Sum Tribal Score | Sum Non Tribal Score | Total Site Score | Score Variance |
|---|---|---|---|---|
| **Site 1 Roberts Tower** | 50 | 177 | 227 | 69.7 |
| **Site 2 Hot Springs** | 49 | 167 | 216 | 37.7 |
| **Site 3 Substation** | 59 | 211 | 270 | 82.2 |
| **Site 4 Zia Enterprise Zone ZEZ** | 58 | 220 | 278 | 101.1 |

Scoring listed in Table 2 is subdivided into Tribal and non Tribal scores, Total site score equals the sum of these values. A score variance is also listed; it indicates that evaluators agreed most consistently (lowest variance) on Site 2's score but agreed least consistently (highest variance) on Site 4's score. Figure 2 plots the subdivision of Tribal and non Tribal scores.

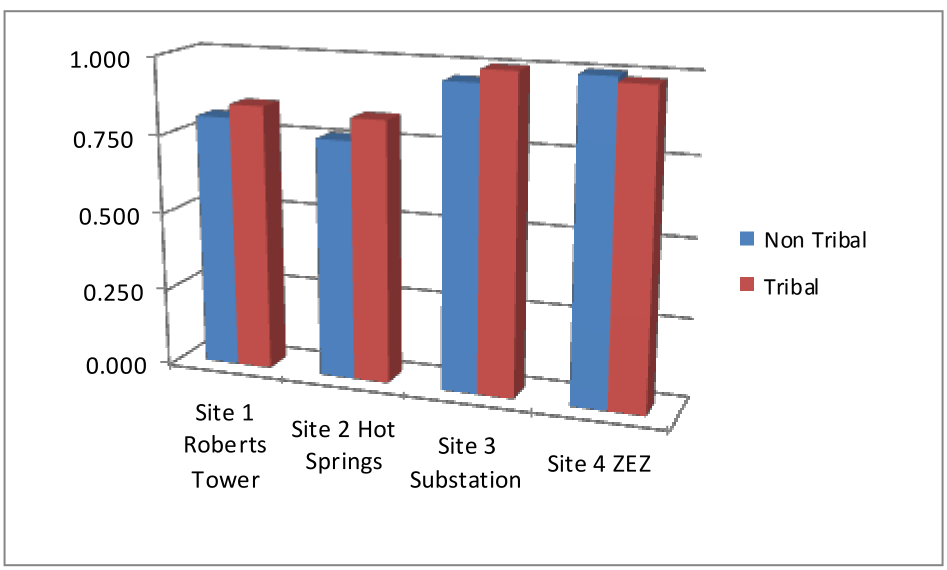


**Figure 2. Tribal Versus Non Tribal Scores (Normalized)**

Figure 2 indicates, while the number of non Tribal evaluators was larger[4], site scores within each evaluator category follow a similar pattern. In this plot all scores were normalized (scaled) by the maximum value recorded in each category. Sites 3 and 4 received consistently higher scores than Sites 1 and 2.

The ultimate value of this exercise was to evaluate ***combinations*** of sites and technologies, not only individual sites. As shown in Table 1, six siting combinations were previously identified as being potentially capable of maximizing energy income for the Pueblo. When site scores are combined into siting combinations, the resulting scores listed in Tables 3 are obtained (refer to Table 1 for a description of sites and technologies).

**Table 3. Combination Site Scores**

| Combined Siting Options | Geothermal 2000 kW | Solar PV 1000 kW | Solar PV 8800 kW | Wind 4200 kW | Combination Score |
|---|---|---|---|---|---|
| **1** | 216 | 227 | N/A | 216 | 659 |
| **2** | 222 | 227 | N/A | 216 | 665 |
| **3** | 222 | N/A | 278 | N/A | 500 |
| **4** | 222 | N/A | 270 | N/A | 492 |
| **5** | 222 | 227 | 278 | N/A | 727 |
| **6** | 222 | 227 | 270 | N/A | 719 |

Combination Score equals the sum of scores listed for each site and technology. As shown in Table 3, the following conclusions can be identified:

- Combinations 5, 6 exhibit highest scores
- Combinations 3, 4 exhibit lowest scores.
- Combinations 1, 2 exhibit scores that fall within 10% of Combinations 5, 6

After review of these results and discussions by Zia's project team Combinations 2 and 5 were selected for detailed feasibility analysis.

Key factors which served as the basis for this decision are: Selection of only Combinations 5, 6 would eliminate wind as a technology option; therefore Combinations 1, 2 were given equal weight. It was important to retain options for geothermal development at Sites 1 and 2 which eliminated Combination 1 from consideration. Lack of significant transmission capacity at Site 1 will be a negative development factor; however this cost will be represented in feasibility analysis of geothermal options. Exposure of wind turbines on the ridge line at Site 1 is a negative development factor; also Zia's property boundary does not allow large setback distances from

[4] Due to the number of non Tribal evaluators actually present during the December 19th session, this group contributed about 75% of total score value.

the ridge line at this site. Prior wind site assessments by Duke Energy at Mesa Prieta near Sites 2 and 3, plus access to transmission corridors, suggests heavier weight needs to be given to this site for wind development.

To simplify follow-on discussions, each combination was relabeled as: Combination 2- Combination A; Combination 5- Combination B. These two combinations offer significantly different technology mixes and capacities, anchored by the location of geothermal development. Their main features are summarized below:

- If ***Geothermal-Wind-Solar (Combination A)*** is developed at Sites 1, 3 or 4, geothermal , solar , and wind capacity is installed; total nameplate capacity equals 3,000 kW.

- If ***Solar-Geothermal (Combination B)*** is developed at Sites 1, 3 and/or 4 geothermal and , solar capacity is installed wind capacity is not developed; total nameplate capacity equals 3,000 kW.

Notably both Combinations are projected to generate nearly equal levels of Net Metered energy; however their annual capacity factors[5] differ substantially. This difference results from the embedded proportions of non-variable geothermal energy versus variable wind and solar energ

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[5] Estimated capacity factors are Combination A, 78%; Combination B, 25%; capacity factor equals actual energy generated divided by maximum energy potentially generated based on nameplate ratings; a lower capacity factor plant may require higher levels of firming to reduce variability, which incurs higher operating cost.

## APPENDIX H, GEOTHERMAL ELECTRIC PLANT SITE 1, OUTPUT AND ESTIMATES:

| Site 1, Summary Economics, Geothermal Electric | |
|---|---|
| First Year Electricity Sales Price, $/kWh | $0.07989 |
| Grants/Incentives | $500,000 |
| Production Tax Credit, $/kWh | $0.0230 |
| Green Tag Value | $0.0100 |
| Wheeling Costs | $0.0055 |
| Royalty Rate | 7.0% |
| Local Property Tax Rate | 0.0% |
| NM State Tax Rate | 5.0% |
| Federal Tax Rate | 37.0% |
| Depreciation Term Years | 5 |
| Electricity Escalation Rate | 0.0% |
| Analysis Term, Years | 20 |
| Discount Rate (NPV Analysis) | 4.5% |
| Internal Rate of Return | 7.50% |
| Installed Plant Cost | $27,573,832 |
| Simple Payback Years | 11.26 |

| Site 1, Geothermal Electric, Operating Parameters | |
|---|---|
| Rejection Temperature, °F | 60 |
| Maximum (Carnot) Efficiency | 29.7% |
| Turbine Isentropic Efficiency | 88.0% |
| Geothermal Brine Exit Temp, °F | 110.0 |
| Gross Thermal Efficiency | 14.9% |
| Net Thermal Efficiency (Parasitic Loads Included) | 14.0% |
| Transmission Losses | 4.5% |
| | |
| Annual MWHs Produced | 30,660 |
| Geothermal MWHs Produced | 10,220 |
| Solar MWHs Produced | 20,440 |
| | |
| O&M Cost, Cost/kWH | $0.015 |
| O&M Escalation Rate, Percent | 0.0% |
| Tons of Carbon Offset/Year | 2,449 |
| Tons of Carbon Offset/30 Yrs | 73,481 |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

| Plant Net Output, kW | Percent on Line | Plant Nominal Size, kW | Parasitic Load, Production Well Pump, kW | Parasitic Load, Cooling Tower | Total Parasitic Load, CT and PW, kW | Temperature, °F | Geothermal Flow, GPM |
|---|---|---|---|---|---|---|---|
| 4,349 | 95.0% | 4,629 | 102 | 178 | 279.8 | 280 | 1,250 |

| **Monthly Temperature, Plant Output, Transmission Losses and Net Power** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Average Temperature, °F | Average Plant Output, kW | Plant Output, kWH | Transmission Losses, kWH | Net Power On line, kWH | Percent Change | Value of Power |
| Jan | 27.5 | 4,062 | 2,871,274 | 129,207 | 2,742,067 | 12% | $219,058 |
| Feb | 31.5 | 3,998 | 2,552,350 | 114,856 | 2,437,495 | 10% | $194,726 |
| Mar | 34.2 | 3,955 | 2,795,406 | 125,793 | 2,669,613 | 9% | $213,269 |
| Apr | 37.4 | 3,904 | 2,670,115 | 120,155 | 2,549,960 | 8% | $203,711 |
| May | 43.7 | 3,802 | 2,687,433 | 120,935 | 2,566,499 | 5% | $205,032 |
| Jun | 49.9 | 3,703 | 2,532,629 | 113,968 | 2,418,661 | 2% | $193,221 |
| Jul | 54.7 | 3,624 | 2,561,757 | 115,279 | 2,446,478 | 0% | $195,444 |
| Aug | 53.3 | 3,648 | 2,578,426 | 116,029 | 2,462,397 | 1% | $196,715 |
| Sep | 48.2 | 3,730 | 2,551,174 | 114,803 | 2,436,371 | 3% | $194,636 |
| Oct | 40.8 | 3,848 | 2,720,031 | 122,401 | 2,597,630 | 6% | $207,519 |
| Nov | 33.1 | 3,971 | 2,716,491 | 122,242 | 2,594,249 | 10% | $207,249 |
| Dec | 27.8 | 4,058 | 2,867,901 | 129,056 | 2,738,845 | 12% | $218,800 |
| **Annual Totals** | | | **32,104,988** | | **30,660,264** | | **$2,449,381** |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

**Site 1, Geothermal Electric Annual Cash Flow Estimate**

| | Year | Year | Year | Year | Year |
|---|---|---|---|---|---|
| Ending Year | 1 | 2 | 3 | 4 | 5 |
| Elect Revenue | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 |
| Wheeling Costs | ($168,631) | ($168,631) | ($168,631) | ($168,631) | ($168,631) |
| Royalty to Zia | ($192,919) | ($192,919) | ($192,919) | ($192,919) | ($192,919) |
| O&M | ($459,904) | ($459,904) | ($459,904) | ($459,904) | ($459,904) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | ($5,514,766) | ($5,514,766) | ($5,514,766) | ($5,514,766) | ($5,514,766) |
| Taxable Income | ($3,580,237) | ($3,580,237) | ($3,580,237) | ($3,580,237) | ($3,580,237) |
| Federal Income Tax | $1,324,688 | $1,324,688 | $1,324,688 | $1,324,688 | $1,324,688 |
| NM Income Tax | $179,012 | $179,012 | $179,012 | $179,012 | $179,012 |
| Federal PTC | $705,186 | $705,186 | $705,186 | $705,186 | $705,186 |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | $2,208,886 | $2,208,886 | $2,208,886 | $2,208,886 | $2,208,886 |
| Net Cash Flow | ($23,430,417) | $4,143,415 | $4,143,415 | $4,143,415 | $4,143,415 |
| Cumulative Cash Flow | ($23,430,417) | ($19,287,003) | ($15,143,588) | ($11,000,173) | ($6,856,758) |
| Present Value of Cash Flow | ($22,421,452) | $3,794,249 | $3,630,860 | $3,474,507 | $3,324,888 |
| Cumulative Present Value | ($22,421,452) | ($18,627,203) | ($14,996,343) | ($11,521,835) | ($8,196,948) |

**Site 1, Geothermal Electric Annual Cash Flow Estimate**

| | Year | Year | Year | Year | Year |
|---|---|---|---|---|---|
| Ending Year | 6 | 7 | 8 | 9 | 10 |
| Elect Revenue | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 |
| Wheeling Costs | ($168,631) | ($168,631) | ($168,631) | ($168,631) | ($168,631) |
| Royalty to Zia | ($192,919) | ($192,919) | ($192,919) | ($192,919) | ($192,919) |
| O&M | ($459,904) | ($459,904) | ($459,904) | ($459,904) | ($459,904) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $1,934,529 | $1,934,529 | $1,934,529 | $1,934,529 | $1,934,529 |
| Federal Income Tax | ($715,776) | ($715,776) | ($715,776) | ($715,776) | ($715,776) |
| NM Income Tax | $(96,726) | $(96,726) | $(96,726) | $(96,726) | $(96,726) |
| Federal PTC | $705,186 | $705,186 | $705,186 | $705,186 | $705,186 |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | ($107,316) | ($107,316) | ($107,316) | ($107,316) | ($107,316) |
| Net Cash Flow | $1,827,213 | $1,827,213 | $1,827,213 | $1,827,213 | $1,827,213 |
| Cumulative Cash Flow | ($5,029,545) | ($3,202,332) | ($1,375,119) | $452,093 | $2,279,306 |
| Present Value of Cash Flow | $1,403,109 | $1,342,688 | $1,284,869 | $1,229,540 | $1,176,593 |
| Cumulative Present Value | ($6,793,839) | ($5,451,151) | ($4,166,282) | ($2,936,742) | ($1,760,149) |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

| Site 1, Geothermal Electric Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 11 | 12 | 13 | 14 | 15 |
| Elect Revenue | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 |
| Wheeling Costs | ($168,631) | ($168,631) | ($168,631) | ($168,631) | ($168,631) |
| Royalty to Zia | ($192,919) | ($192,919) | ($192,919) | ($192,919) | ($192,919) |
| O&M | ($459,904) | ($459,904) | ($459,904) | ($459,904) | ($459,904) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $1,934,529 | $1,934,529 | $1,934,529 | $1,934,529 | $1,934,529 |
| Federal Income Tax | ($715,776) | ($715,776) | ($715,776) | ($715,776) | ($715,776) |
| NM Income Tax | $(96,726) | $(96,726) | $(96,726) | $(96,726) | $(96,726) |
| Federal PTC | $0 | $0 | $0 | $0 | $0 |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | ($812,502) | ($812,502) | ($812,502) | ($812,502) | ($812,502) |
| Net Cash Flow | $1,122,027 | $1,122,027 | $1,122,027 | $1,122,027 | $1,122,027 |
| Cumulative Cash Flow | $3,401,333 | $4,523,360 | $5,645,387 | $6,767,414 | $7,889,440 |
| Present Value of Cash Flow | $691,392 | $661,619 | $633,128 | $605,864 | $579,774 |
| Cumulative Present Value | ($1,068,758) | ($407,139) | $225,989 | $831,853 | $1,411,627 |

| Site 1, Geothermal Electric Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 16 | 17 | 18 | 19 | 20 |
| Elect Revenue | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 | $2,755,983 |
| Wheeling Costs | ($168,631) | ($168,631) | ($168,631) | ($168,631) | ($168,631) |
| Royalty to Zia | ($192,919) | ($192,919) | ($192,919) | ($192,919) | ($192,919) |
| O&M | ($459,904) | ($459,904) | ($459,904) | ($459,904) | ($459,904) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $1,934,529 | $1,934,529 | $1,934,529 | $1,934,529 | $1,934,529 |
| Federal Income Tax | ($715,776) | ($715,776) | ($715,776) | ($715,776) | ($715,776) |
| NM Income Tax | $(96,726) | $(96,726) | $(96,726) | $(96,726) | $(96,726) |
| Federal PTC | $0 | $0 | $0 | $0 | $0 |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | ($812,502) | ($812,502) | ($812,502) | ($812,502) | ($812,502) |
| Net Cash Flow | $1,122,027 | $1,122,027 | $1,122,027 | $1,122,027 | $1,122,027 |
| Cumulative Cash Flow | $9,011,467 | $10,133,494 | $11,255,521 | $12,377,548 | $13,499,575 |
| Present Value of Cash Flow | $554,808 | $530,917 | $508,054 | $486,176 | $465,240 |
| Cumulative Present Value | $1,966,435 | $2,497,352 | $3,005,406 | $3,491,582 | $3,956,823 |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

| Expense Description | Amount | Cost per kWH | Comments |
|---|---|---|---|
| Well Field | | | |
| Royalty | $192,919 | $0.00629 | |
| Contracted Services | $22,850 | $0.00075 | Well/Pipe Maintenance |
| Power Plant | | | |
| Salaries | $77,691 | $0.00253 | One Full Time Equivalent |
| Benefits | $28,334 | $0.00092 | |
| Major Maintenance Expense | $73,121 | $0.00238 | |
| Contracted Services | $22,850 | $0.00075 | Plant Tuning, Checks Etc |
| Consumables | $13,710 | $0.00045 | Lubricants, Lights, General Maintenance |
| Chemicals | $19,194 | $0.00063 | |
| Cooling Water for Heat Reject | $13,710 | $0.00045 | Payment to Zia Pueblo |
| Safety | $7,312 | $0.00024 | |
| Other | $4,570 | $0.00015 | |
| Transmission Maintenance & Wheeling Cost | | | |
| Transmission Costs | $168,631 | $0.00550 | Wheeling To PNM |
| Transmission Line Maint | $1,371 | $0.00004 | Maintenance of Poles/Wires |
| Overhead Costs | | | |
| Legal Expense | $16,452 | $0.00054 | 80 hours of legal work per year |
| Management | $16,160 | $0.00053 | 4 hours per week @ $65/Hr |
| Property Taxes | $0 | $0.00000 | No Property Taxes on Zia Land |
| Insurance | $113,623 | $0.00371 | Insurance Coverage to be determined. |
| Accounting | $16,160 | $0.00053 | Part Time Accountant, Collecting Monthly Data |
| Other | $12,796 | $0.00042 | |
| Total Costs | $821,454 | $0.02679 | Sum of all Operating Costs |

| | |
|---|---|
| Royalty Rate Used In Annual Cash Flow Analysis, $/kWH | $0.00629 |
| Maint Cost Used in Annual Cash Flow Analysis, $/kWH | $0.01500 |
| Wheeling Cost Used in Annual Cash Flow Analysis, kWH | $0.00550 |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

| Site 1 Geothermal, Electric Transmission Cost Estimate | |
|---|---|
| Item | Cost |
| Interconnection Customer's (Zia Pueblo) Facility, Installation of SCADA equipment, Fiber-Optic line to Point of Interconnect substation, and associated engineering | $188,500 |
| Point of Interconnection Substation, Construction of a new, single-breaker substation including revenue metering, transfer-trip equipment, and microwave communications | $0 |
| New Transmission Line, 0.5 miles 22 kV, 3 wires, Wooden Posts | $132,500 |
| Upgrades, Jemez substation to facilitate transfer trip. | $50,000 |
| Network Upgrade, Jemez Substation, Engineering and installation of P & C equipment | $29,000 |
| Network Upgrade, Communications, Engineering/Installation of communications upgrades | $0 |
| Total Electric Connectivity | $400,000 |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

| Plant Characteristics | |
|---|---|
| Nominal Plant Size, MW | 4.63 |
| Plant Output, MW | 4,349 |
| Water Flow Rate, GPM | 1,250 |
| Resource Temperature, °F | 280 |
| Net Thermal Efficiency | 14.0% |

| Major Item | Cost | Comments |
|---|---|---|
| Well Drilling and Completion | $12,000,000 | Cost to Drill 2 Wells ~ 12,000 feet deep or less |
| Well Pumps (1), ea at 1200 GPM, with 400 Feet of Casing, Line Shaft and Fabricated Well Head | $99,163 | |
| Electric Motors for Pump (1) @ 500 HP Ea | $41,383 | |
| Flow Testing, Requires a Test Pump, Generator, Diesel Fuel, Instruments | $317,468 | Labor/Fuel/Equipment Rental for a 30 Day Test @ 1200 GPM, Assumes test pumps will be used for production |
| Transmission/Electrical (Approx 0.5 Miles of 69 kV transmission, substation, transformers controls, see attachment) | $400,000 | This is total cost of Transmission, which includes the regulatory requirements, rights of way, environmental, etc . . . |
| Plant | | |
| Site Work | $96,291 | Grading, Concrete, Fencing, Road Improvement |
| Pipe System | $390,000 | Pipe Connecting Wells, 2600' 10 Inch Pipe |
| Power Cycle Equipment | $11,572,864 | Estimate, Site Assembled |
| Permitting, Water Rights | $80,000 | Construction Permitting and Water Rights |
| Construction Labor/Site Assembly | $578,643 | 3 Month Site Assembly |
| Site Engineering | $747,515 | 3% Percentage of Well Pump, Transmission, Piping, Site Work, Pipe System, Electric Mtr, Drilling, 3% Power Plant Equipment |
| Construction Management | $920,504 | 4% Percent of All Except Power Plant, 3% Power Plant |
| Environmental Reviews | $30,000 | Project on Native American Land Minimal Review |
| PPA Negotiation/Contract | $300,000 | Simplified contract PNM or Other Utility Process |
| | | |
| **Total Cost** | **$27,573,832** | |

Appendix H, Geothermal Electric Plant Site 1, Output and Estimates:

| Heat Rejection, kBTU/Hr | Power Plant Gross Output, kWe | Efficiency |
|---|---|---|
| 90,413 | 4,629 | 14.87% |

| | | | |
|---|---|---|---|
| Water Evaporated | 84,434 | Lbs/Hr (Make Up Water) | |
| | 168.9 | Gal/Min (Make Up Water) | |
| Air Required | 3,194,806 | Lbs of Air/Hr | |
| Air Required | 709,957 | CFM | |
| Heat Rejected by Source | | | Percent of Heat Rej |
| Air | 7,668 | kBTU/Hr | 8.5% |
| Liq Water | 2,533 | kBTU/Hr | 2.8% |
| Water Vapor | 80,212 | kBTU/Hr | 88.7% |
| Total Heat Rejected | 90,413 | kBTU/Hr | 100.0% |

| | | | |
|---|---|---|---|
| CT Fan HP | 99 | 0.75 | CT Fan Pressure, Inches of Water |
| CT Fan kW | 78 | 0.85 | CT Fan Mechanical Efficiency |
| | | 0.94 | CT Fan Electrical Efficiency |
| CT Pump HP | 18.0 | 20 | CT Pump PSI |
| CT Pump kW | 14.3 | 0.78 | CT Pump Mechanical Eff |
| | | 0.94 | CT Pump Electrical Efficiency |
| | | 1,206 | CT Pump Flow |
| | | 15 | Water Temperature Rise Through HX |

| | | | |
|---|---|---|---|
| PW Shaft HP | 130.2 | 1,250 | PW Pump GPM |
| PW kW | 102.2 | 17 | PW Static Level |
| | | 200 | PW Drawdown |
| | | 40 | Plant Pressure Drop, PSI |
| | | 0.75 | PW Mech Efficiency |
| | | 0.95 | PW Elect Efficiency |

| | | |
|---|---|---|
| Saturation Humidity Ratio | | |
| 0.0080 | lb Water Vapor/Lb Dry Air @ 50F | PW = Production Well |
| 0.0157 | lb Water Vapor/Lb Dry Air @ 70F | CT = Cooling Tower |
| 0.0264 | lb Water Vapor/Lb Dry Air @ 85F | |

| | | | |
|---|---|---|---|
| 75 | Air Start Point, F | 55 | Water Start Point, F |
| 85 | Air End Point, F | 85 | Water End Point, F |
| 0.24 | Air Density, Lb/CF | | |
| 950 | Water Heat of Vaporization, BTU/Lb | | |

## APPENDIX I: SOLAR AND GEOTHERMAL PLANT SITE 1, OUTPUT AND ESTIMATES:

| Site 1 Solar Geothermal Combination, Summary Economics | |
|---|---|
| First Year Electricity Sales Price, $/kWh | $0.09192 |
| Grants/Incentives | $500,000 |
| Production Tax Credit, $/kWh | $0.0230 |
| Green Tag Value | $0.0100 |
| Wheeling Costs | $0.0055 |
| Royalty Rate | 7.0% |
| Local Property Tax Rate | 0.0% |
| NM State Tax Rate | 5.0% |
| Federal Tax Rate | 37.0% |
| Depreciation Term Years | 5 |
| Electricity Escalation Rate | 0.0% |
| Analysis Term, Years | 20 |
| Discount Rate (NPV Analysis) | 4.5% |
| Internal Rate of Return | 7.50% |
| Installed Plant Cost | $126,668,407 |
| Simple Payback Years | 13.28 |

| Geothermal and Solar Combination, Operating Parameters | |
|---|---|
| Rejection Temperature, °F | 60 |
| Maximum (Carnot) Efficiency | 48.5% |
| Turbine Isentropic Efficiency | 88.0% |
| Geothermal Brine Exit Temp, °F | 110.0 |
| Gross Thermal Efficiency | 22.8% |
| Net Thermal Efficiency (Parasitic Loads Included) | 22.4% |
| Transmission Losses | 4.5% |
| | |
| Annual MWHs Produced | 103,769 |
| Geothermal MWHs Produced | 34,590 |
| Solar MWHs Produced | 69,179 |
| | |
| O&M Cost, Cost/kWH | $0.015 |
| O&M Escalation Rate, Percent | 0.0% |
| Tons of Carbon Offset/Year | 9,538 |
| Tons of Carbon Offset/30 Yrs | 286,152 |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Plant Net Output, kW | Percent on Line | Plant Nominal Size, kW | Parasitic Load, Production Well Pump, kW | Parasitic Load, Cooling Tower | Total Parasitic Load, CT and PW, kW | Temperature, °F | Geothermal Flow, GPM |
|---|---|---|---|---|---|---|---|
| 14,720 | 95.0% | 15,000 | 102 | 178 | 279.8 | 280 | 1,250 |

| **Monthly Temperature, Plant Output, Transmission Losses and Net Power** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Average Temperature, °F | Average Plant Output, kW | Plant Output, kWH | Transmission Losses, kWH | Net Power On line, kWH | Percent Change | Value of Power |
| Jan | 27.5 | 13,749 | 9,717,741 | 437,298 | 9,280,443 | 12% | $1,002,503 |
| Feb | 31.5 | 13,531 | 8,638,353 | 388,726 | 8,249,627 | 10% | $891,151 |
| Mar | 34.2 | 13,386 | 9,460,967 | 425,744 | 9,035,224 | 9% | $976,014 |
| Apr | 37.4 | 13,212 | 9,036,923 | 406,662 | 8,630,262 | 8% | $932,269 |
| May | 43.7 | 12,869 | 9,095,538 | 409,299 | 8,686,239 | 5% | $938,316 |
| Jun | 49.9 | 12,532 | 8,571,607 | 385,722 | 8,185,885 | 2% | $884,266 |
| Jul | 54.7 | 12,267 | 8,670,191 | 390,159 | 8,280,032 | 0% | $894,436 |
| Aug | 53.3 | 12,347 | 8,726,606 | 392,697 | 8,333,909 | 1% | $900,256 |
| Sep | 48.2 | 12,623 | 8,634,371 | 388,547 | 8,245,824 | 3% | $890,741 |
| Oct | 40.8 | 13,025 | 9,205,864 | 414,264 | 8,791,600 | 6% | $949,697 |
| Nov | 33.1 | 13,441 | 9,193,881 | 413,725 | 8,780,156 | 10% | $948,461 |
| Dec | 27.8 | 13,733 | 9,706,324 | 436,785 | 9,269,540 | 12% | $1,001,326 |
| **Annual Totals** | | | **108,658,367** | | **103,768,740** | | **$11,209,435** |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Site 1, Geothermal and Solar Combination, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 1 | 2 | 3 | 4 | 5 |
| Elect Revenue | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 |
| Wheeling Costs | ($570,728) | ($570,728) | ($570,728) | ($570,728) | ($570,728) |
| Royalty to Zia | ($740,327) | ($740,327) | ($740,327) | ($740,327) | ($740,327) |
| O&M | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | ($25,333,681) | ($25,333,681) | ($25,333,681) | ($25,333,681) | ($25,333,681) |
| Taxable Income | ($17,625,172) | ($17,625,172) | ($17,625,172) | ($17,625,172) | ($17,625,172) |
| Federal Income Tax | $6,521,314 | $6,521,314 | $6,521,314 | $6,521,314 | $6,521,314 |
| NM Income Tax | $881,259 | $881,259 | $881,259 | $881,259 | $881,259 |
| Federal PTC | $2,386,681 | $2,386,681 | $2,386,681 | $2,386,681 | $2,386,681 |
| NM PTC | $1,867,837 | $1,867,837 | $1,867,837 | $1,867,837 | $1,867,837 |
| Total Tax Savings | $11,657,091 | $11,657,091 | $11,657,091 | $11,657,091 | $11,657,091 |
| Net Cash Flow | ($107,302,807) | $19,365,600 | $19,365,600 | $19,365,600 | $19,365,600 |
| Cumulative Cash Flow | ($107,302,807) | ($87,937,207) | ($68,571,607) | ($49,206,007) | ($29,840,407) |
| Present Value of Cash Flow | ($102,682,112) | $17,733,660 | $16,970,010 | $16,239,244 | $15,539,946 |
| Cumulative Present Value | ($102,682,112) | ($84,948,452) | ($67,978,443) | ($51,739,199) | ($36,199,253) |

| Site 1, Geothermal and Solar Combination, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 6 | 7 | 8 | 9 | 10 |
| Elect Revenue | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 |
| Wheeling Costs | ($570,728) | ($570,728) | ($570,728) | ($570,728) | ($570,728) |
| Royalty to Zia | ($740,327) | ($740,327) | ($740,327) | ($740,327) | ($740,327) |
| O&M | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $7,708,509 | $7,708,509 | $7,708,509 | $7,708,509 | $7,708,509 |
| Federal Income Tax | $(2,852,148) | $(2,852,148) | $(2,852,148) | $(2,852,148) | $(2,852,148) |
| NM Income Tax | $(385,425) | $(385,425) | $(385,425) | $(385,425) | $(385,425) |
| Federal PTC | $2,386,681 | $2,386,681 | $2,386,681 | $2,386,681 | $2,386,681 |
| NM PTC | $1,867,837 | $1,867,837 | $1,867,837 | $1,867,837 | $1,867,837 |
| Total Tax Savings | $1,016,944 | $1,016,944 | $1,016,944 | $1,016,944 | $1,016,944 |
| Net Cash Flow | $8,725,454 | $8,725,454 | $8,725,454 | $8,725,454 | $8,725,454 |
| Cumulative Cash Flow | ($21,114,953) | ($12,389,499) | ($3,664,046) | $5,061,408 | $13,786,862 |
| Present Value of Cash Flow | $6,700,239 | $6,411,712 | $6,135,609 | $5,871,397 | $5,618,561 |
| Cumulative Present Value | ($29,499,014) | ($23,087,303) | ($16,951,693) | ($11,080,297) | ($5,461,735) |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Site 1, Geothermal and Solar Combination, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | **Year** | **Year** | **Year** | **Year** | **Year** |
| Ending Year | 11 | 12 | 13 | 14 | 15 |
| Elect Revenue | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 |
| Wheeling Costs | ($570,728) | ($570,728) | ($570,728) | ($570,728) | ($570,728) |
| Royalty to Zia | ($740,327) | ($740,327) | ($740,327) | ($740,327) | ($740,327) |
| O&M | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $7,708,509 | $7,708,509 | $7,708,509 | $7,708,509 | $7,708,509 |
| Federal Income Tax | $(2,852,148) | $(2,852,148) | $(2,852,148) | $(2,852,148) | $(2,852,148) |
| NM Income Tax | $(385,425) | $(385,425) | $(385,425) | $(385,425) | $(385,425) |
| Federal PTC | $- | $- | $- | $- | $- |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | $(3,237,574) | $(3,237,574) | $(3,237,574) | $(3,237,574) | $(3,237,574) |
| Net Cash Flow | $4,470,935 | $4,470,935 | $4,470,935 | $4,470,935 | $4,470,935 |
| Cumulative Cash Flow | $18,257,797 | $22,728,733 | $27,199,668 | $31,670,604 | $36,141,539 |
| Present Value of Cash Flow | $2,754,985 | $2,636,349 | $2,522,822 | $2,414,184 | $2,310,224 |
| Cumulative Present Value | ($2,706,751) | ($70,401) | $2,452,421 | $4,866,604 | $7,176,828 |

| Site 1, Geothermal and Solar Combination, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | **Year** | **Year** | **Year** | **Year** | **Year** |
| Ending Year | 16 | 17 | 18 | 19 | 20 |
| Elect Revenue | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 | $10,576,095 |
| Wheeling Costs | ($570,728) | ($570,728) | ($570,728) | ($570,728) | ($570,728) |
| Royalty to Zia | ($740,327) | ($740,327) | ($740,327) | ($740,327) | ($740,327) |
| O&M | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) | ($1,556,531) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $7,708,509 | $7,708,509 | $7,708,509 | $7,708,509 | $7,708,509 |
| Federal Income Tax | $(2,852,148) | $(2,852,148) | $(2,852,148) | $(2,852,148) | $(2,852,148) |
| NM Income Tax | $(385,425) | $(385,425) | $(385,425) | $(385,425) | $(385,425) |
| Federal PTC | $- | $- | $- | $- | $- |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | $(3,237,574) | $(3,237,574) | $(3,237,574) | $(3,237,574) | $(3,237,574) |
| Net Cash Flow | $4,470,935 | $4,470,935 | $4,470,935 | $4,470,935 | $4,470,935 |
| Cumulative Cash Flow | $40,612,475 | $45,083,410 | $49,554,346 | $54,025,281 | $58,496,217 |
| Present Value of Cash Flow | $2,210,740 | $2,115,541 | $2,024,441 | $1,937,264 | $1,853,841 |
| Cumulative Present Value | $9,387,569 | $11,503,110 | $13,527,551 | $15,464,815 | $17,318,657 |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Expense Description | Amount | Cost per kWH | Comments |
|---|---|---|---|
| | | Well Field | |
| Royalty | $740,327 | $0.00713 | |
| Contracted Services | $77,336 | $0.00075 | Well/Pipe Maintenance |
| | | Power Plant | |
| Salaries | $262,942 | $0.00253 | One Full Time Equivalent |
| Benefits | $95,896 | $0.00092 | |
| Major Maintenance Expense | $247,475 | $0.00238 | |
| Contracted Services | $77,336 | $0.00075 | Plant Tuning, Checks Etc |
| Consumables | $46,402 | $0.00045 | Lubricants, Lights, General Maintenance |
| Chemicals | $64,962 | $0.00063 | |
| Cooling Water for Heat Reject | $46,402 | $0.00045 | Payment to Zia Pueblo |
| Safety | $24,747 | $0.00024 | |
| Other | $15,467 | $0.00015 | |
| | | Transmission Maintenance & Wheeling Cost | |
| Transmission Costs | $570,728 | $0.00550 | Wheeling To PNM |
| Transmission Line Maint | $4,640 | $0.00004 | Maintenance of Poles/Wires |
| | | Overhead Costs | |
| Legal Expense | $55,682 | $0.00054 | 80 hours of legal work per year |
| Management | $54,692 | $0.00053 | 4 hours per week @ $65/Hr |
| Property Taxes | $0 | $0.00000 | No Property Taxes on Zia Land |
| Insurance | $384,552 | $0.00371 | Insurance Coverage to be determined. |
| Accounting | $54,692 | $0.00053 | Part Time Accountant, Collecting Monthly Data |
| Other | $43,308 | $0.00042 | |
| Total Costs | $2,867,586 | $0.02763 | Sum of all Operating Costs |

| | |
|---|---|
| Royalty Rate Used In Annual Cash Flow Analysis, $/kWH | $0.00713 |
| Maint Cost Used in Annual Cash Flow Analysis, $/kWH | $0.01500 |
| Wheeling Cost Used in Annual Cash Flow Analysis, kWH | $0.00550 |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Site 1, Geothermal and Solar Combination Electric Transmission Cost Estimate | |
|---|---|
| Item | Cost |
| Interconnection Customer's (Zia Pueblo) Facility, Installation of SCADA equipment, Fiber-Optic line to Point of Interconnect substation, and associated engineering | $150,000 |
| Point of Interconnection Substation, Construction of a new, single-breaker substation including revenue metering, transfer-trip equipment, and microwave communications | $300,000 |
| New Transmission Line, 18 miles 69 kV, 3 wires, Wooden Posts | $3,600,000 |
| Upgrades, Jemez substation to facilitate transfer trip. | $50,000 |
| Network Upgrade, Jemez Substation, Engineering and installation of P & C equipment | $30,000 |
| Network Upgrade, Communications, Engineering/Installation of communications upgrades | $50,000 |
| Total Electric Connectivity | $4,180,000 |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Plant Characteristics | |
|---|---|
| Nominal Plant Size, MW | 15.00 |
| Plant Output, MW | 14,720 |
| Water Flow Rate, GPM | 1,250 |
| Resource Temperature, °F | 196 |
| Net Thermal Efficiency | 22.4% |

| Major Item | Cost | Comments |
|---|---|---|
| Well Drilling and Completion | $12,000,000 | Cost to Drill 2 Wells ~ 12,000 feet deep or less |
| Well Pumps (1), ea at 1200 GPM, with 400 Feet of Casing, Line Shaft and Fabricated Well Head | $99,163 | |
| Electric Motors for Pump (1) @ 500 HP Ea | $41,383 | |
| Flow Testing, Requires a Test Pump, Generator, Diesel Fuel, Instruments | $317,468 | Labor/Fuel/Equipment Rental for a 30 Day Test @ 1200 GPM, Assumes test pumps will be used for production |
| Transmission/Electrical (transmission, substation, transformers controls, see attachment) | $4,180,000 | This is total cost of Transmission, which includes the regulatory requirements, rights of way, environmental, etc . . . |
| Plant | | |
| Site Work | $200,000 | Grading, Concrete, Fencing, Road Improvement |
| Pipe System | $390,000 | Pipe Connecting Wells, 2600' 10 Inch Pipe |
| Power Cycle Equipment | $30,000,000 | Estimate, Site Assembled |
| Permitting, Water Rights | $80,000 | Construction Permitting and Water Rights |
| Construction Labor/Site Assembly | $1,350,000 | 3 Month Site Assembly |
| Site Engineering | $1,416,840 | 3% Percentage of Well Pump, Transmission, Piping, Site Work, Pipe System, Electric Mtr, Drilling, 3% Power Plant Equipment |
| Construction Management | $1,659,521 | 4% Percent of All Except Power Plant, 3% Power Plant |
| Environmental Reviews | $30,000 | Project on Native American Land Minimal Review |
| PPA Negotiation/Contract | $300,000 | Simplified contract PNM or Other Utility Process |
| st Per kW w/o Const Interest, Contingency) | **$52,064,375** | |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Solar Field Summary Stats/Cost | |
|---|---|
| Solar Field Aperture, Square Meters | 131,684 |
| Solar Field Aperture, Acres | 33 |
| Storage Size $kWH_{thermal}$ | 295,132 |
| | |
| Solar Field | $38,846,780 |
| HTF Component | $11,851,560 |
| Storage Component (12 Hours Bottom Cycle Only) | $23,905,692 |
| | |
| Total Solar Cost | $74,604,032 |

| Solar Field Component | Material Cost ($\$/m^2$) | Labor Cost ($\$/m^2$) | Total Cost ($\$/m^2$) |
|---|---|---|---|
| Mirrors | $48 | - | $48 |
| Receiver Tubes & Fittings | $70 | - | $70 |
| Collector Frames | $79 | - | $79 |
| Misc. Collector Components | $2 | - | $2 |
| Foundations and Support Structures | $18 | - | $18 |
| Instrumentation & Controls | $8 | $0 | $8 |
| Electrical | $2 | $1 | $3 |
| Field Installation | - | $62 | $62 |
| Fabrication Tent | $1 | $1 | $1 |
| Sun Tracker | $4 | - | $4 |
| **Totals** | **$231** | **$64** | **$295** |

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| **HTF Component** | **Material Cost ($/m$^2$)** | **Labor Cost ($/m$^2$)** | **Total Cost ($/m$^2$)** |
|---|---|---|---|
| Freeze Protection System | $1 | $0 | $1 |
| Ullage System | $1 | $0 | $1 |
| Pumps | $6 | $0 | $6 |
| Expansion and Blanketing Systems | $7 | $1 | $8 |
| Solar Field Piping | $34 | $15 | $49 |
| Power Block Piping | $1 | $0 | $1 |
| Foundations and Supports | $1 | $1 | $2 |
| Fluid | $22 | - | $22 |
| Totals | **$73** | **$17** | **$90** |

| **Storage Component (12 Hours Bottom Cycle)** | **Material Cost ($/m$^2$)** | **Labor Cost ($/m$^2$)** | **Total Cost ($/m$^2$)** | **Total Cost ($/kWh$_{thermal}$)** |
|---|---|---|---|---|
| Pumps & Heat Exchangers | $33 | $2 | $35 | $17 |
| Tanks | $44 | $6 | $50 | $25 |
| Storage Fluid | $72 | $1 | $73 | $36 |
| Piping and Fittings | $1 | $1 | $2 | $1 |
| Foundations and Support Structures | $0 | $1 | $1 | $0 |
| Instrumentation & Controls | $3 | $4 | $7 | $3 |
| Electrical | - | - | $0 | $0 |
| Totals | **$153** | **$14** | **$167** | **$81** |

* Cost Data taken From, “Line-Focus Solar Power Plant Cost Reduction Plan,” Charles Kutscher, Mark Mehos, Craig Turchi, and Greg Glatzmaier Sandia National Laboratory, 2010.

Appendix I, Solar and Geothermal Plant Site 1, Output and Estimates:

| Heat Rejection, kBTU/Hr | Power Plant Gross Output, kWe | Efficiency |
|---|---|---|
| 173,294 | 15,000 | 22.80% |

| | | |
|---|---|---|
| Water Evaporated | 161,834 | Lbs/Hr (Make Up Water) |
| | 323.8 | Gal/Min (Make Up Water) |
| Air Required | 6,123,463 | Lbs of Air/Hr |
| Air Required | 1,360,770 | CFM |

| Heat Rejected by Source | | | Percent of Heat Rej |
|---|---|---|---|
| Air | 14,696 | kBTU/Hr | 8.5% |
| Liq Water | 4,855 | kBTU/Hr | 2.8% |
| Water Vapor | 153,743 | kBTU/Hr | 88.7% |
| Total Heat Rejected | 173,294 | kBTU/Hr | 100.0% |

| | | | |
|---|---|---|---|
| CT Fan HP | 189 | 0.75 | CT Fan Pressure, Inches of Water |
| CT Fan kW | 150 | 0.85 | CT Fan Mechanical Efficiency |
| | | 0.94 | CT Fan Electrical Efficiency |
| CT Pump HP | 34.5 | 20 | CT Pump PSI |
| CT Pump kW | 27.4 | 0.78 | CT Pump Mechanical Eff |
| | | 0.94 | CT Pump Electrical Efficiency |
| | | 2,312 | CT Pump Flow |
| | | 15 | Water Temperature Rise Through HX |

| | | | |
|---|---|---|---|
| PW Shaft HP | 130.2 | 1,250 | PW Pump GPM |
| PW kW | 102.2 | 17 | PW Static Level |
| | | 200 | PW Drawdown |
| | | 40 | Plant Pressure Drop, PSI |
| | | 0.75 | PW Mech Efficiency |
| | | 0.95 | PW Elect Efficiency |

| Saturation Humidity Ratio | | |
|---|---|---|
| 0.0080 | lb Water Vapor/Lb Dry Air @ 50F | PW = Production Well |
| 0.0157 | lb Water Vapor/Lb Dry Air @ 70F | CT = Cooling Tower |
| 0.0264 | lb Water Vapor/Lb Dry Air @ 85F | |

| | | | |
|---|---|---|---|
| 75 | Air Start Point, F | 55 | Water Start Point, F |
| 85 | Air End Point, F | 85 | Water End Point, F |
| 0.24 | Air Density, Lb/CF | | |
| 950 | Water Heat of Vaporization, BTU/Lb | | |

## APPENDIX J: GEOTHERMAL ELECTRIC PLANT SITE 2, OUTPUT AND ESTIMATES:

| Site 2, Summary Economics | |
|---|---|
| First Year Electricity Sales Price, $/kWh | $0.21971 |
| Grants/Incentives | $500,000 |
| Production Tax Credit, $/kWh | $0.0220 |
| Green Tag Value | $0.0050 |
| Wheeling Costs | $0.0055 |
| Royalty Rate | 7.0% |
| Local Property Tax Rate | 0.0% |
| NM State Tax Rate | 5.0% |
| Federal Tax Rate | 37.0% |
| Depreciation Term Years | 5 |
| Electricity Escalation Rate | 0.0% |
| Analysis Term, Years | 20 |
| Discount Rate (NPV Analysis) | 4.5% |
| Internal Rate of Return | 7.50% |
| Installed Plant Cost | $5,447,734 |
| Simple Payback Years | 9.35 |

| Site 2, Operating Parameters | |
|---|---|
| Rejection Temperature, $^{o}$F | 60 |
| Maximum (Carnot) Efficiency | 18.2% |
| Turbine Isentropic Efficiency | 88.0% |
| Geothermal Brine Exit Temp, $^{o}$F | 110.0 |
| Gross Thermal Efficiency | 3.6% |
| Net Thermal Efficiency (Parasitic Loads Included) | 2.5% |
| Transmission Losses | 4.5% |
| | |
| Annual MWHs Produced | 2,653 |
| | |
| | |
| | |
| O&M Cost, Cost/kWH | $0.024 |
| O&M Escalation Rate, Percent | 0.0% |
| Tons of Carbon Offset/Year | 583 |
| Tons of Carbon Offset/30 Yrs | 17,487 |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Plant Net Output, kW | Percent on Line | Plant Nominal Size, kW | Parasitic Load, Production Well Pump, kW | Parasitic Load, Cooling Tower | Total Parasitic Load, CT and PW, kW | Temperature, °F | Geothermal Flow, GPM |
|---|---|---|---|---|---|---|---|
| 358 | 95.0% | 529 | 123 | 49 | 171.5 | 176 | 1,500 |

| **Site 2, Monthly Temperature, Plant Output, Transmission Losses and Net Power** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Average Temperature, °F | Average Plant Output, kW | Plant Output, kWH | Transmission Losses, kWH | Net Power On line, kWH | Percent Change | Value of Power |
| Jan | 27.5 | 365 | 258,044 | 11,612 | 246,432 | 22% | $50,883 |
| Feb | 31.5 | 355 | 226,798 | 10,206 | 216,592 | 19% | $44,722 |
| Mar | 34.2 | 349 | 246,451 | 11,090 | 235,361 | 17% | $48,597 |
| Apr | 37.4 | 341 | 233,135 | 10,491 | 222,644 | 14% | $45,971 |
| May | 43.7 | 325 | 229,952 | 10,348 | 219,604 | 9% | $45,344 |
| Jun | 49.9 | 310 | 212,125 | 9,546 | 202,580 | 4% | $41,829 |
| Jul | 54.7 | 298 | 210,747 | 9,484 | 201,263 | 0% | $41,557 |
| Aug | 53.3 | 302 | 213,294 | 9,598 | 203,696 | 1% | $42,059 |
| Sep | 48.2 | 314 | 214,959 | 9,673 | 205,286 | 5% | $42,388 |
| Oct | 40.8 | 332 | 234,933 | 10,572 | 224,361 | 11% | $46,326 |
| Nov | 33.1 | 351 | 240,221 | 10,810 | 229,411 | 18% | $47,369 |
| Dec | 27.8 | 364 | 257,529 | 11,589 | 245,940 | 22% | $50,782 |
| **Annual Totals** | | | **2,778,189** | | **2,653,170** | | **$547,827** |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Site 2, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 1 | 2 | 3 | 4 | 5 |
| Elect Revenue | $596,182 | $596,182 | $596,182 | $596,182 | $596,182 |
| Wheeling Costs | ($14,592) | ($14,592) | ($14,592) | ($14,592) | ($14,592) |
| Royalty to Zia | ($41,733) | ($41,733) | ($41,733) | ($41,733) | ($41,733) |
| O&M | ($63,676) | ($63,676) | ($63,676) | ($63,676) | ($63,676) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | ($1,089,547) | ($1,089,547) | ($1,089,547) | ($1,089,547) | ($1,089,547) |
| Taxable Income | ($613,366) | ($613,366) | ($613,366) | ($613,366) | ($613,366) |
| Federal Income Tax | $226,945 | $226,945 | $226,945 | $226,945 | $226,945 |
| NM Income Tax | $30,668 | $30,668 | $30,668 | $30,668 | $30,668 |
| Federal PTC | $58,370 | $58,370 | $58,370 | $58,370 | $58,370 |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | $315,984 | $315,984 | $315,984 | $315,984 | $315,984 |
| Net Cash Flow | ($4,655,570) | $792,164 | $792,164 | $792,164 | $792,164 |
| Cumulative Cash Flow | ($4,655,570) | ($3,863,406) | ($3,071,241) | ($2,279,077) | ($1,486,913) |
| Present Value of Cash Flow | ($4,455,091) | $725,409 | $694,171 | $664,278 | $635,673 |
| Cumulative Present Value | ($4,455,091) | ($3,729,682) | ($3,035,511) | ($2,371,233) | ($1,735,560) |

| Site 2, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 6 | 7 | 8 | 9 | 10 |
| Elect Revenue | $596,182 | $596,182 | $596,182 | $596,182 | $596,182 |
| Wheeling Costs | ($14,592) | ($14,592) | ($14,592) | ($14,592) | ($14,592) |
| Royalty to Zia | ($41,733) | ($41,733) | ($41,733) | ($41,733) | ($41,733) |
| O&M | ($63,676) | ($63,676) | ($63,676) | ($63,676) | ($63,676) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $476,181 | $476,181 | $476,181 | $476,181 | $476,181 |
| Federal Income Tax | ($176,187) | ($176,187) | ($176,187) | ($176,187) | ($176,187) |
| NM Income Tax | $(23,809) | $(23,809) | $(23,809) | $(23,809) | $(23,809) |
| Federal PTC | $58,370 | $58,370 | $58,370 | $58,370 | $58,370 |
| NM PTC | $- | $- | $- | $- | $- |
| Total Tax Savings | ($141,626) | ($141,626) | ($141,626) | ($141,626) | ($141,626) |
| Net Cash Flow | $334,555 | $334,555 | $334,555 | $334,555 | $334,555 |
| Cumulative Cash Flow | ($1,152,358) | ($817,804) | ($483,249) | ($148,695) | $185,860 |
| Present Value of Cash Flow | $256,903 | $245,840 | $235,254 | $225,123 | $215,429 |
| Cumulative Present Value | ($1,478,657) | ($1,232,817) | ($997,563) | ($772,440) | ($557,011) |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Site 2, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 11 | 12 | 13 | 14 | 15 |
| Elect Revenue | $596,182 | $596,182 | $596,182 | $596,182 | $596,182 |
| Wheeling Costs | ($14,592) | ($14,592) | ($14,592) | ($14,592) | ($14,592) |
| Royalty to Zia | ($41,733) | ($41,733) | ($41,733) | ($41,733) | ($41,733) |
| O&M | ($63,676) | ($63,676) | ($63,676) | ($63,676) | ($63,676) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $476,181 | $476,181 | $476,181 | $476,181 | $476,181 |
| Federal Income Tax | ($176,187) | ($176,187) | ($176,187) | ($176,187) | ($176,187) |
| NM Income Tax | $(23,809) | $(23,809) | $(23,809) | $(23,809) | $(23,809) |
| Federal PTC | $0 | $0 | $0 | $0 | $0 |
| NM PTC | $0 | $0 | $0 | $0 | $0 |
| Total Tax Savings | ($199,996) | ($199,996) | ($199,996) | ($199,996) | ($199,996) |
| Net Cash Flow | $276,185 | $276,185 | $276,185 | $276,185 | $276,185 |
| Cumulative Cash Flow | $462,045 | $738,230 | $1,014,414 | $1,290,599 | $1,566,784 |
| Present Value of Cash Flow | $170,185 | $162,856 | $155,843 | $149,132 | $142,710 |
| Cumulative Present Value | ($386,826) | ($223,970) | ($68,127) | $81,006 | $223,716 |

| Site 2, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 16 | 17 | 18 | 19 | 20 |
| Elect Revenue | $596,182 | $596,182 | $596,182 | $596,182 | $596,182 |
| Wheeling Costs | ($14,592) | ($14,592) | ($14,592) | ($14,592) | ($14,592) |
| Royalty to Zia | ($41,733) | ($41,733) | ($41,733) | ($41,733) | ($41,733) |
| O&M | ($63,676) | ($63,676) | ($63,676) | ($63,676) | ($63,676) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $476,181 | $476,181 | $476,181 | $476,181 | $476,181 |
| Federal Income Tax | ($176,187) | ($176,187) | ($176,187) | ($176,187) | ($176,187) |
| NM Income Tax | $(23,809) | $(23,809) | $(23,809) | $(23,809) | $(23,809) |
| Federal PTC | $0 | $0 | $0 | $0 | $0 |
| NM PTC | $0 | $0 | $0 | $0 | $0 |
| Total Tax Savings | ($199,996) | ($199,996) | ($199,996) | ($199,996) | ($199,996) |
| Net Cash Flow | $276,185 | $276,185 | $276,185 | $276,185 | $276,185 |
| Cumulative Cash Flow | $1,842,969 | $2,119,154 | $2,395,338 | $2,671,523 | $2,947,708 |
| Present Value of Cash Flow | $136,565 | $130,684 | $125,057 | $119,671 | $114,518 |
| Cumulative Present Value | $360,281 | $490,965 | $616,022 | $735,693 | $850,211 |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Expense Description | Amount | Cost per kWH | Comments |
|---|---|---|---|
| | | Well Field | |
| Royalty | $41,733 | $0.01573 | |
| Contracted Services | $3,164 | $0.00119 | Well/Pipe Maintenance |
| | | Power Plant | |
| Salaries | $10,757 | $0.00405 | One Full Time Equivalent |
| Benefits | $3,923 | $0.00148 | |
| Major Maintenance Expense | $10,124 | $0.00382 | |
| Contracted Services | $3,164 | $0.00119 | Plant Tuning, Checks Etc |
| Consumables | $1,898 | $0.00072 | Lubricants, Lights, General Maintenance |
| Chemicals | $2,658 | $0.00100 | |
| Cooling Water for Heat Reject | $1,898 | $0.00072 | Payment to Zia Pueblo |
| Safety | $1,012 | $0.00038 | |
| Other | $633 | $0.00024 | |
| | | Transmission Maintenance & Wheeling Cost | |
| Transmission Costs | $14,592 | $0.00550 | Wheeling To PNM |
| Transmission Line Maint | $190 | $0.00007 | Maintenance of Poles/Wires |
| | | Overhead Costs | |
| Legal Expense | $2,278 | $0.00086 | 80 hours of legal work per year |
| Management | $2,237 | $0.00084 | 4 hours per week @ $65/Hr |
| Property Taxes | $0 | $0.00000 | No Property Taxes on Zia Land |
| Insurance | $15,732 | $0.00593 | Insurance Coverage to be determined. |
| Accounting | $2,237 | $0.00084 | Part Time Accountant, Collecting Monthly Data |
| Other | $1,772 | $0.00067 | |
| Total Costs | $120,001 | $0.04523 | Sum of all Operating Costs |

| | |
|---|---|
| Royalty Rate Used In Annual Cash Flow Analysis, $/kWH | $0.01573 |
| Maint Cost Used in Annual Cash Flow Analysis, $/kWH | $0.02400 |
| Wheeling Cost Used in Annual Cash Flow Analysis, kWH | $0.00550 |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Site 2, Electric Transmission Cost Estimate | |
|---|---|
| Item | Cost |
| Interconnection Customer's (Zia Pueblo) Facility, Installation of SCADA equipment, Fiber-Optic line to Point of Interconnect substation, and associated engineering | $188,500 |
| Point of Interconnection Substation, Construction of a new, single-breaker substation including revenue metering, transfer-trip equipment, and microwave communications | $0 |
| New Transmission Line, 0.5 miles 22 kV, 3 wires, Wooden Posts | $132,500 |
| Upgrades, Jemez substation to facilitate transfer trip. | $50,000 |
| Network Upgrade, Jemez Substation, Engineering and installation of P & C equipment | $29,000 |
| Network Upgrade, Communications, Engineering/Installation of communications upgrades | $0 |
| Total Electric Connectivity | $400,000 |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Plant Characteristics | |
|---|---|
| Nominal Plant Size, MW | 0.529 |
| Plant Output, MW | 0.358 |
| Water Flow Rate, GPM | 1,500 |
| Resource Temperature, °F | 196 |
| Net Thermal Efficiency | 2.5% |

| Major Item | Cost | Comments |
|---|---|---|
| Well Drilling and Completion | $2,000,000 | Cost to Drill 2 Wells ~ 2,000 feet deep or less |
| Well Pumps (1), at 1500 GPM, with 400 Feet of Casing, Line Shaft and Fabricated Well Head | $99,163 | |
| Electric Motors for Pump (1) @ 500 HP Ea | $41,383 | |
| Flow Testing, Requires a Test Pump, Generator, Diesel Fuel, Instruments | $346,495 | Labor/Fuel/Equipment Rental for a 30 Day Test @ 1500 GPM, Assumes test pumps will be used for production |
| Transmission/Electrical (Approx 0.5 Miles of 69 kV transmission, substation, transformers controls, see attachment) | $400,000 | This is total cost of Transmission, which includes the regulatory requirements, rights of way, environmental, etc . . . |
| Plant | | |
| Site Work | $55,293 | Grading, Concrete, Fencing, Road Improvement |
| Pipe System | $390,000 | Pipe Connecting Wells, 2600' 10 Inch Pipe |
| Power Cycle Equipment | $1,183,078 | Estimate, Site Assembled, Based on UTC Machine, plus cooling tower |
| Permitting, Water Rights | $80,000 | Construction Permitting and Water Rights |
| Construction Labor/Site Assembly | $59,154 | 3 Month Site Assembly |
| Site Engineering | $225,771 | 5% Percentage of Well Pump, Transmission, Piping, Site Work, Pipe System, Electric Mtr, Drilling,5% Power Plant Equipment |
| Construction Management | $237,398 | 5% Percent of All Except Power Plant, 4% Power Plant |
| Environmental Reviews | $30,000 | Project on Native American Land Minimal Review |
| PPA Negotiation/Contract | $300,000 | Simplified contract PNM or Other Utility Process |
| **Total Cost** | **$5,447,734** | |

Appendix J, Geothermal Electric Plant Site 2, Output and Estimates:

| Heat Rejection, kBTU/Hr | Power Plant Gross Output, kWe | Efficiency |
|---|---|---|
| 47,674 | 529 | 3.65% |

| | | | |
|---|---|---|---|
| Water Evaporated | 44,521 | Lbs/Hr (Make Up Water) | |
| | 89.1 | Gal/Min (Make Up Water) | |
| Air Required | 1,684,594 | Lbs of Air/Hr | |
| Air Required | 374,354 | CFM | |
| Heat Rejected by Source | | | Percent of Heat Rej |
| Air | 4,043 | kBTU/Hr | 8.5% |
| Liq Water | 1,336 | kBTU/Hr | 2.8% |
| Water Vapor | 42,295 | kBTU/Hr | 88.7% |
| Total Heat Rejected | 47,674 | kBTU/Hr | 100.0% |

| | | | |
|---|---|---|---|
| CT Fan HP | 52 | 0.75 | CT Fan Pressure, Inches of Water |
| CT Fan kW | 41 | 0.85 | CT Fan Mechanical Efficiency |
| | | 0.94 | CT Fan Electrical Efficiency |
| CT Pump HP | 9.5 | 20 | CT Pump PSI |
| CT Pump kW | 7.5 | 0.78 | CT Pump Mechanical Eff |
| | | 0.94 | CT Pump Electrical Efficiency |
| | | 636 | CT Pump Flow |
| | | 15 | Water Temperature Rise Through HX |

| | | | |
|---|---|---|---|
| PW Shaft HP | 156.2 | 1,500 | PW Pump GPM |
| PW kW | 122.6 | 17 | PW Static Level |
| | | 200 | PW Drawdown |
| | | 40 | Plant Pressure Drop, PSI |
| | | 0.75 | PW Mech Efficiency |
| | | 0.95 | PW Elect Efficiency |

| | | |
|---|---|---|
| Saturation Humidity Ratio | | |
| 0.0080 | lb Water Vapor/Lb Dry Air @ 50F | PW = Production Well |
| 0.0157 | lb Water Vapor/Lb Dry Air @ 70F | CT = Cooling Tower |
| 0.0264 | lb Water Vapor/Lb Dry Air @ 85F | |

| | | | |
|---|---|---|---|
| 75 | Air Start Point, F | 55 | Water Start Point, F |
| 85 | Air End Point, F | 85 | Water End Point, F |
| 0.24 | Air Density, Lb/CF | | |
| 950 | Water Heat of Vaporization, BTU/Lb | | |

## APPENDIX K: GEOTHERMAL ELECTRIC PLANT SITE 3, OUTPUT AND ESTIMATES:

| Summary Economics, Site 3 | |
|---|---|
| First Year Electricity Sales Price, $/kWh | $0.10622 |
| Grants/Incentives | $500,000 |
| Production Tax Credit, $/kWh | $0.0230 |
| Green Tag Value | $0.0100 |
| Wheeling Costs | $0.0055 |
| Royalty Rate | 7.0% |
| Local Property Tax Rate | 0.0% |
| NM State Tax Rate | 5.0% |
| Federal Tax Rate | 37.0% |
| Depreciation Term Years | 5 |
| | 0.0% |
| Analysis Term, Years | 20 |
| Discount Rate (NPV Analysis) | 4.5% |
| Internal Rate of Return | 7.50% |
| Installed Plant Cost | $14,482,833 |
| Simple Payback Years | 10.47 |

| Operating Parameters | |
|---|---|
| Rejection Temperature, °F | 60 |
| Maximum (Carnot) Efficiency | 25.1% |
| Turbine Isentropic Efficiency | 88.0% |
| Geothermal Brine Exit Temp, °F | 110.0 |
| Gross Thermal Efficiency | 8.8% |
| Net Thermal Efficiency (Parasitic Loads Included) | 8.0% |
| Transmission Losses | 4.5% |
| | |
| Annual MWHs Produced | 13,020 |
| | |
| | |
| | |
| O&M Cost, Cost/kWH | $0.018 |
| O&M Escalation Rate, Percent | 0.0% |
| Tons of Carbon Offset/Year | 1,383 |
| Tons of Carbon Offset/30 Yrs | 41,491 |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Plant Net Output, kW | Percent on Line | Plant Nominal Size, kW | Parasitic Load, Production Well Pump, kW | Parasitic Load, Cooling Tower | Total Parasitic Load, CT and PW, kW | Temperature, °F | Geothermal Flow, GPM |
|---|---|---|---|---|---|---|---|
| 1,819 | 95.0% | 1,993 | 102 | 72 | 174.6 | 234 | 1,250 |

| **Monthly Temperature, Plant Output, Transmission Losses and Net Power, Site 3** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Average Temperature, °F | Average Plant Output, kW | Plant Output, kWH | Transmission Losses, kWH | Net Power On line, kWH | Percent Change | Value of Power |
| Jan | 27.5 | 1,746 | 1,233,866 | 55,524 | 1,178,342 | 15% | $117,761 |
| Feb | 31.5 | 1,712 | 1,092,885 | 49,180 | 1,043,705 | 13% | $104,306 |
| Mar | 34.2 | 1,689 | 1,194,000 | 53,730 | 1,140,270 | 11% | $113,957 |
| Apr | 37.4 | 1,662 | 1,137,032 | 51,166 | 1,085,866 | 10% | $108,520 |
| May | 43.7 | 1,609 | 1,137,266 | 51,177 | 1,086,089 | 6% | $108,542 |
| Jun | 49.9 | 1,557 | 1,064,790 | 47,916 | 1,016,874 | 3% | $101,625 |
| Jul | 54.7 | 1,516 | 1,071,229 | 48,205 | 1,023,024 | 0% | $102,239 |
| Aug | 53.3 | 1,528 | 1,079,988 | 48,599 | 1,031,388 | 1% | $103,075 |
| Sep | 48.2 | 1,571 | 1,074,534 | 48,354 | 1,026,180 | 4% | $102,555 |
| Oct | 40.8 | 1,633 | 1,154,395 | 51,948 | 1,102,447 | 8% | $110,177 |
| Nov | 33.1 | 1,698 | 1,161,400 | 52,263 | 1,109,137 | 12% | $110,845 |
| Dec | 27.8 | 1,743 | 1,232,093 | 55,444 | 1,176,649 | 15% | $117,592 |
| **Annual Totals** | | | **13,633,478** | | **13,019,971** | | **$1,301,194** |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Site 3, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | **Year** | **Year** | **Year** | **Year** | **Year** |
| Ending Year | 1 | 2 | 3 | 4 | 5 |
| Elect Revenue | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 |
| Wheeling Costs | ($71,610) | ($71,610) | ($71,610) | ($71,610) | ($71,610) |
| Royalty to Zia | ($105,926) | ($105,926) | ($105,926) | ($105,926) | ($105,926) |
| O&M | ($237,263) | ($237,263) | ($237,263) | ($237,263) | ($237,263) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | ($2,896,567) | ($2,896,567) | ($2,896,567) | ($2,896,567) | ($2,896,567) |
| Taxable Income | ($1,798,131) | ($1,798,131) | ($1,798,131) | ($1,798,131) | ($1,798,131) |
| Federal Income Tax | $665,309 | $665,309 | $665,309 | $665,309 | $665,309 |
| NM Income Tax | $89,907 | $89,907 | $89,907 | $89,907 | $89,907 |
| Federal PTC | $299,459 | $299,459 | $299,459 | $299,459 | $299,459 |
| NM PTC | $0 | $0 | $0 | $0 | $0 |
| Total Tax Savings | $1,054,675 | $1,054,675 | $1,054,675 | $1,054,675 | $1,054,675 |
| Net Cash Flow | ($12,329,724) | $2,153,110 | $2,153,110 | $2,153,110 | $2,153,110 |
| Cumulative Cash Flow | ($12,329,724) | ($10,176,614) | ($8,023,504) | ($5,870,394) | ($3,717,285) |
| Present Value of Cash Flow | ($11,798,779) | $1,971,667 | $1,886,763 | $1,805,515 | $1,727,765 |
| Cumulative Present Value | ($11,798,779) | ($9,827,112) | ($7,940,349) | ($6,134,834) | ($4,407,069) |

| Site 3, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | **Year** | **Year** | **Year** | **Year** | **Year** |
| Ending Year | 6 | 7 | 8 | 9 | 10 |
| Elect Revenue | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 |
| Wheeling Costs | ($71,610) | ($71,610) | ($71,610) | ($71,610) | ($71,610) |
| Royalty to Zia | ($105,926) | ($105,926) | ($105,926) | ($105,926) | ($105,926) |
| O&M | ($237,263) | ($237,263) | ($237,263) | ($237,263) | ($237,263) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $1,098,435 | $1,098,435 | $1,098,435 | $1,098,435 | $1,098,435 |
| Federal Income Tax | ($406,421) | ($406,421) | ($406,421) | ($406,421) | ($406,421) |
| NM Income Tax | $(54,922) | $(54,922) | $(54,922) | $(54,922) | $(54,922) |
| Federal PTC | $299,459 | $299,459 | $299,459 | $299,459 | $299,459 |
| NM PTC | $0 | $0 | $0 | $0 | $0 |
| Total Tax Savings | ($161,883) | ($161,883) | ($161,883) | ($161,883) | ($161,883) |
| Net Cash Flow | $936,552 | $936,552 | $936,552 | $936,552 | $936,552 |
| Cumulative Cash Flow | ($2,780,733) | ($1,844,181) | ($907,629) | $28,923 | $965,474 |
| Present Value of Cash Flow | $719,174 | $688,205 | $658,569 | $630,210 | $603,072 |
| Cumulative Present Value | ($3,687,895) | ($2,999,690) | ($2,341,121) | ($1,710,911) | ($1,107,839) |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Site 3, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 11 | 12 | 13 | 14 | 15 |
| Elect Revenue | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 |
| Wheeling Costs | ($71,610) | ($71,610) | ($71,610) | ($71,610) | ($71,610) |
| Royalty to Zia | ($105,926) | ($105,926) | ($105,926) | ($105,926) | ($105,926) |
| O&M | ($237,263) | ($237,263) | ($237,263) | ($237,263) | ($237,263) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $1,098,435 | $1,098,435 | $1,098,435 | $1,098,435 | $1,098,435 |
| Federal Income Tax | ($406,421) | ($406,421) | ($406,421) | ($406,421) | ($406,421) |
| NM Income Tax | $(54,922) | $(54,922) | $(54,922) | $(54,922) | $(54,922) |
| Federal PTC | $0 | $0 | $0 | $0 | $0 |
| NM PTC | $0 | $0 | $0 | $0 | $0 |
| Total Tax Savings | ($461,343) | ($461,343) | ($461,343) | ($461,343) | ($461,343) |
| Net Cash Flow | $637,092 | $637,092 | $637,092 | $637,092 | $637,092 |
| Cumulative Cash Flow | $1,602,567 | $2,239,659 | $2,876,752 | $3,513,844 | $4,150,936 |
| Present Value of Cash Flow | $392,576 | $375,670 | $359,493 | $344,013 | $329,199 |
| Cumulative Present Value | ($715,264) | ($339,593) | $19,900 | $363,913 | $693,111 |

| Site 3, Annual Cash Flow Estimate | | | | | |
|---|---|---|---|---|---|
| | Year | Year | Year | Year | Year |
| Ending Year | 16 | 17 | 18 | 19 | 20 |
| Elect Revenue | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 | $1,513,235 |
| Wheeling Costs | ($71,610) | ($71,610) | ($71,610) | ($71,610) | ($71,610) |
| Royalty to Zia | ($105,926) | ($105,926) | ($105,926) | ($105,926) | ($105,926) |
| O&M | ($237,263) | ($237,263) | ($237,263) | ($237,263) | ($237,263) |
| Property Taxes | $0 | $0 | $0 | $0 | $0 |
| Depreciation | $0 | $0 | $0 | $0 | $0 |
| Taxable Income | $1,098,435 | $1,098,435 | $1,098,435 | $1,098,435 | $1,098,435 |
| Federal Income Tax | ($406,421) | ($406,421) | ($406,421) | ($406,421) | ($406,421) |
| NM Income Tax | $(54,922) | $(54,922) | $(54,922) | $(54,922) | $(54,922) |
| Federal PTC | $0 | $0 | $0 | $0 | $0 |
| NM PTC | $0 | $0 | $0 | $0 | $0 |
| Total Tax Savings | ($461,343) | ($461,343) | ($461,343) | ($461,343) | ($461,343) |
| Net Cash Flow | $637,092 | $637,092 | $637,092 | $637,092 | $637,092 |
| Cumulative Cash Flow | $4,788,029 | $5,425,121 | $6,062,214 | $6,699,306 | $7,336,399 |
| Present Value of Cash Flow | $315,023 | $301,457 | $288,476 | $276,053 | $264,166 |
| Cumulative Present Value | $1,008,134 | $1,309,591 | $1,598,067 | $1,874,120 | $2,138,286 |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Expense Description | Amount | Cost per kWH | Comments |
|---|---|---|---|
| Well Field | | | |
| Royalty | $105,926 | $0.00814 | |
| Contracted Services | $11,788 | $0.00091 | Well/Pipe Maintenance |
| Power Plant | | | |
| Salaries | $40,080 | $0.00308 | One Full Time Equivalent |
| Benefits | $14,618 | $0.00112 | |
| Major Maintenance Expense | $37,723 | $0.00290 | |
| Contracted Services | $11,788 | $0.00091 | Plant Tuning, Checks Etc |
| Consumables | $7,073 | $0.00054 | Lubricants, Lights, General Maintenance |
| Chemicals | $9,902 | $0.00076 | |
| Cooling Water for Heat Reject | $7,073 | $0.00054 | Payment to Zia Pueblo |
| Safety | $3,772 | $0.00029 | |
| Other | $2,358 | $0.00018 | |
| Transmission Maintenance & Wheeling Cost | | | |
| Transmission Costs | $71,610 | $0.00550 | Wheeling To PNM |
| Transmission Line Maint | $707 | $0.00005 | Maintenance of Poles/Wires |
| Overhead Costs | | | |
| Legal Expense | $8,488 | $0.00065 | 80 hours of legal work per year |
| Management | $8,337 | $0.00064 | 4 hours per week @ $65/Hr |
| Property Taxes | $0 | $0.00000 | No Property Taxes on Zia Land |
| Insurance | $58,618 | $0.00450 | Insurance Coverage to be determined. |
| Accounting | $8,337 | $0.00064 | Part Time Accountant, Collecting Monthly Data |
| Other | $6,601 | $0.00051 | |
| Total Costs | $414,799 | $0.03186 | Sum of all Operating Costs |

| | |
|---|---|
| Royalty Rate Used In Annual Cash Flow Analysis, $/kWH | $0.00814 |
| Maint Cost Used in Annual Cash Flow Analysis, $/kWH | $0.01822 |
| Wheeling Cost Used in Annual Cash Flow Analysis, kWH | $0.00550 |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Site 3, Electric Transmission Cost Estimate | |
|---|---|
| Item | Cost |
| Interconnection Customer's (Zia Pueblo) Facility, Installation of SCADA equipment, Fiber-Optic line to Point of Interconnect substation, and associated engineering | $188,500 |
| Point of Interconnection Substation, Construction of a new, single-breaker substation including revenue metering, transfer-trip equipment, and microwave communications | $0 |
| New Transmission Line, 0.5 miles 22 kV, 3 wires, Wooden Posts | $132,500 |
| Upgrades, Jemez substation to facilitate transfer trip. | $50,000 |
| Network Upgrade, Jemez Substation, Engineering and installation of P & C equipment | $29,000 |
| Network Upgrade, Communications, Engineering/Installation of communications upgrades | $0 |
| Total Electric Connectivity | $400,000 |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Plant Characteristics, Site 3 | |
|---|---|
| Nominal Plant Size, MW | 1.993 |
| Plant Output, MW | 1.841 |
| Water Flow Rate, GPM | 1,250 |
| Resource Temperature, °F | 196 |
| Net Thermal Efficiency | 8.1% |

| Major Item | Cost | Comments |
|---|---|---|
| Well Drilling and Completion | $6,800,000 | Cost to Drill 2 Wells ~ 7,500 to 8,000 feet deep or less |
| Well Pumps (1), at 1500 GPM, with 400 Feet of Casing, Line Shaft and Fabricated Well Head | $99,163 | |
| Electric Motors for Pump (1) @ 500 HP Ea | $41,383 | |
| Flow Testing, Requires a Test Pump, Generator, Diesel Fuel, Instruments | $346,495 | Labor/Fuel/Equipment Rental for a 30 Day Test @ 1500 GPM, Assumes test pumps will be used for production |
| Transmission/Electrical (Approx 0.5 Miles of 69 kV transmission, substation, transformers controls, see attachment) | $400,000 | This is total cost of Transmission, which includes the regulatory requirements, rights of way, environmental, etc . . . |
| Plant | | |
| Site Work | $69,933 | Grading, Concrete, Fencing, Road Improvement |
| Pipe System | $390,000 | Pipe Connecting Wells, 2600' 10 Inch Pipe |
| Power Cycle Equipment | $4,455,721 | Estimate, Site Assembled, Based on UTC Machine, plus cooling tower |
| Permitting, Water Rights | $80,000 | Construction Permitting and Water Rights |
| Construction Labor/Site Assembly | $222,786 | 3 Month Site Assembly |
| Site Engineering | $630,135 | 5% Percentage of Well Pump, Transmission, Piping, Site Work, Pipe System, Electric Mtr, Drilling,5% Power Plant Equipment |
| Construction Management | $617,217 | 5% Percent of All Except Power Plant, 4% Power Plant |
| Environmental Reviews | $30,000 | Project on Native American Land Minimal Review |
| PPA Negotiation/Contract | $300,000 | Simplified contract PNM or Other Utility Process |
| **Total Cost** | **$14,482,833** | |

Appendix K, Geothermal Electric Plant Site 3, Output and Estimates:

| Heat Rejection, kBTU/Hr | Power Plant Gross Output, kWe | Efficiency |
|---|---|---|
| 70,668 | 1,993 | 8.78% |

| | | | |
|---|---|---|---|
| Water Evaporated | 66,014 | Lbs/Hr (Make Up Water) | |
| | 132.1 | Gal/Min (Make Up Water) | |
| Air Required | 2,497,809 | Lbs of Air/Hr | |
| Air Required | 555,069 | CFM | |
| Heat Rejected by Source | | | Percent of Heat Rej |
| Air | 5,995 | kBTU/Hr | 8.5% |
| Liq Water | 1,980 | kBTU/Hr | 2.8% |
| Water Vapor | 62,713 | kBTU/Hr | 88.7% |
| Total Heat Rejected | 70,688 | kBTU/Hr | 100.0% |

| | | | |
|---|---|---|---|
| CT Fan HP | 77 | 0.75 | CT Fan Pressure, Inches of Water |
| CT Fan kW | 61 | 0.85 | CT Fan Mechanical Efficiency |
| | | 0.94 | CT Fan Electrical Efficiency |
| CT Pump HP | 14.1 | 20 | CT Pump PSI |
| CT Pump kW | 11.2 | 0.78 | CT Pump Mechanical Eff |
| | | 0.94 | CT Pump Electrical Efficiency |
| | | 943 | CT Pump Flow |
| | | 15 | Water Temperature Rise Through HX |

| | | | |
|---|---|---|---|
| PW Shaft HP | 130.2 | 1,250 | PW Pump GPM |
| PW kW | 102.2 | 17 | PW Static Level |
| | | 200 | PW Drawdown |
| | | 40 | Plant Pressure Drop, PSI |
| | | 0.75 | PW Mech Efficiency |
| | | 0.95 | PW Elect Efficiency |

| | | |
|---|---|---|
| Saturation Humidity Ratio | | |
| 0.0080 | lb Water Vapor/Lb Dry Air @ 50F | PW = Production Well |
| 0.0157 | lb Water Vapor/Lb Dry Air @ 70F | CT = Cooling Tower |
| 0.0264 | lb Water Vapor/Lb Dry Air @ 85F | |

| | | | |
|---|---|---|---|
| 75 | Air Start Point, F | 55 | Water Start Point, F |
| 85 | Air End Point, F | 85 | Water End Point, F |
| 0.24 | Air Density, Lb/CF | | |
| 950 | Water Heat of Vaporization, BTU/Lb | | |

# APPENDIX L: US GEOTHERMAL BINARY PLANTS IN OPERATION

**Binary Geothermal Power Plants in Operation 2013 in the US**

| Plant Name | Owner | Location | Start Year | Plant Type | # of Units | Installed capacity (MW) | Additional Information |
|---|---|---|---|---|---|---|---|
| MAMMOTH PACIFIC I | Constellation Power and ORMAT | Sierra Nevada Mtns.-Mono, CA | 1984 | Binary | 4 | 10 | The Mammoth Pacific Power Plants, located in the Sierra Nevada Mountains, are fueled by geothermal brine from the Casa Diablo Hot Springs. Mammoth Pacific I was built in 1984 and generates10 megawatts. The two other projects were built in 1990 and generate 15 megawatts. The power from all three projects is sold to Southern California Edison. The projects consist of 12 production wells and 8 injection wells. A total of eight single-stage, radial-flow gas expanders are used. |
| WABUSKA I | Home Stretch Geothermal | Wabuska, NV | 1984 | Binary | 1 | 1.1 | |
| WINEAGLE | Wineagle Development | Lassen County, CA | 1985 | Binary | 2 | 0.7 | |
| ORMESA | Ormat | East Mesa, Imperial County, CA | 1986 | Binary | 1 | 44 | |
| STEAM BOAT I | Ormat | Washoe, NV | 1986 | Binary | 7 | 8.4 | Ormat has purchased this plant in July 2003 from US Energy Systems, Inc. http://www.ormat.com |
| SAN EMIDIO (EMPIRE) | U.S. Geothermal | San Emidio, NV | 1987 | Binary | 4 | 4.8 | http://www.usgeothermal.com/ |
| SODA LAKE | Magma Energy (US) Corp | Fallon, NV | 1987 | Binary | 4 | 5.1 | The plant has been operating continually since 1987 providing clean, green energy to the Churchill County area through the SPPCo grid. www.magmaenergycorp.com |
| WABUSKA II | Home Stretch Geothermal | Wabuska, NV | 1987 | Binary | 1 | 1.1 | |
| AMEDEE | Amedee Geothermal Venture | Amedee, CA | 1988 | Binary | 2 | 1.6 | This plant runs by itself. If it detects a problem, it automatically radios the operator to come to the site. |
| ORMESA IE | Ormat | Imperial Valley, CA | 1988 | Binary | 1 | 10 | Ormesa IE is part of the Ormesa Complex at East Mesa Geothermal Field. The Ormesa Complex has an overall net capacity of approximately 76 MW. |
| STEAMBOAT 1A | Ormat | Reno, NV | 1988 | Binary | 2 | 2.4 | |

Appendix L, US Geothermal Binary Plants in Operation

| Binary Geothermal Power Plants in Operation 2013 in the US (Continued) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Plant Name | Owner | Location | Start Year | Plant Type | # of Units | Installed capacity (MW) | Additional Information |
| ORMESA IH | Ormat | Imperial Valley, CA | 1989 | Binary | 1 | 12 | Ormesa IH is part of the Ormesa Complex at East Mesa Geothermal Field. The Ormesa Complex has an overall net capacity of approximately 76 MW |
| MAMMOTH PACIFIC II | Constellation Power and ORMAT | Sierra Nevada Mtns-Mono, CA | 1990 | Binary | 6 | 30 | The Mammoth Pacific Power Plants, located in the Sierra Nevada Mountains, are fueled by geothermal brine from the Casa Diablo Hot Springs. Mammoth Pacific I was built in 1984 and generates10 megawatts. The two other projects were built in 1990 and generate 15 megawatts. The power from all three projects is sold to Southern California Edison. The projects consist of 12 production wells and 8 injection wells. A total of eight single-stage, radial-flow gas expanders are used. |
| SODA LAKE II | Magma Energy (US) Corp | Fallon, NV | 1991 | Binary | 6 | 18 | The plant has been supplying clean, green energy to the Churchill County area through the SPPCogrid for over 13 years. www.magmaenergycorp.com |
| STEAMBOAT 2 | Ormat | Reno, NV | 1992 | Binary | 2 | 29 | http://www.ormat.com |
| STEAMBOAT 3 | Ormat | Reno, NV | 1992 | Binary | 2 | 24 | http://www.ormat.com |
| HEBER II | Ormat | Imperial Valley, CA | 1993 | Binary | 7 | 51 | Heber 2 is part of the Heber Complex, which includes Heber, Heber 2, Gould, and Heber South. The total output of the Heber Complex is approximately 92 MW. http://www.ormat.com |
| PUNA | Puna Geothermal Venture | Pahoa, HI | 1993 | Binary | 10 | 35 | Puna Geothermal Venture (PGV), a partnership wholly owned by subsidiaries of Ormat Nevada, Inc. was issued a permit to produce a power plant of 30 megawatts of geothermal power in the Kapoho section of the Kilauea East Rift Zone (KERZ) in the Puna District of the Big Island. Under a Power Purchase Agreement with Hawaii Electric Light Company, PGV delivers an average of 25-30 megawatts of firm energy on a continuous basis, supplying approximately 20 percent of the total electricity needs of the Big Island. In helping meet the Big Island's growing demand for electrical energy, the company uses modern re-injection technology developed in its Mainland operations to dispose of spent gases and fluids from the generating process. http://www.punageothermalventure.com/ |

Appendix L, US Geothermal Binary Plants in Operation

| Binary Geothermal Power Plants in Operation 2013 in the US (Continued) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Plant Name | Owner | Location | Start Year | Plant Type | # of Units | Installed capacity (MW) | Additional Information |
| SIGC BINARY | Ormat | Imperial Valley, CA | 1993 | Binary | 6 | 40.2 | |
| RICHARD BURDETT | Ormat | Steamboat, NV | 2005 | Binary | 2 | 27 | http://www.ormat.com |
| CHENA | Chena Power, LLC | Near Fairbanks, AK | 2006 | Binary | 3 | 0.73 | The Chena project has attracted world-wide attention and won two awards in 2006 –a U.S. Environmental Protection Agency and Department of Energy 2006 National Green Power Award for on-site generation and Power Engineering magazine named it Renewable/Sustainable Energy Project of the Year. The project was made possible through a partnership between UTC Power, Chena Hot Springs Resort, the U.S. Department of Energy, Alaska Energy Authority, Alaska Industrial Development and Export Authority and the Denali Commission. The revolutionary low temperature technology was developed by UTC Power. |
| DESERT PEAK | Ormat | Churchill County, NV | 2006 | Binary | 1 | | |
| GOULD | Ormat | Imperial Valley, CA | 2006 | Binary | 2 | 10 | Gould is part of the Heber Complex, which includes Heber, Heber 2, Gould, and Heber South. The total output of the Heber Complex is approximately 92 MW. http://www.ormat.com |
| BLUNDELL 2 | PacifiCorp | near Milford, UT | 2007 | Binary | 1 | 9 | http://www.pacificorp.com/ |
| GALENA II | Ormat | Churchill County, NV | 2007 | Binary | 1 | 15 | http://www.ormat.com |
| GALENA III | Ormat | Reno, NV | 2008 | Binary | 1 | 30 | http://www.ormat.com |
| HEBER SOUTH | Ormat | Imperial Valley, CA | 2008 | Binary | 1 | 14.5 | Heber South is part of the Heber Complex, which includes Heber, Heber 2, Gould, and Heber South. The total output of the Heber Complex is approximately 92 MW. |
| RAFT RIVER | U.S. Geothermal | Cassia County, ID | 2008 | Binary | 1 | 15.8 | http://www.usgeothermal.com/ |
| FAULKNER | Nevada Geothermal Power | Humboldt County, NV | 2009 | Binary | 1 | 50 | |

APPENDIX M: GEOTHERMAL TECHNICAL REPORT

# PUEBLO OF ZIA GEOTHERMAL RESERVOIR CHARACTERIZATION

## SUMMARY AND FINAL TECHNICAL REPORT

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Prepared
for
Pueblo of Zia
and
USDOE Contract DE-EE00005628
Pueblo of Zia Renewable Energy
Development Feasibility Study

September 2013

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## APPENDICES



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## 1.0 INTRODUCTION

The Pueblo of Zia straddles the boundary between the Colorado Plateau and Rio Grande rift. In this area, the regional background conductive heat flow is elevated (75 to 85 $mW/m^2$) and typically shows temperature gradients in the subsurface exceeding 30 to 40 $^oC/km$ (Figure 1). Shallow heat flow over and adjacent convective geothermal systems show heat flow exceeding 105 $mW/m^2$.

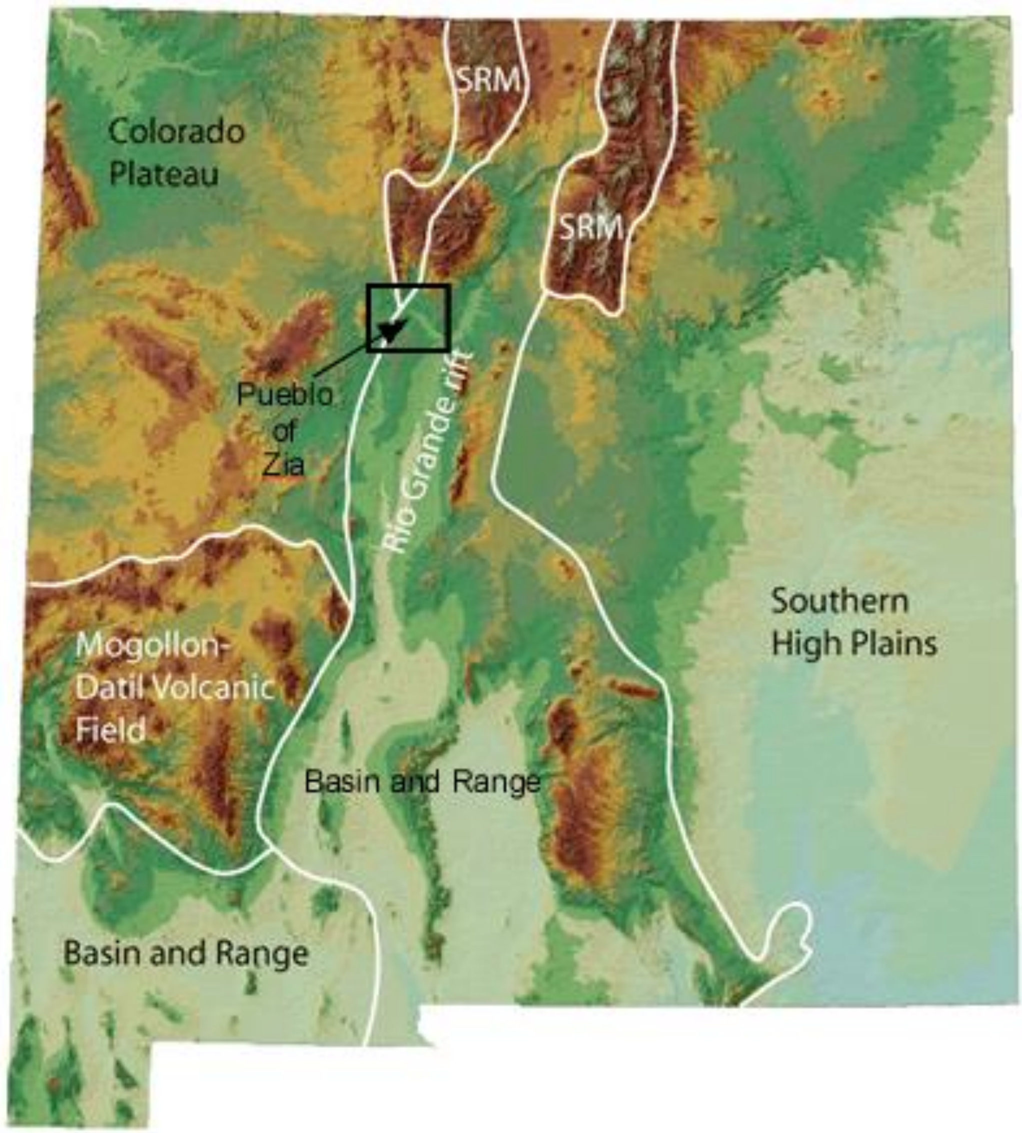


Figure 1. Shaded topographic map of New Mexico showing the location of physiographic provinces, Rio Grande rift and Pueblo of Zia. SRM is Southern Rocky Mountain Province (modified from NMBGMR).

.

Figure 2 is a generalized geothermal resource potential map of New Mexico showing the general location of Pueblo of Zia in geographic relation to major groupings of New Mexico geothermal resources and their distribution.

The elongated red area in the northern Pueblo of Zia region box is the outflow plume of the high-temperature geothermal system in the Valles caldera (Figure 2). The smaller red area to the west is the Kaseman thermal well area on the Colorado Plateau and is the focus of Pueblo of Zia Site 2 (see Figure 2 and 3). Sites 1, 3, and 4 are located a light blue area that represents a deep-seated sedimentary basin resource within the Rio Grande rift (see Figure 3).


Figure 2. Generalized geothermal resource map of New Mexico, showing the Pueblo of Zia region. Red areas are known "shallow" convective or advective geothermal systems. Light blue and dark blue area represent deep-seated sedimentary basin geothermal resources whose aquifers or reservoirs are heated by the local background geothermal gradient (modified from Witcher, 2006).

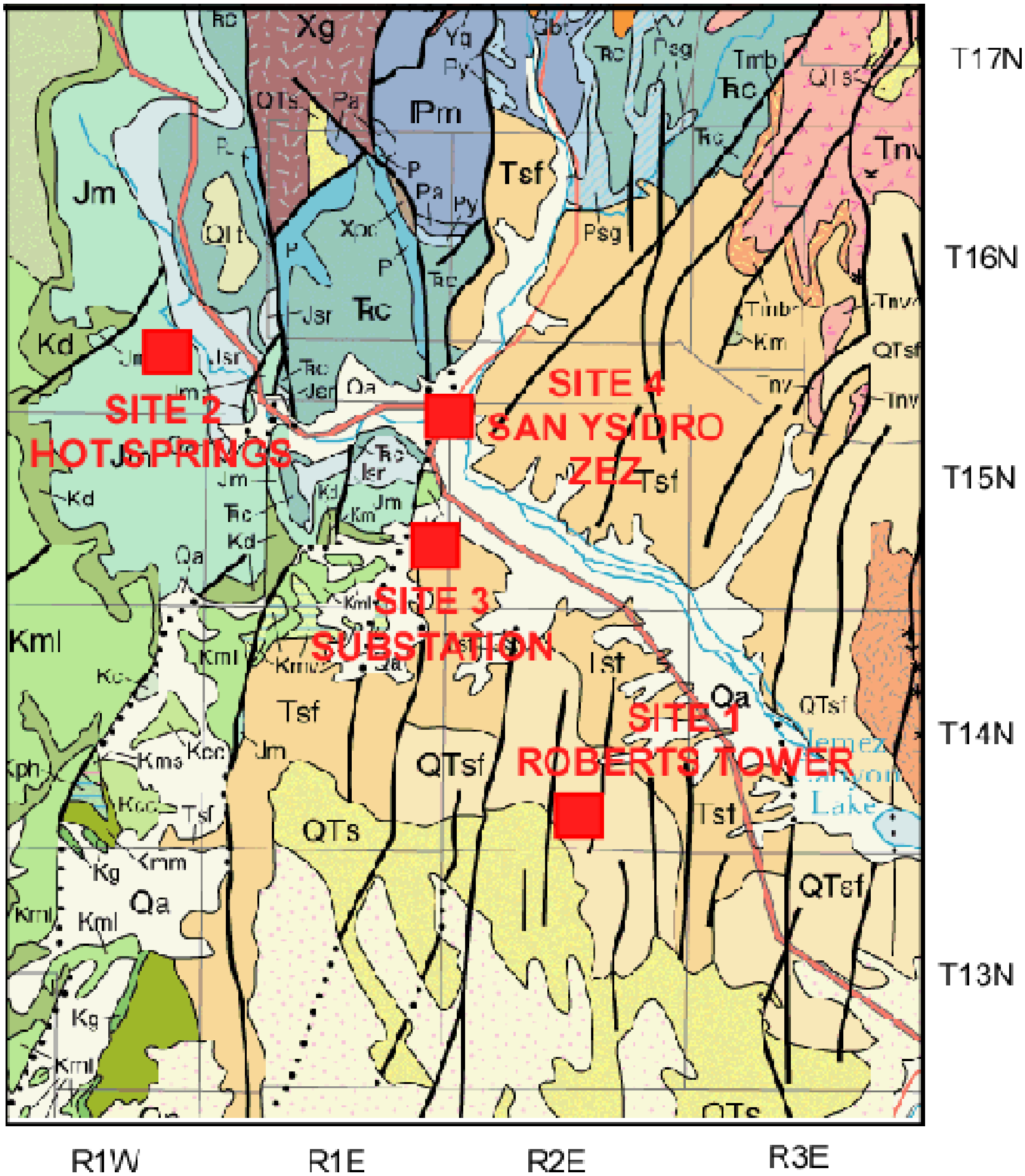


Figure 3. Geologic map of the Pueblo of Zia region. The brown hatched area in the northwest part of the map represents Precambrian basement (granite and metamorphic rocks) in the Nacimiento Mountains. The blue and green colors represent Paleozoic (blue) and Mesozoic (green) sedimentary formations. Units with labels P, Pa, Py, Psg and in part Trc represent the "redbed" sandstone reservoir targets buried at depth at the sites. The brown, orange, yellow, and cream colors are sediments and volcanic rocks, filling the Albuquerque basin of the Rio Grande rift. Bold black lines are fault zones. (Geology from NMBGMR).

## 2.0 RESOURCE ASSESSMENT

### 2.1 Approach

Deep oil and gas exploration in the Albuquerque basin of the Rio Grande rift has encountered temperatures sufficient for geothermal binary electrical power generation and large-scale direct-use geothermal heating. Part 1 (Appendix A) documents an investigation of the conductive thermal regime and hydrogeology of the deep subsurface beneath the northern Albuquerque basin at Pueblo of Zia Sites 1, 3, and 4.

The reservoir setting for Part 1 applies a conductive thermal regime. In this case, a reservoir or subsurface temperature is dependant upon the magnitude of background or typical heat flow in the upper crust and the thermal conductivity values of the stacked blankets of insulating sediment. Permeability, fluid in storage, and natural flow rates are important for viable geothermal production and reservoir sustainability.

Measurements of hydraulic properties of potential deep-seated reservoir rocks or bedrock aquifer systems beneath Pueblo of Zia are unavailable. However, a few thousand measurements are available as a result of ground water and oil and gas development in the surrounding region. This assessment compiles the measurements and evaluates the data for extrapolation into the deep subsurface at Pueblo of Zia.

Assuming that the thermal regime is predominantly conductive, primary temperature estimates use regional heat flow information in conjunction with estimates of thermal conductivity for the rock column units overlying the deep reservoir. Deep oil and gas bottom-hole-temperatures (BHT) provide a temperature-depth curve to check estimates and show a minimum temperature at the depth in the highest permeability rock units.

Part 2 (Appendix B) discusses a convective geothermal system on the eastern margin of the Colorado Plateau segment of Pueblo of Zia lands that was identified while drilling the Kaseman oil and gas test wells in the 1920's. Zones of water production, temperature, and chemistry of fluids, and silica geothermometry are applied to assess the geothermal resource.

### 2.2 Pueblo of Zia Sites 1, 3, and 4 Geothermal Reservoirs

A favorable geothermal reservoir underlies the Pueblo of Zia Site 1 (see Appendix A for full discussion). The Triassic Aqua Zarca (Santa Rosa Sandstone)-Permian San Andres-Glorieta aquifer system may be as much as 400 ft composite thickness and has a transmissivity sufficient to produce up to 1,500 gpm of 137 to 154 $^{o}$C water (heat flow 75 to 85 $m$W/m$^2$) from a depth between 9,400 to 12,000 ft, depending upon exact well location (Table 1).

Pueblo of Zia Site 3 shows 112 $^{o}$C water (heat flow 85 $m$W/m$^2$) from 7,600 to 8,000 ft depth from the Triassic Aqua Zarca-Permian San Andres-Glorieta aquifer system and should be capable of 1,500 gpm production with a single production well and injection well couplet (see Appendix A).

The temperature and potential production rates indicate favorability for small-scale (<5 MWe installed) electrical power production at Sites 1 and 3 with potential for cascaded direct-use for heating a greenhouse or other purposes. Because of the Pliocene-Quaternary fault density in the Albuquerque basin, a preliminary analysis of reservoir volume and potential compartmentalization is advised prior to designing a production and injection well field and the analysis will require a detailed study of seismic data along with test results of a geothermal well into the Aqua Zarca-San Andres-Glorieta reservoir.

Pueblo of Zia Site 4 has little or no geothermal power production potential (see Appendix A) due to temperatures less than 100 $^oC$ (Table 1).

## 2.3 Pueblo of Zia Site 2 Geothermal Reservoir

A area on Pueblo of Zia adjacent the Kaseman wells, also called “Zia hot wells, hot springs, or warm springs,” is the main focus of Part 2 (Appendix B) and the region around the wells is designated as Pueblo of Zia Site 2.

Deeply circulating sodium-sulfate-chloride water beneath the eastern San Juan Basin on the Colorado Plateau is heated by the background geotherm. These fluids flow southeast as part of a regional ground water flow system in Triassic Aqua Zarca sandstone and Paleozoic redbed aquifers, including the Madera limestone. Structure on the eastern Colorado Plateau and the Nacimiento uplift force flow upwards toward the surface.

The chalcedony geothermometer for the Kaseman 2 fluids is 54 $^oC$ in close agreement with the observed artesian discharge temperature at 53 $^oC$. The quartz geothermometer for the Kaseman 2 fluids is 85 $^oC$. Projection of systematic temperature increases for produced fluids during the drilling of the Kaseman 2 well into the lower Madera Formation gives an independent estimate of around 80 $^oC$ (Table 1).

Temperatures at Pueblo of Zia Site 2 eliminate viable economic geothermal power production potential (Part 2, Appendix B) even though high flow rates are possible in excess of 2,000 gpm. The best geothermal applications for Site 2 are direct-use geothermal, including use in thermal desalination processes.

Table 1. Summary of reservoir characteristics.

| **SITE LOCATION** | **RESERVOIR** | **DEPTH** | **DEPTH** | **TRANS** | **SALINITY** | **HEAT FLOW** | **TEMP (HF)** | **TEMP (BHT)** | **RATE** |
|---|---|---|---|---|---|---|---|---|---|
| (location) | Formation | min ft | max ft | ft2/d | mg/L | *m*W/m$^2$ | max $^oC$ | min $^oC$ | gpm |
| 1 (Roberts Tower | Aqua Zarca-Glorieta | 9,400 | 12,000 | 2,687 | 15,000 | 75 | 114 | 137 | 1,250 |
| 1 (Roberts Tower | Aqua Zarca-Glorieta | 9,400 | 12,000 | 2,687 | 15,000 | 85 | 114 | 153 | 1,250 |
| 2 (Warm Springs) | Aqua Zarca-Glorieta | 550 | 2,000 + | 2,300 | 11,000 | 105 + | 85 (qtz) | 54 (chal) | 1,500 |
| 3 (Substation) | Aqua Zarca-Glorieta | 7,600 | 8,000 | 2,299 | 15,000 | 85 | 112 | 110 | 1,250 |
| 4 (San Ysidro - ZEZ) | Aqua Zarca-Glorieta | 1,600 | 2,600 | 1,055 | 15,000 | 105 + | 80 | 51 | 1,500 |

## 3.0 REFERENCES

NMBGMR New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, New Mexico.

Witcher, J. C., 2006, Geothermal Energy in New Mexico: New Mexico Earth Matters, New Mexico Bureau of Geology and Mineral Resources, v. 6, no. 2, p. 1-4.

# PUEBLO OF ZIA GEOTHERMAL RESERVOIR CHARACTERIZATION
# PART 1
# CONDUCTIVE DEEP STRATIGRAPHIC RESERVOIRS
# SITES 1, 3 AND 4, NORTHERN ALBUQUERQUE BASIN/RIO GRANDE RIFT, NEW MEXICO

**FINAL TECHNICAL REPORT**

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## 1.0 INTRODUCTION

Deep oil and gas exploration in the Albuquerque basin has encountered temperatures sufficient for geothermal binary electrical power generation and large-scale direct-use geothermal heating. Part 1 of this report documents an investigation of the thermal regime and hydrogeology of the deep subsurface of the northern Albuquerque basin on Pueblo of Zia lands.

### 1.1 Purpose

Data and required parameters for deep geothermal reservoirs beneath Pueblo of Zia in the northern Albuquerque basin are outlined. Previous studies in the Albuquerque basin and the adjacent Colorado Plateau have documented subsurface temperature and heat flow in the basin and most efforts focused on characterizing and delineating convective geothermal resources that concentrate heat at relatively shallow depth, especially those of the Colorado Plateau found at “warm springs” on western Pueblo of Zia lands, south end of the Nacimiento Mountains just west of San Ysidro, and the thermal springs along the Jemez River south of Jemez Pueblo. Part 2 of the report, discusses the convective geothermal systems on the Colorado Plateau.

The reservoir setting for Part 1 applies a conductive thermal regime. In this case, a reservoir or subsurface temperature is dependant upon the magnitude of background or typical heat flow in the upper crust and the thermal conductivity values of the stacked blankets of insulating sediment. However, the measure of a viable geothermal reservoir is only partly satisfied by temperature. Permeability, fluid in storage, and natural flow through rates or induced recharge potential are just as important for viable geothermal production and reservoir sustainability. Permeability is addressed in this report.

Potential reservoir hosts beneath the Pueblo of Zia lands are identified and characterized. Analyses of these data are used to select reservoir targets and predict their behavior when produced. These data and analyses provide the basis to perform engineering and cost feasibility for geothermal power.

### 1.2 Previous Studies

In the early 1980's several geothermal studies were conducted in the Albuquerque basin and in the vicinity of Pueblo of Zia. Studies by Jiracek and others (1982) and Jiracek (1983) concentrated mostly on shallow thermal anomalies on the West Mesa in the vicinity of the Albuquerque volcanoes. While the volcanoes are too old to provide active heat sources, the thermal convection is identified along structure associated with the alignment of the volcano vent zones.

Grant (1981 and 1982) and Riddle and Grant (1981) discussed the geothermal potential of the Albuquerque basin with emphasis on the area at the intersection of the Sandia, Tijeras Canyon, and Hubble Springs faults on Kirkland Air Force Base lands. Finally, Jiracek (1983) and Grant (1982) provide discussion of geothermal resources and indicators in the Albuquerque basin in the general.

Kauffman and Houghton (1979 and 1980) present preliminary engineering and economic feasibility studies for direct-use geothermal in the Albuquerque basin. Kauffman and Houghton (1979) argued that application of geothermal heat for space heating of facilities with heat loads over 10 MMBtu/hr ($10^7$ Btu/hr) had potential cost advantages with fossil fuels at the time of their studies. The Kauffman and Houghton (1980) study evaluated the use of geothermal to provide space heating and cooling on the University of New Mexico (UNM) campus. At the time, heating a portion of the UNM campus appeared feasible; but space cooling did not compete with existing coolers and evaporative cooling. Geothermal studies in the Pueblo of Zia area include Witcher (1988a) and Witcher (2004, 1992, 1991, 1990, 1988b), Ross and others (2000), and Albrecht and others (2011), and Huang and others (2011) on adjacent Jemez Pueblo lands.

Important hydrogeologic information on bedrock units in the area is summarized in Stone and others (1983) and Titus (1963 and 1980). In recent years, a large number of hydrogeologic studies have been carried out in the Albuquerque basin as a part of a major effort by city, state, and federal agencies to understand the water resources in the Middle Rio Grande Valley. Bartolino and Cole (2002), and Plummer and others (2004) present overview of the hydrogeochemistry and ground-water framework of the Albuquerque basin. Numerical ground water flow models are discussed in Tiedeman and others (1998) and in McAda and Barroll (2002).

Around fifty oil and gas tests have been drilled in the Albuquerque basin. Only fourteen of the holes were drilled across potential geothermal reservoir rocks. Nine of the holes tested the Cretaceous rocks and five holes penetrated all or parts of the Paleozoic section. Gas and some oil shows were reported in Cretaceous sandstones (Point Lookout and Dakota). Black (1982, 1989, and 1999), Black and Hiss (1974), Johnson and others (2001), and Molenaar (1988) provide discussions on the oil and gas exploration and deep drilling in the Albuquerque basin.

## 2.0 GEOLOGY

Important summaries of various aspects of Albuquerque area geology include Kelly (1977), Kelley and Northrop (1975), Kelley and Kudo (1978), and Pazzaglia and others (1999). Discussions of gravity and aeromagnetic survey results are found in Grauch and others (1999), and Grauch (1999), respectively. Russel and

Snelson (1994) detail deep subsurface structure interpreted from seismic reflection surveys in the Albuquerque basin. Lozinsky (1994), Connell and others (1998), and Connell and others (2001) detail the character of Tertiary basin fill deposits.

## 2.1 Regional Setting and Structure

The Albuquerque basin portion of Pueblo of Zia overlies the central Rio Grande rift, a part of the Basin and Range physiographic province in central New New Mexico. (Baldridge and others, 1995; Chapin and Cather, 1994; Morgan and Golombek, 1984; (Figure 2.1). The Rio Grande rift is associated with high heat flow (>86 $mW/m^2$), Pleistocene and Holocene faulting, and widespread Quaternary basaltic volcanism (Baldridge and others, 1995; and Morgan and Golombek, 1984).


Figure 2.1. Map of the Rio Grande rift and Albuquerque basin (Connell, 2001).

The Rio Grande rift is an evolving active continental rift that shows several phases of development (Baldridge and others, 1995; Chapin and Cather, 1994, Morgan and Golombek, 1984). Initial extension is coeval with the beginning of regional mid-Tertiary (Oligocene) bimodal basaltic and rhyolitic (ignimbrite) volcanism and rifting is consistent with back-arc extension associated with a westward retreating subduction arc and the floundering of the shallow, low-angle Laramide Orogeny subducted slab (Dickinson, 1981). At about 10 to 12 Ma, extension began to create the present-day topography via large normal faults that finished blocking out half-graben structures and complementary horst blocks. During Pliocene, the basins or grabens were largely back filled with sediments and drainage integration and through flow of the axial-fluvial Rio Grande with entrenchment during the Pleistocene completed the landscape evolution observed today.

## 2.2 Albuquerque Basin

Gravity maps may dramatically show differences in the types of near surface rocks where density differences are pronounced such as between basin-fill sediments (lower density) and bedrock (higher density). Gravity data show that the Albuquerque basin is segmented into three general sub basins (Figure 2.2). From north to south, the basins are the Santa Domingo, the Calabacillas, and Belen (Connell, 2001 and 2004). The Calabacillas and Belen sub basins represent large and complex half-graben rift structures with master faults facing opposing directions. In the Calabacillas basin, the master faults are the Sandia and Rio Grande faults and face to the west with the hangwall (basin side) rotated downward and with sedimentary dips to the east (May and Russell (1994). More than 22,000 ft thickness of Tertiary basin fill overlies bedrock in the parts of the Calabacillas basin. The Tijeras accommodation zone facilitates the strain for the opposing half-graben structures in the Calabacillas and Belen basins. The Tijeras accommodation zone is on strike with the northeast trending Tijeras fault zone separating the Sandia and Manzano Mountains (Figure 2.4).

## 2.3 Pueblo of Zia Area Structure

Seismic surveys (May and Russell, 1994), deep oil and gas drilling (Black, 1992), geologic mapping (Connell, 2004, Maldonado and others (1999), and Personious and others (1999), and gravity and aeromagnetic surveys (Grauch and others, 1999 and Grauch, 1999) are used to delineate structure with importance for geothermal reservoir characterization.

The Zia Pueblo area lies at the convergence of several structural features with a history of Pleistocene movement and potential to create or enhance existing fracture permeability.

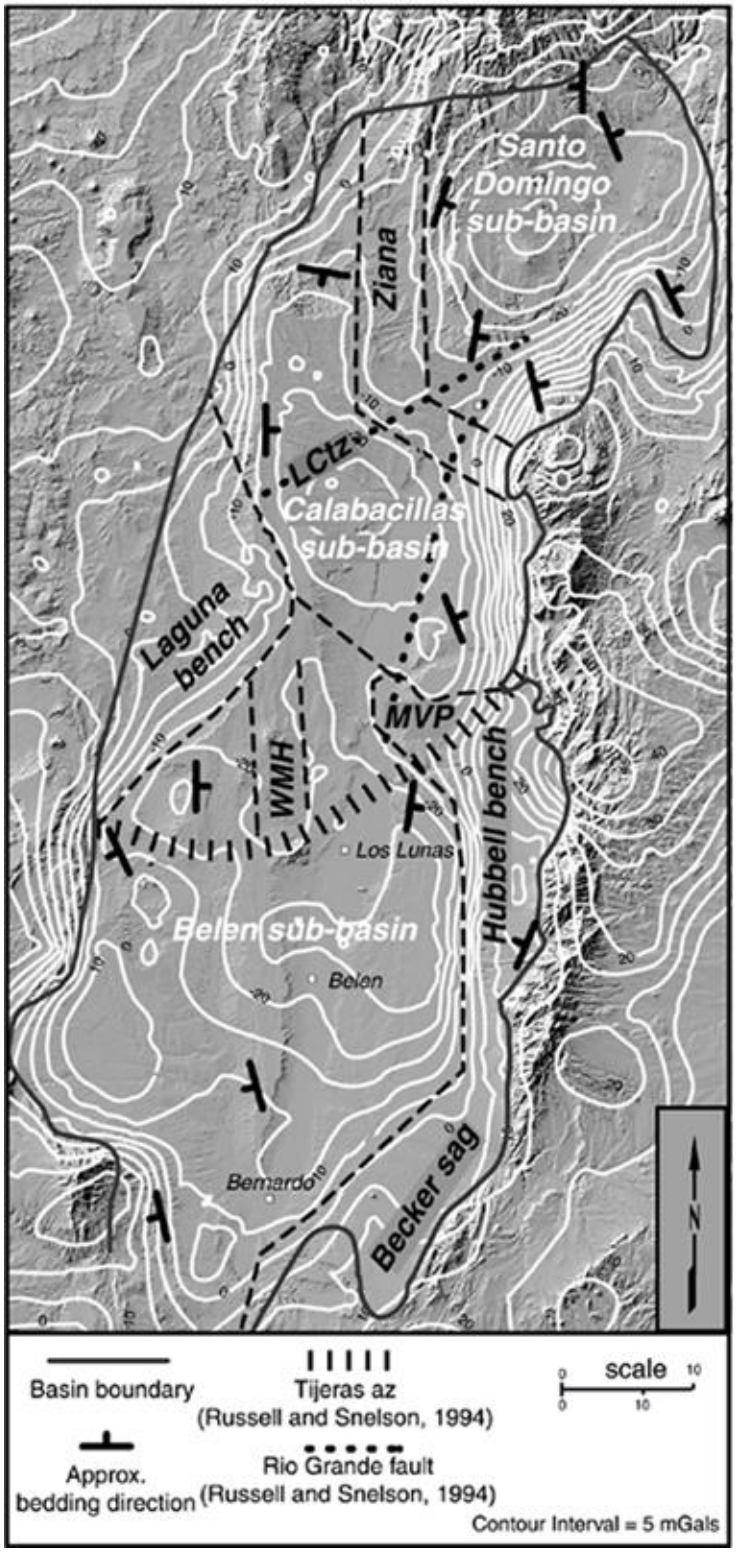


Figure 2.2. Gravity map and shaded relief map of the Albuquerque basin (Connell, 2001 and 2004).

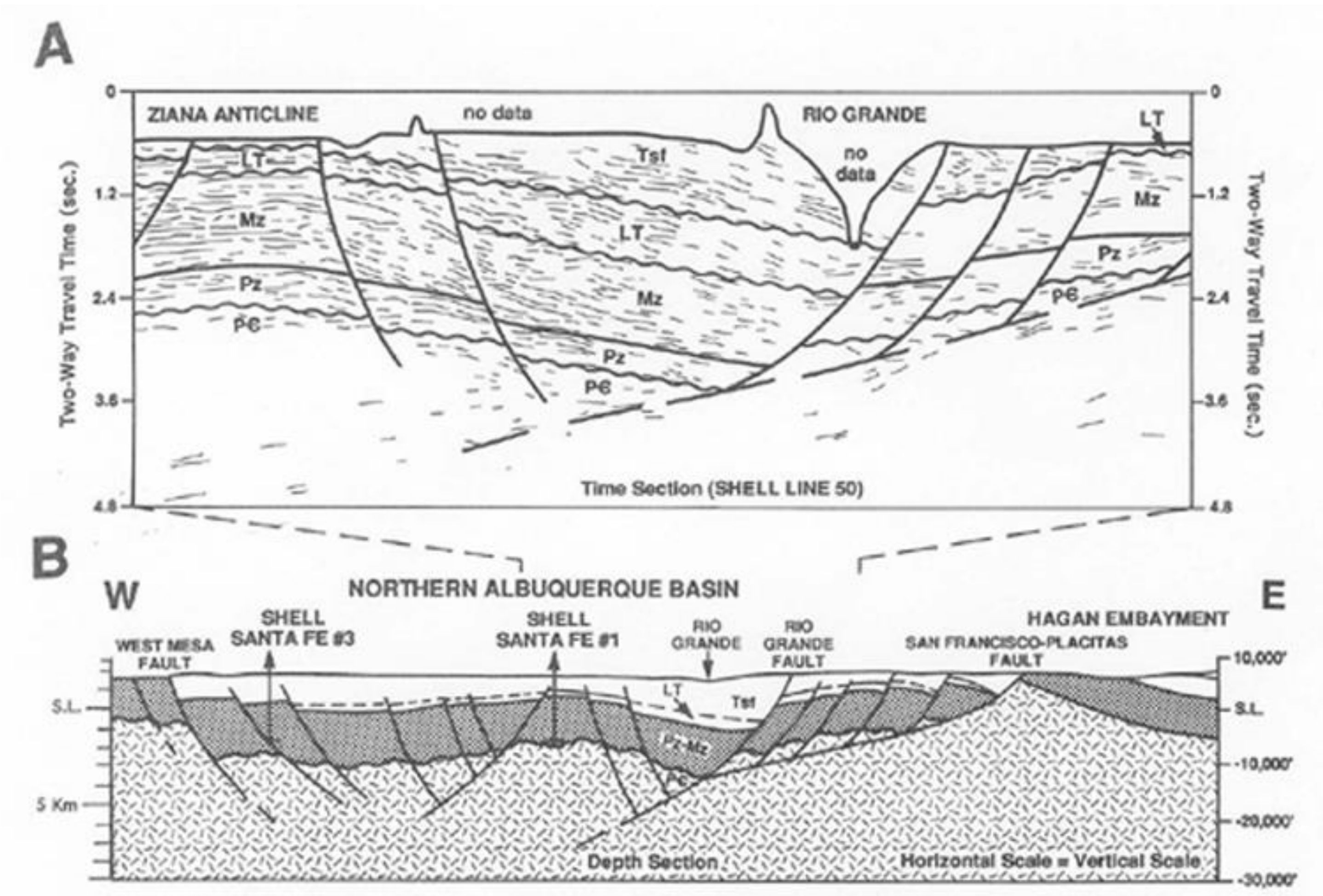


Figure 2.3. East-to-west seismic and geologic cross sections of the Albuquerque basin on a line approximately 3 miles south of Site 1. The depths for the seismic section are in seconds. The seismic section crosses the highway between Pueblo of Zia and Bernalillo where the Ziana anticline is shown (from May and Russell, 1994).

The Pueblo of Zia Pueblo Site 1 area overlies an intrabasin, half-graben block between the San Ysidro fault (equivalent to West Mesa fault in cross section) on the west and the buried Rio Grande master half-graben fault on the east (Figure 2.3 B) and specificically at a northward projected location between the Shell Santa Fe #3 and Shell Santa Fe #1 test wells. The Shell Santa Fe #1 well is drilled over the Ziana anticline or intrabasin horst block (Figure 2.3). Pueblo of Zia Sites 3 occupies a relative structure settings equivalent to the Shell Santa Fe #3 well while Site 4 would be closer to the western boundary fault (West Mesa fault in the cross section and equivalent to San Ysidro) fault or even on the fault footwall.

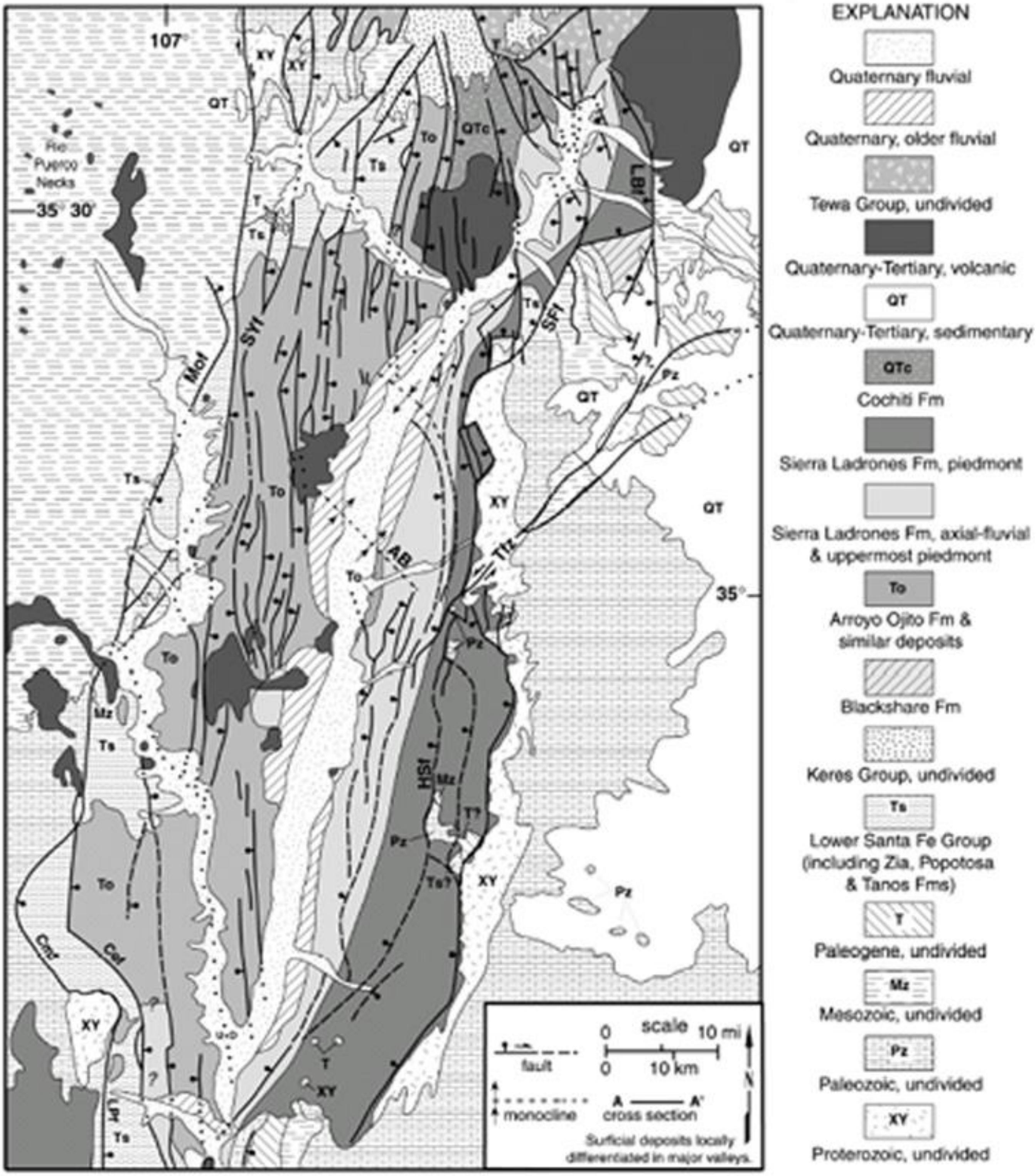


Figure 2.4. Summary Geologic Map of the Albuquerque basin (Connell, 2001).

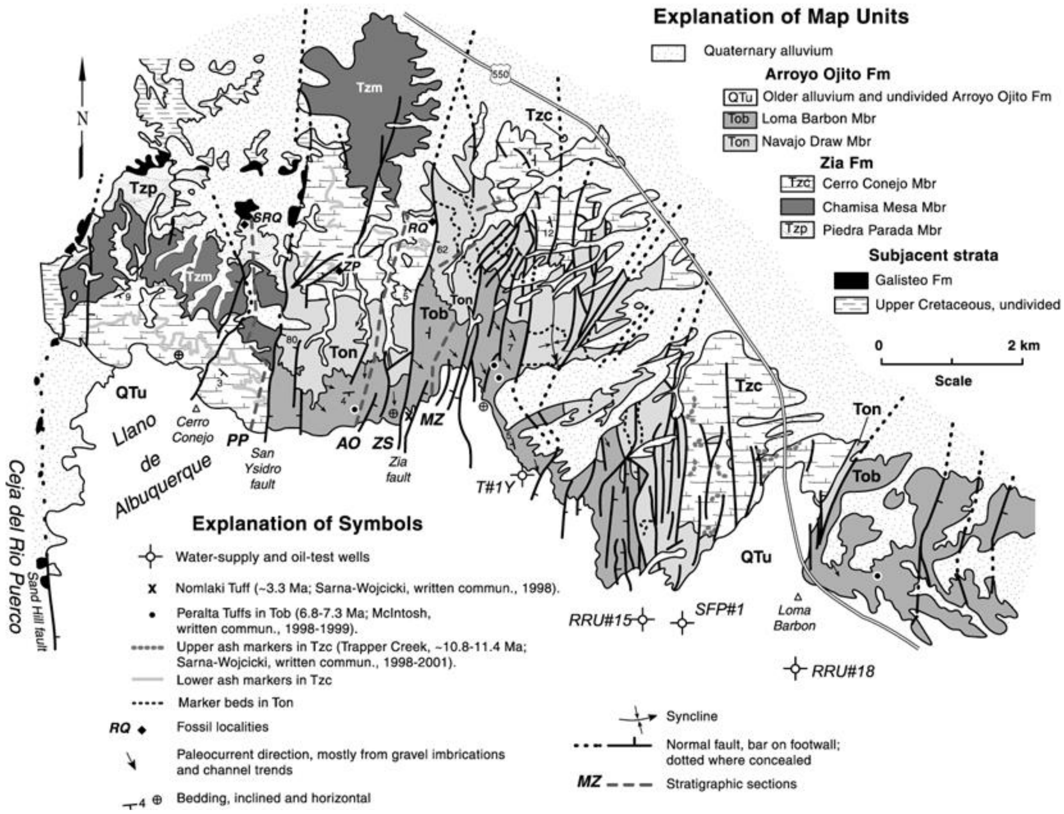


Figure 2.5. Geologic map of the Pueblo of Zia Site 1 area.

## 2.4 Aquifers and Confining Aquitards

Evaluation of potential reservoirs is focused on Mesozoic and Paleozoic sandstone and carbonate rocks due to their deeper and higher temperature locations beneath Tertiary basin fills on Pueblo of Zia. These units also have known characteristics as aquifers at shallow depth on the adjacent Colorado Plateau to the west and in the Sandia and Manzano Mountains and Estancia area to the east which allows evaluation of water transmitting and storage properties.

Figure 2.6 is a stratigraphic column for the Albuquerque basin subsurface. Potential reservoir rocks are colored red. Discussion of the reservoir rocks will begin with the oldest and deepest buried unit and end with the youngest and shallowest units.

Mississippian carbonate rocks, Arroyo Penasco Formation, where preserved in the subsurface may host solution permeability. Unfortunately, the discontinuous nature and limited volume probably rule this unit out as a geothermal reservoir target.

The Pennsylvanian Madera Group may have reservoir potential where fracturing and solution permeability of fractures and bedding in carbonate units is well developed. Total thickness of the Madera Group is about 1,300 to 1,400 ft in the Sandia and Manzano Mountains (Kelley and Northrop, 1975). Localized highly productive reservoirs are known in the Madera Group on the east side of the Sanda and Manzano Mountains (Titus, 1980). The Madera Group conformably overlies the Sandia Formation. The Sandia Formation consists mostly of sandstone with interbedded limestone, and shale with an average thickness of about 150 ft (Kelley and Northrop, 1975). The Madera Group consists of three formations, the Los Moyos, Wild Cow, and Bursum (Myers, 1982; and Kues and Giles, 2004). The Los Moyos Formation is between 450 and 500 ft thickness and mostly consists of thick-bedded, gray-to-black, cherty limestone. The Wild Cow Formation, 780 to 875 ft thick, contains thin-to-thick bedded, cherty limestone interbedded with arkosic sandstone, conglomeratic sandstone, and micaceous siltstone and shale. The approximately 130 ft of Bursum Formation at the top of the Madera Group carbonate unit does not have reservoir potential and consists mostly of purple red and green shale with minor beds of limestone and arkosic conglomerate. The mostly marine Pennsylvanian Bursum Formation is transitional into the overlying mostly terrestrial Permian Abo Formation which consists of a maximum of 700 to 900 ft thickness of red brown sandstone and mudstone with minor limestone and conglomerate beds.

The Yeso Formation sandstone, and in particular, the Meseta Blanca Member provides another potential reservoir host. The Meseta Blanca Member is conformable with the underlying Abo Formation. The basal Yeso consists of 70 to 150 ft of red-orange, eolian, thick-bedded, variably-cemented, clean, fine-to-medium sandstone (Kelley and Northrop, 1975). The Meseta Blanca Member is probably correlative with the De Chelly Sandstone of the Cutler Group to the west on the Colorado Plateau (Baars, 1962). The 250 to 400 ft thick San Ysidro Member of the Yeso Formation provides a cap rock over the potential Meseta Blanca reservoir. The San Ysidro Member is formed by orange-red sandstone with interbeds of limestone, shale, and gypsum (anhydrite in the deep subsurface) and gypsiferous siltstone. The presence of evaporates in the Yeso indicates that water quality in the Meseta Blanca and overlying Permian Glorieta reservoir units may be poor.

The Permian San Andres Formation is comprised of the Glorieta Sandstone Member and San Andres Limestone Member and forms one of the more important potential reservoir hosts in the area. The San Andres carbonate units are prone to have good solution permeability as a result of erosion and subaerial exposure during the Triassic (Titus, 1980). However, the San Andres does not show solution permeability everywhere. The marine Glorieta Sandstone is a light yellow grey-to-white, well-sorted, clean quartz sandstone that is sometimes highly cemented. The Glorieta is around 150 ft thick and occurs in massive beds with abundant cross bedding. The San Andres Limestone Member is a gray, fine-crystalline, thick-bedded limestone that has interbedded tan, medium-grained sandstone and may be absent in the Pueblo of Zia area as a result of Triassic erosion.

Unconformably overlying the San Andres Formation aquifer are sandstone beds forming the lower Chinle Group. The sandstone also forms reservoirs as an the upper part of an aquifer system that includes the San Andres and Glorieta units. In the Pueblo of Zia region, the correlative Chinle Group sandstones include the Shinarump Formation to the west around Mesa Lucero, the Aqua Zarca Formation around the flanks of the Nacimiento Mountain near San Ysidro, and the Santa Rosa Formation on the east side of the Sandia and Manzano Mountains (Lucas, 2004). Hot artesian wells drilled into the Aqua Zarca Formation on Pueblo of Zia northwest of San Ysidro attest to the potential of the sandstones as reservoirs (Clark, 1929, Renick, 1931, and Witcher, 1988). The Santa Rosa Formation consists mostly of medium-grained, white-to-red brown, thin-to-thick bedded sandstone with local conglomeratic lenses. Thickness of the Santa Rosa Sandstone in the Sandia Mountains ranges from 100 to 400 ft. The lower Chinle Group sandstones are overlain by thick and relatively impermeable sequences of colorful mudstone and siltstone with subordinate sandstone designated as the Petrified Forest Formation. Thickness of the Chinle (Petrified Forest) aquitard is around 1,300 to 1,400 ft.

The Jurassic Entrada Formation unconformably overlies the Upper Triassic Chinle Group. The Entrada is an eolian, fine-to-medium grained, massive, cross-bedded, quartz sandstone with reservoir potential. The Entrada ranges from 60 to 120 ft thickness in the area. The Todilto Formation, a less than 200 ft thick aquitard composed of mostly anhydrite (gypsum), minor limestone and black shale caps the Entrada Formation and is the rock mined for gypsum at White Mesa on Pueblo of Zia.

A maximum 190 ft of cyclically bedded, red and gray sandstone, mudstone and siltstone of the Summerville Formation overlies the Todilto Formation (Lucas, 2004). The Jurassic Summerville is not believed to have major aquifer potential in the Pueblo of Zia subsurface. However, the disconformably overlying Salt Wash Member of the Jurassic Morrison Formation is believed to have potential to host a reservoir. The Salt Wash Member is a fluvial sandstone and conglomerate with subordinate interbeds of mudstone. The Salt Wash Member is approximately 250 ft maximum thickness (Lucas, 2004). The Salt Wash Member grades upward into the Brushy Basin Member of the Morrison Formation. The Brushy Basin is an aquitard with 420 ft maximum thickness and consists of colorful bentonitic claystone and siltstone.

The upper sandstone unit of the Jurassic Morrison Formation, the Jackpile Sandstone Member, and the Cretaceous Dakota Formation may form another aquifer system between the Brushy Basin Member shales of the Morrison Formation and the Cretaceous Mancos Shale. The Jurassic Jackpile Sandstone Member is light yellow, gray-to-white, trough-cross bedded sandstone with minor conglomerate and interbeds of green gray clay with an estimated maximum thickness of 200 ft (Lucas and others, 1999). An important unconformity separates the Jurassic rocks from the Cretaceous rocks. The Jurassic section is truncated southward in the northwest Albuquerque basin subsurface (Black, 1982). The stratigraphy of the transgressive Cretaceous Dakota Formation is variable and complex and consists of four members, depending upon location in the region (Owen and Siemers, 1977). The sandstone members are generally fine-to-coarse, cross-bedded, quartz sandstone with minor black shale interbeds. The Dakota is between 150 and 200 ft thick. Approximately 1,400 to 1,500 ft thickness of black-to-gray, marine shales and minor sandstones of the Cretaceous Mancos Formation confine the Dakota-Jackpile aquifer system.

The regressive Cretaceous Point Lookout Sandstone, the upper most reservoir host characterized in this study, is conformable on the Mancos shales and consists of thick bedded, very fine-to-medium grained, cross-bedded, clean, quartz sandstone with thin interbeds of dark marine shale (Molenaar, 1977; Kernodle, 1996). The Point Lookout is estimated to be 100 to 200 ft thick in the subsurface. The conformably overlying mudstones and carbonaceous shales and coal of the Cretaceous Menefee Formation are truncated by Tertiary erosion and probably do not exceed 1,000 ft in thickness.

The Cretaceous aquifers and aquitards are overlain by hundreds to thousands of feet thickness of Laramide basin fill of the Galisteo Formation north of the Tijeras-Canoncito Fault system (Cather, 2004). Middle Tertiary volcanoclastic sediments overlie the Galisteo Formation. Many thousand feet of Late Tertiary rift basin fill of the Santa Fe Group deeply bury older rocks in the northwest Albuquerque basin subsurface. Rocks younger than the Point Lookout Formation are not discussed in terms of geothermal reservoir potential.

### 2.5 Reservoirs beneath Zia Pueblo Site 1, 3, and 4

Several important regional unconformities have major impact on potential geothermal reservoirs in the northwest Albuquerque basin. First the San Andres limestone is generally removed by erosion and the Glorieta sandstone is thinner. However, the Triassic-Permian unconformity does provide potential for enhanced solution permeability where the San Andres limestone is preserved below the Triassic Aqua Zarca-Santa Rosa Sandstone.

Faulting in the northwest Albuquerque basin may act to compartmentalize stratigraphic reservoirs where fault displacement juxtaposes aquifers against aquitards or where sufficient fault zone gouge develops to block lateral water flow. On the other hand, young and repeated faulting enhances beneficial fracture permeability. Quaternary faulting is discussed by Personius and others 1999, and mapped by Connell, 2004.

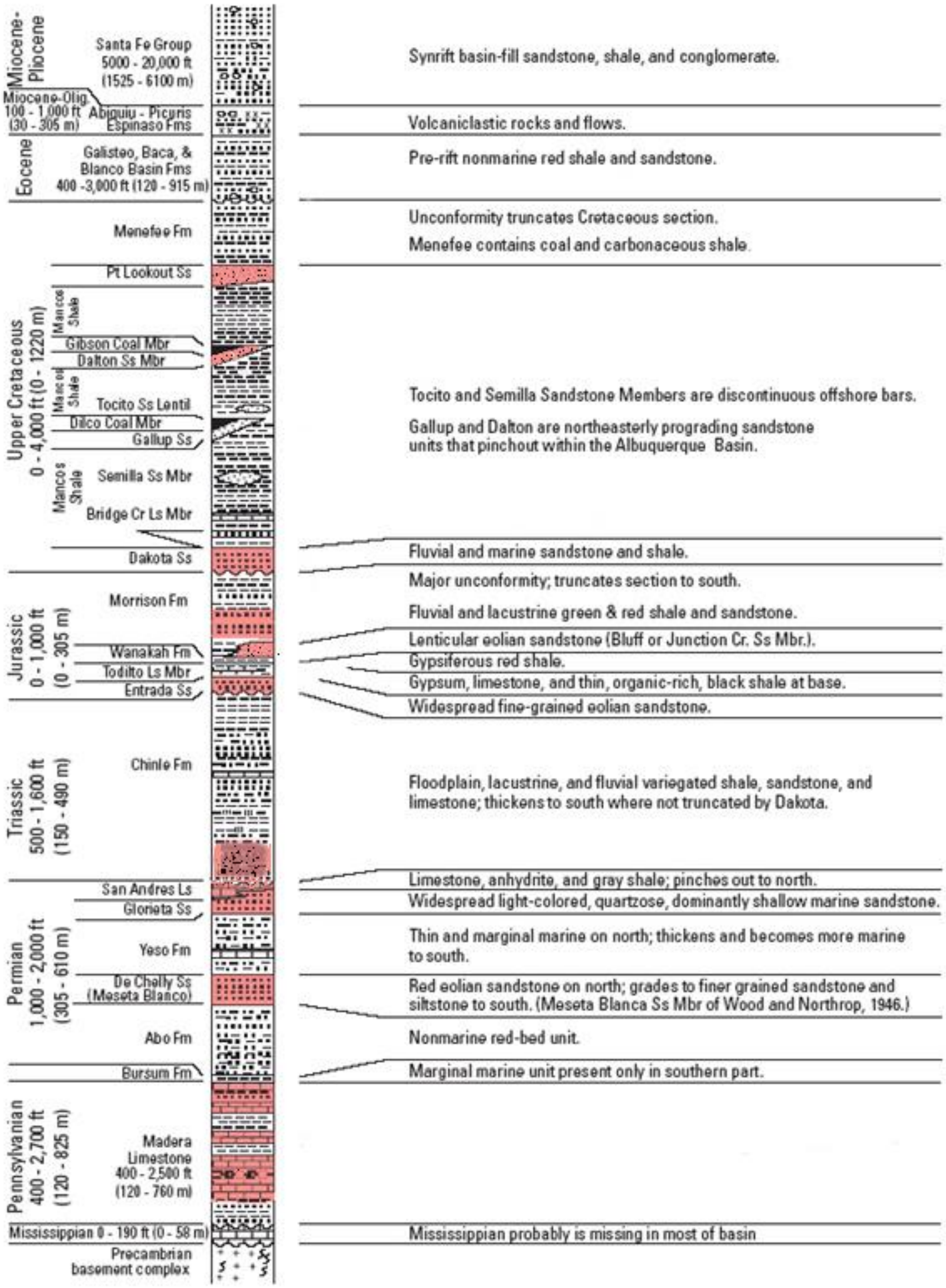


Figure 2.6. Summary stratigraphic column for the Albuquerque basin (modified from Molenaar (1988)

The Davis Petroleum Corp, Tamara 1Y and the Shell, Santa Fe #1 oil and gas test wells provide key formation datums required to delineate subsurface reservoir depths and thickness beneath Zia Pueblo Site 1 (Tables 2.1, 2.3, 2.4, and 2.5 and Appendix A). Formation tops are from Lozinsky (1994), files of New Mexico Bureau of Geology and Mineral Resources, Socorro.

Table 2.1. Stratigraphic framework of the Davis Petroleum Corporation, Tarmara 1Y oil and gas test well.

| Davis Petroleum Corp, Tamara 1Y | | |
|---|---|---|
| **UNIT** | **TOPS DEPTH ft** | **REMARKS** |
| Sante Fe Group | 0 | Connell and others (2001) |
| Arroyo Ojito Fm | 0 | Connell and others (2001) |
| Zia Fm | 1,260 | Connell and others (2001) |
| volcanoclastics | 3,760 | Connell and others (2001) |
| Galisteo Fm | 5,309 | Connell and others (2001) |
| Menefee Fm | 6,442 | |
| Point Lookout | | **absent; Hosta Dalton 6,510 ft;** |
| Mancos Fm | | **not picked; Gallup 7,044 ft; Greenhorn 8,040 ft** |
| Dakota SS | 8,170 | |
| Morrison Fm | 8,330 | |
| Brushy Basin Mbr | | |
| Salt Wash Mbr | | **partial, faulted out** |
| Summerville Fm | | **faulted out** |
| Todilto Fm | 8,470 | |
| Entrada SS | 8,550 | |
| Chinle Grp | | |
| Petrified Forest Fm | 8,680 | **drilled incomplete section (TD 8,732 ft)** |
| Aqua Zarca Fm | | |
| San Andres Fm | | |
| San Andres Mbr | | |
| Glorieta Mbr | | |
| Yeso | | |
| San Ysidro Mbr | | |
| Meseta Blanca Mbr | | |
| Abo | | |
| Madera Grp | | |
| Bursum Fm | | |
| Wild Cow Fm | | |
| Los Moyos Fm | | |
| Sandia Fm | | |
| Arroyo Penasco Fm | | |
| | | **TD (8,732 ft reported in Chinle?)** |

Table 2.2. Stratigraphic framework of the Shell Santa Fe #1 oil and gas test well.

| Shell, Santa Fe Pacific 1 | | |
|---|---|---|
| **UNIT** | **TOPS DEPTH ft** | **REMARKS** |
| Santa Fe Group | 0 | **below 1,500 ft to top Galisteo,~2,000 ppm TDS** |
| Galisteo Fm | 2,970 | **>10,000 ppm TDS** |
| Menefee Fm | 3,644 | **2956 ft of Cretaceous above the Dakota SS** |
| Point Lookout | 4,378 | |
| Mancos Fm | 4,520 | **faulted** |
| Dakota SS | 6,600 | |
| Morrison Fm | 6,907 | **thickness includes the Summerville Fm** |
| Brushy Basin Mbr | | **not picked** |
| Salt Wash Mbr | | **not picked** |
| Summerville Fm | | **not picked** |
| Todilto Fm | 7,412 | |
| Entrada SS | 7,530 | |
| Chinle Grp | 7,726 | |
| Petrified Forest Fm | | |
| Aqua Zarca Fm | | **not picked** |
| San Andres Fm | 8,880 | |
| San Andres Mbr | | **probably thin or absent** |
| Glorieta Mbr | | |
| Yeso | 8,992 | |
| San Ysidro Mbr | 8,992 | |
| Meseta Blanca Mbr | 9,378 | |
| Abo | 9,632 | |
| Madera Grp | 10,375 | **units below Abo Fm and above Precambrian** |
| Bursum Fm | | **not picked** |
| Wild Cow Fm | | **not picked** |
| Los Moyos Fm | | **not picked** |
| Sandia Fm | | **not picked** |
| Arroyo Penasco Fm | | **absent or not picked** |
| Precambran | 10,955 | |
| TOTAL | | **TD (11,045 ft)** |

Table 2.3. Estimated subsurface stratigraphy at the Pueblo of Zia Site 1 area.

| PUEBLO OF ZIA ALBUQUERQUE BASIN (NW REGION)<br>SITE 1 - ROBERTS TOWER AREA | | | |
|---|---|---|---|
| **AGE** | **UNIT** | **DEPTH ft** | **THICKNESS ft** |
| Tertiary | Sante Fe Group | 0 | **3,760** |
| Tertiary | volcanoclastic seds | 3,760 | **1,549** |
| Tertiary | Galisteo Fm | 5,309 | **1,136** |
| Cretaceous | Menefee Fm (or above Kds) | 6,442 | **1,100** |
| Cretaceous | Crevasse Canyon | 7,542 | **200** |
| Cretaceous | Mancos Fm | 7,742 | **900** |
| Cretaceous | Dakota SS | 8,642 | **310** |
| Jurassic | Morrison Fm | 8,952 | **350** |
| | Brushy Basin Mbr | 8,952 | **100** |
| | Salt Wash Mbr | 9,052 | **250** |
| Jurassic | Summerville Fm | 9,302 | **150** |
| Jurassic | Todilto Fm | 9,452 | **80** |
| Jurassic | Entrada SS | 9,532 | **130** |
| Triassic | Chinle Grp | 9,662 | **1,600** |
| | Petrified Forest Fm | 9,662 | **1,300** |
| | Aqua Zarca Fm | 10,962 | **300** |
| Permian | San Andres Fm | 11,262 | **112** |
| | San Andres Mbr | 11,262 | **12** |
| | Glorieta Mbr | 11,274 | **100** |
| | Yeso | 11,374 | **640** |
| | San Ysidro Mbr | 11,374 | **386** |
| | Meseta Blanca Mbr | 11,760 | **254** |
| Permian | Abo | 12,014 | **743** |
| Pennslyvanian | Madera Grp | 12,757 | **880** |
| | Bursum Fm | 12,757 | **100** |
| | Wild Cow Fm | 12,857 | **450** |
| | Los Moyos Fm | 13,307 | **300** |
| Pennslyvanian | Sandia Fm | 13,607 | **30** |
| Mississippian | Arroyo Penasco Fm | 13,637 | **<50** |
| | TOTAL | | **13,637** |

The stratigraphy in Table 2.3 provides a basis to estimate depths, formation temperatures, and hydraulic conductivity (transmissivity) for potential reservoir rocks beneath Pueblo of Zia Site 1.

Table 2.4. Estimated subsurface stratigraphy at the Pueblo of Zia Site 3.

| PUEBLO OF ZIA ALBUQUERQUE BASIN (NW REGION) SITE 3 - SUBSTATION SAN YSIDRO | | | |
|---|---|---|---|
| **AGE** | **UNIT** | **DEPTH ft** | **THICKNESS ft** |
| Tertiary | Sante Fe Group | 0 | **2,550** |
| Tertiary | volcanoclastic seds | 2,550 | **800** |
| Tertiary | Galisteo Fm | 3,350 | **250** |
| Cretaceous | Menefee Fm (or above Kds) | 3,600 | **600** |
| Cretaceous | Crevasse Canyon | 4,200 | **200** |
| Cretaceous | Mancos Fm | 4,400 | **900** |
| Cretaceous | Dakota SS | 5,300 | **300** |
| Jurassic | Morrison Fm | 5,600 | **350** |
| | Brushy Basin Mbr | 5,600 | **100** |
| | Salt Wash Mbr | 5,700 | **250** |
| Jurassic | Summerville Fm | 5,950 | **150** |
| Jurassic | Todilto Fm | 6,100 | **100** |
| Jurassic | Entrada SS | 6,200 | **80** |
| Triassic | Chinle Grp | 6,280 | **1,600** |
| | Petrified Forest Fm | 6,280 | **1,300** |
| | Aqua Zarca Fm | 7,580 | **300** |
| Permian | San Andres Fm | 7,880 | **112** |
| | San Andres Mbr | 7,880 | **0** |
| | Glorieta Mbr | 7,880 | **100** |
| | Yeso | 7,980 | **640** |
| | San Ysidro Mbr | 7,980 | **386** |
| | Meseta Blanca Mbr | 8,366 | **254** |
| Permian | Abo | 8,620 | **743** |
| Pennslyvanian | Madera Grp | 9,363 | **880** |
| | Bursum Fm | 9,363 | **100** |
| | Wild Cow Fm | 9,463 | **450** |
| | Los Moyos Fm | 9,913 | **300** |
| Pennslyvanian | Sandia Fm | 10,213 | **30** |
| Mississippian | Arroyo Penasco Fm | 10,243 | **<50** |
| | | TOTAL | **10,243** |

Tables 2.4 shows the subsurface formation tops and thicknesses for Pueblo of Zia Site 3. Formation depths shown in Table 2.4 for the San Ysidro Substation area around Site 3 were estimated from a few formation top ranges provided by Bruce Black (personal communication). Stratigraphic information of Pueblo of Zia Site 4 is shown in Table 2.5. Thicknesses and formation tops are based upon cross section 'B' of Woodward and Ruetschilling (1976).

Table 2.5. Estimated subsurface stratigraphy at the Pueblo of Zia Site 4.

| PUEBLO OF ZIA ALBUQUERQUE BASIN (NW REGION) SITE4- SAN YSIDRO ZIA ENTERPRISE ZONE (ZEZ) | | | |
|---|---|---|---|
| **AGE** | **UNIT** | **DEPTH ft** | **THICKNESS ft** |
| Cretaceous | Dakota SS | 0 | **150** |
| Jurassic | Morrison Fm | 150 | **350** |
| | Brushy Basin Mbr | 150 | **100** |
| | Salt Wash Mbr | 250 | **250** |
| Jurassic | Summerville Fm | 500 | **150** |
| Jurassic | Todilto Fm | 650 | **80** |
| Jurassic | Entrada SS | 730 | **130** |
| Triassic | Chinle Grp | 860 | **1,600** |
| | Petrified Forest Fm | 860 | **1,300** |
| | Aqua Zarca Fm | 2,160 | **300** |
| Permian | San Andres Fm | 2,460 | **112** |
| | San Andres Mbr | 2,460 | **0** |
| | Glorieta Mbr | 2,460 | **100** |
| | Yeso | 2,560 | **640** |
| | San Ysidro Mbr | 2,560 | **386** |
| | Meseta Blanca Mbr | 2,946 | **254** |
| Permian | Abo | 3,200 | **743** |
| Pennslyvanian | Madera Grp | 3,943 | **880** |
| | Bursum Fm | 3,943 | **100** |
| | Wild Cow Fm | 4,043 | **450** |
| | Los Moyos Fm | 4,493 | **300** |
| Pennslyvanian | Sandia Fm | 4,793 | **30** |
| Mississippian | Arroyo Penasco Fm | 4,823 | **<50** |
| TOTAL | | | **4,823** |

## 2.6 Hydraulic Conductivity

Besides water quality and temperature, the water transmitting properties and storage capacity of a geothermal reservoir are among the most important parameters required to evaluate geothermal potential. Intrinsic permeability (k) is a measure of the fluid transmitting property of the rock only and is generally reported as millidarcies (md) or as feet squared ($ft^2$). However, in order to evaluate the flow of a particular fluid through a specific rock volume, the properties of the fluid must also be taken into account. In this case, hydraulic conductivity (K) is related to intrinsic permeability (k) by taking into account the viscosity or resistance to flow of the fluid.

<u>Equation 1</u>

$K = k\,(pg/u)$ Lohman (1972)

where:
- K - hydraulic conductivity (ft/d)
- k - intrinsic permeability ($ft^2$)
- *g* - acceleration of gravity
- *u* - dynamic viscosity
- *p* - fluid density

Dynamic viscosity of the fluid is dependent upon temperature, gas content, and salinity of the fluid. Hydraulic conductivity (K) is commonly reported as feet per day (ft/d). In order, to evaluate the ability of an aquifer or a reservoir has a whole to transmit water, hydraulic conductivity is multiplied by the aquifer or reservoir thickness to obtain the transmissivity (T) which is commonly reported as feet squared per day ($ft^2/d$). Transmissivity is obtained from well flow or pump tests and permeability (k) is often obtained from permeameter tests of rock cores or from drill stem tests. Porosity ($\phi$) or percent of void space in a rock is usually measured with core or geophysical logs. Storativity (S) is also obtained during well flow or pump tests. Storativity or storage coefficient (S) is a dimensionless measure of the volume of water released from a unit area ($ft^2$) of reservoir per unit of head change (ft).

Measurements of hydraulic properties of potential deep-seated reservoir rocks or bedrock aquifer systems beneath Pueblo of Zia are unavailable. However, many measurements are available as a result of ground water and oil and gas development in the surrounding region. The approach taken in this study is to compile the measurements and evaluate the data for extrapolation into the deep subsurface at Pueblo of Zia. Appendix C is a database that lists a summary of more than 170 results that are reported from 21 published and unpublished sources. The actual number of measurements represents more than three thousand.

Tables 2.6, 2.7, and 2.8 lists a summary of the database in Appendix C for the major bedrock reservoir units or aquifer systems. Two major categories of permeability information are used. Where core or drill stem test (DST) data are reported, the data are characterized as representing matrix permeability of a small reservoir volume. Well pump or flow test data are assumed to represent the reservoir permeability of a large rock volume. The calculated values of intrinsic permeability (k) for the pump test data are 1.1 to 189.5 times the measured values of intrinsic permeability for core (see Appendix C). One interpretation is that the pump test data reflect the influence of fracture and solution permeability. Finally, all data are corrected for temperature and salinity (total dissolved solids or TDS) in order to determine transmissivity (T) for expected temperature and salinity beneath the Pueblo of Zia Site 1, 3, and 4.

Table 2.6. Geothermal reservoir characteristics for Pueblo of Zia Site 1.

| matix permeability | CORE/DST | est | est | est | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|
| RESERVOIR | LITH | THICK | TEMP | TDS | HCOND K | TRANS T |
| | | ft | oF | mg/L | ft/d | ft2/d |
| CREVASSE CAN/DALTON SS | SAND | 200 | 208 | 10,000 | 0.027 | 5.40 |
| DAKOTA | SAND | 310 | 232 | 10,000 | 0.010 | 3.10 |
| MORRISON (SALT WASH) | SAND | 250 | 238 | 10,000 | | |
| ENTRADA | SAND | 130 | 243 | 10,000 | 3.427 | 445.56 |
| AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 278 | 15,000 | 0.036 | 14.58 |
| DECHELLY/MESETA BLANCA | SAND | 250 | 289 | 15,000 | 0.010 | 2.49 |
| MADERA | LIME/SAND | 300 | 315 | 15,000 | 0.215 | 64.41 |
| **w/fracture permeability** | **PUMP TEST** | **est** | **est** | **est** | **T-TDScorr** | **T-TDScorr** |
| **RESERVOIR** | **LITH** | **THICK** | **TEMP** | **TDS** | **HCOND K** | **TRANS T** |
| | | **ft** | **oF** | **mg/L** | **ft/d** | **ft2/d** |
| CREVASSE CAN/DALTON SS | SAND | 200 | 208 | 10,000 | | |
| DAKOTA | SAND | 310 | 232 | 10,000 | 0.264 | 81.99 |
| MORRISON (SALT WASH) | SAND | 250 | 238 | 10,000 | 1.634 | 408.58 |
| ENTRADA | SAND | 130 | 243 | 10,000 | 3.722 | 483.81 |
| AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 278 | 15,000 | 6.555 | 2,687.40 |
| DECHELLY/MESETA BLANCA | SAND | 250 | 289 | 15,000 | | |
| MADERA | LIME | 300 | 315 | 15,000 | 3.206 | 961.83 |

Table 2.7. Geothermal reservoir characterics for Pueblo of Zia Site 3

| matix permeability | CORE/DST | est | est | est | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|
| RESERVOIR | LITH | THICK | TEMP | TDS | HCOND K | TRANS T |
| | | ft | ºF | mg/L | ft/d | ft²/d |
| DAKOTA | SAND | 150 | 183 | 10,000 | 0.008 | 1.15 |
| MORRISON (SALT WASH) | SAND | 500 | 190 | 10,000 | | |
| ENTRADA | SAND | 130 | 195 | 10,000 | 2.680 | 348.40 |
| AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 234 | 15,000 | 0.029 | 11.90 |
| DECHELLY/MESETA BLANCA | SAND | 250 | 247 | 15,000 | 0.008 | 2.06 |
| MADERA | LIME/SAND | 300 | 276 | 15,000 | 0.181 | 54.33 |
| **w/fracture permeability** | **PUMP TEST** | **est** | **est** | **est** | **T-TDScorr** | **T-TDScorr** |
| **RESERVOIR** | **LITH** | **THICK** | **TEMP** | **TDS** | **HCOND K** | **TRANS T** |
| | | **ft** | **ºF** | **mg/L** | **ft/d** | **ft²/d** |
| DAKOTA | SAND | 150 | 183 | 10,000 | 0.210 | 31.50 |
| MORRISON (SALT WASH) | SAND | 500 | 190 | 10,000 | 1.272 | 635.88 |
| ENTRADA | SAND | 130 | 195 | 10,000 | 2.910 | 378.31 |
| AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 234 | 15,000 | 5.608 | 2,299.28 |
| DECHELLY/MESETA BLANCA | SAND | 250 | 247 | 15,000 | | |
| MADERA | LIME | 300 | 276 | 15,000 | 2.704 | 811.30 |

Table 2.8. Geothermal reservoir characterics for Zia Pueblo Site 4.

| matix permeability | CORE/DST | est | est | est | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|
| RESERVOIR | LITH | THICK | TEMP | TDS | HCOND K | TRANS T |
| | | ft | ºF | mg/L | ft/d | ft²/d |
| AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 124 | 15,000 | 0.013 | 5.46 |
| DECHELLY/MESETA BLANCA | SAND | 250 | 139 | 15,000 | 0.004 | 1.06 |
| MADERA | LIME/SAND | 300 | 175 | 15,000 | 0.108 | 32.39 |
| **w/fracture permeability** | **PUMP TEST** | **est** | **est** | **est** | **T-TDScorr** | **T-TDScorr** |
| **RESERVOIR** | **LITH** | **THICK** | **TEMP** | **TDS** | **HCOND K** | **TRANS T** |
| | | **ft** | **ºF** | **mg/L** | **ft/d** | **ft²/d** |
| AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 124 | 15,000 | 2.573 | 1,054.95 |
| DECHELLY/MESETA BLANCA | SAND | 250 | 139 | 15,000 | | |
| MADERA | LIME | 300 | 175 | 15,000 | 1.612 | 483.64 |

Temperatures are from Tables 3.1 through Table 3.4 in Section 3.3. Salinities for particular reservoir units are from drill stem test data and from Hiss and others (1975). Salinities should be considered minimum values for the Paleozoic reservoir units due to the presence of evaporates (anhydrite and halite) in underlying Permian units such as the Yeso Formation in the region. Recent gravity modeling work in the Belen basin to the south infers significant halite accumulations in the Yeso Formation (Grauch and others, 1999). Salinity and temperature corrected hydraulic conductivity and transmissivity are calculated with the following:

Equation 2 Weiss (1982)

$$K_{hc} = k\,(1+(TDS/1{,}000)/300)/365u$$

where:

- $K_{hc}$ - hydraulic conductivity (ft/d)
- $k$ - intrinsic permeability (md or millidarcies)
- $u$ - viscosity (centipoises)(temperature corrected)
- TDS - total dissolved solids (mg/L)

Equation 3 Teller and Chafin (1986)

$$u = 1.93 - (0.818 \log(0.556\,T - 22.8))$$

where:

- $u$ - viscosity (centipoises)(temperature corrected)
- T - temperature ($^oF$)

A temperature correction for viscosity is essential to realistically estimate the geothermal reservoir hydraulic conductivity. Transmissivity ($ft^2/d$) is estimated from the product of the reservoir thickness and the corrected hydraulic conductivity.

## 3.0 THERMAL REGIME

Regional heat flow data provides a foundation to evaluate the geothermal energy potential of an area. Heat flow data can be used to calculate subsurface temperature and to evaluate the dynamics of hydrothermal convection. Conductive heat flow (Q) is the product of rock thermal conductivity (K) and the temperature gradient (dT/dz).

<u>Equation 4</u>

$$Q = (K)(dT/dz)$$

where:

- Q - heat flow ($mW/m^2$)
- K - thermal conductivity ($W/mK^o$)
- dT/dz - temperature gradient ($^oC/km$)
- T - temperature ($^oC$)
- z - depth (km)

Conductive heat flow in the shallow crust represents the summation of heat from the mantle and heat generated by radioactive decay of uranium, thorium, and potassium in the crust that flows or conducts out of the near surface (Birch, 1950). Most of the heat generation occurs in a “radioactive granite” layer that is generally between 9 and 12 km thickness in the upper crust (Roy and others, 1968 and 1972). Also, in regions of active rifting such as the Rio Grande rift and Abuquerque basin, magma that is generated in the mantle may intrude or pool in the sill-like magma bodies in the lower and middle crust and add additional heat the shallow crust (Baldridge and others, 1995; and Morgan and Golombek, 1984).

Equation 5

$$Q = Q_m + Q_{cp} + Q_{mc}$$

where:

- $Q$ - heat flow ($m$W/m$^2$)
- $Q_m$ - mantle heat flow ($m$W/m$^2$)
- $Q_{cp}$ - crustal heat production for radioactive decay ($m$W/m$^2$)
- $Q_{mc}$ - heat from crystallizing magma intrusion in lower crust ($m$W/m$^2$)

### 3.2 Regional Heat Flow

Published heat flow data for the region is tabulated in Appendix D. Primary references for heat flow include Reiter and others (1975 and 1978), Edwards, and others (1978), and Reiter and others (1986). A mean or background heat flow for the Pueblo of Zia Site 1, is 77 $m$W/m$^2$ (Reiter and others,1986).

### 3.3 Estimates of Reservoir Temperature

Assuming that the thermal regime is predominantly conductive, three approaches may be applied to estimate subsurface reservoir temperatures. The first approach uses regional heat flow information in conjunction with estimates of thermal conductivity for the rock column units overlying the deep reservoir. This approach is more rigorous and likely more reliable indicator of subsurface temperature. The second approach uses shallow temperature gradients to predict deep temperature conditions. This approach is the least reliable and may be subject to great error when subsurface thermal conductivities vary and the shallow measurement has been modified even slightly by convective (ground water flow) processes (see Section 3.4). The third approach uses deep oil and gas bottom-hole-temperatures (BHT) to determine a "typical" temperature-depth curve for the basin.

Tables 3.1 and 3.2 summarize estimated temperatures beneath Pueblo of Zia Site 1 obtained using a heat flow of 75 $m$W/m$^2$ and 85 $m$W/m$^2$. The 75 $m$W/m$^2$ heat flow would represent a minimum average. The 85 $m$W/m$^2$ represents a minimum average for most of the Rio Grande rift. However, the 75 $m$W/m$^2$ is believed to represent the best conservative estimate of subsurface temperature. The 75 $m$W/m$^2$ estimates are a few degrees higher than the BHT estimates from deep oil and gas wells and is therefore interpreted to represent a minimum estimated temperature. Section 3.5 discusses the oil and gas BHT temperature-depth curve.

Table 3.1. Subsurface temperature model for 75 $m$W/m$^2$ heat flow at Pueblo of Zia Site 1.

| **RESERVOIR TEMPS** | **ZIA SITE #1** | | | | |
|---|---|---|---|---|---|
| **Mean Annual Temp** | **13.8** | **°C** | | | |
| **Background Heat Flow** | **75** | ***m*W/m$^2$** | | | |
| **Formation** | **Depth ft** | **δT + MAT °C** | **δT + MAT °F** | **BHT model uncorr °C** | **BHT model uncorr °F** |
| Upper Santa Fe | 1,500 | 30.9 | 87.7 | 29.1 | 84.4 |
| Lower Santa Fe | 3,760 | 54.4 | 130.0 | 52.2 | 125.9 |
| Tertiary volcanic sediment | 5,310 | 114.6 | 238.3 | 68.0 | 154.4 |
| Galisteo | 4,896 | 81.8 | 179.3 | 63.8 | 146.8 |
| Menefee | 5,996 | 95.8 | 204.4 | 75.0 | 167.0 |
| Crevasse Canyon | 6,196 | 97.6 | 207.7 | 77.1 | 170.7 |
| Mancos | 7,096 | 109.1 | 228.3 | 86.3 | 187.3 |
| Dakota | 7,406 | 111.3 | 232.3 | 89.4 | 193.0 |
| Morrison/Brushy Basin | 7,506 | 112.4 | 234.3 | 90.4 | 194.8 |
| Morrison/Salt Wash | 7,756 | 114.7 | 238.5 | 93.0 | 199.4 |
| Summerville | 7,906 | 116.2 | 241.1 | 94.5 | 202.1 |
| Todilto | 7,986 | 116.6 | 242.0 | 95.3 | 203.6 |
| Entrada | 8,116 | 117.5 | 243.5 | 96.7 | 206.0 |
| Chinle/Petrified Forest | 9,416 | 134.0 | 273.2 | 109.9 | 229.9 |
| Chinle/Aqua Zarca | 9,716 | 136.7 | 278.1 | 113.0 | 235.4 |
| San Andres LS | 9,726 | 136.8 | 278.3 | 113.1 | 235.6 |
| Glorieta SS | 9,826 | 137.4 | 279.3 | 114.1 | 237.4 |
| Yeso/San Ysidro | 10,216 | 141.3 | 286.3 | 118.1 | 244.6 |
| Yeso/Meseta Blanca | 10,466 | 142.9 | 289.2 | 120.7 | 249.2 |
| Abo | 11,206 | 150.3 | 302.5 | 128.2 | 262.8 |
| Madera Group/Bursum | 11,306 | 151.3 | 304.3 | 129.2 | 264.6 |
| Madera Group/Wild Cow | 11,756 | 154.9 | 310.9 | 133.8 | 272.9 |
| Madera Group/Los Moyos | 12,056 | 157.1 | 314.8 | 136.9 | 278.4 |
| Sandia | 12,086 | 157.4 | 315.4 | 137.2 | 279.0 |
| Arroyo Penasco | 12,086 | 157.4 | 315.4 | 137.2 | 279.0 |

At Site 1, using a heat flow of 75 *m*W/m$^2$, an average reservoir temperature of 136 ºC is predicted for a depth of 9,700 ft in the middle of the Aqua Zarca-San Andres-Glorieta reservoir (δT+MAT column in Table 3.1). The BHT reservoir estimate is 112 ºC and is 24 ºC less than estimates using heat flow (BHT model column in Table 3.1).

Table 3.2. Subsurface temperature model for 85 *m*W/m$^2$ heat flow at Pueblo of Zia Site 1.

| RESERVOIR TEMPS | ZIA SITE #1 | | | | |
|---|---|---|---|---|---|
| Mean Annual Temp | 13.8 | ºC | | | |
| Background Heat Flow | 85 | *m*W/m$^2$ | | | |
| Formation | Depth ft | δT + MAT ºC | δT + MAT ºF | BHT model uncorr ºC | BHT model uncorr ºF |
| Upper Santa Fe | 1,500 | 33.2 | 91.8 | 29.1 | 84.4 |
| Lower Santa Fe | 3,760 | 59.8 | 139.7 | 52.2 | 125.9 |
| Tertiary volcanic sediment | 5,310 | 129.9 | 265.8 | 68.0 | 154.4 |
| Galisteo | 4,896 | 90.9 | 195.6 | 63.8 | 146.8 |
| Menefee | 5,996 | 106.7 | 224.1 | 75.0 | 167.0 |
| Crevasse Canyon | 6,196 | 108.8 | 227.8 | 77.1 | 170.7 |
| Mancos | 7,096 | 121.8 | 251.2 | 86.3 | 187.3 |
| Dakota | 7,406 | 124.3 | 255.7 | 89.4 | 193.0 |
| Morrison/Brushy Basin | 7,506 | 125.6 | 258.0 | 90.4 | 194.8 |
| Morrison/Salt Wash | 7,756 | 128.2 | 262.7 | 93.0 | 199.4 |
| Summerville | 7,906 | 129.8 | 265.7 | 94.5 | 202.1 |
| Todilto | 7,986 | 130.4 | 266.6 | 95.3 | 203.6 |
| Entrada | 8,116 | 131.3 | 268.4 | 96.7 | 206.0 |
| Chinle/Petrified Forest | 9,416 | 150.0 | 302.1 | 109.9 | 229.9 |
| Chinle/Aqua Zarca | 9,716 | 153.1 | 307.7 | 113.0 | 235.4 |
| San Andres LS | 9,726 | 153.2 | 307.8 | 113.1 | 235.6 |
| Glorieta SS | 9,826 | 153.9 | 309.0 | 114.1 | 237.4 |
| Yeso/San Ysidro | 10,216 | 158.3 | 316.9 | 118.1 | 244.6 |
| Yeso/Meseta Blanca | 10,466 | 160.1 | 320.2 | 120.7 | 249.2 |
| Abo | 11,206 | 168.5 | 335.2 | 128.2 | 262.8 |
| Madera Group/Bursum | 11,306 | 169.6 | 337.2 | 129.2 | 264.6 |
| Madera Group/Wild Cow | 11,756 | 173.7 | 344.7 | 133.8 | 272.9 |
| Madera Group/Los Moyos | 12,056 | 176.2 | 349.2 | 136.9 | 278.4 |
| Sandia | 12,086 | 176.6 | 349.9 | 137.2 | 279.0 |
| Arroyo Penasco | 12,086 | 176.6 | 349.9 | 137.2 | 279.0 |

A Site 1 heat flow of 85 *m*W/m$^2$ gives an average reservoir temperature of 152 ºC at a depth of 9,700 ft in the middle of the Aqua Zarca-San Andres-Glorieta reservoir (δT+MAT column in Table 3.2). The BHT reservoir estimate is 112 ºC and is 40 ºC less than estimates using heat flow (BHT model column in Table 3.2).

Table 3.3 Subsurface temperature model for 85 *m*W/m² heat flow at Pueblo of Zia Sites 3.

| RESERVOIR TEMPS | ZIA SITE #3 | | | | |
|---|---|---|---|---|---|
| **Mean Annual Temp** | **13.8** | **°C** | | | |
| **Background Heat Flow** | **85** | ***m*W/m²** | | | |
| **Formation** | **Depth ft** | **dT + MAT °C** | **dT + MAT °F** | **BHT model uncorr °C** | **BHT model uncorr °F** |
| Upper Santa Fe | 1,250 | 30.0 | 86.0 | 26.6 | 79.8 |
| Lower Santa Fe | 2,550 | 45.3 | 113.5 | 39.8 | 103.7 |
| Tertiary volcanic sediment | 3,350 | 109.7 | 229.5 | 48.0 | 118.4 |
| Galisteo | 3,600 | 57.5 | 135.6 | 42.4 | 108.3 |
| Menefee | 4,200 | 66.2 | 151.1 | 48.5 | 119.3 |
| Crevasse Canyon | 4,400 | 68.2 | 154.8 | 50.6 | 123.0 |
| Mancos | 5,300 | 81.2 | 178.2 | 59.7 | 139.5 |
| Dakota | 5,600 | 83.6 | 182.5 | 62.8 | 145.1 |
| Morrison/Brushy Basin | 5,700 | 84.9 | 184.9 | 63.8 | 146.9 |
| Morrison/Salt Wash | 5,950 | 87.5 | 189.5 | 66.4 | 151.5 |
| Summerville | 6,100 | 89.2 | 192.6 | 67.9 | 154.3 |
| Todilto | 6,200 | 89.9 | 193.7 | 68.9 | 156.1 |
| Entrada | 6,280 | 90.4 | 194.8 | 69.8 | 157.6 |
| Chinle/Petrified Forest | 7,580 | 109.2 | 228.5 | 83.0 | 181.5 |
| Chinle/Aqua Zarca | 7,880 | 112.3 | 234.1 | 86.1 | 187.0 |
| San Andres LS | 7,880 | 112.3 | 234.1 | 86.1 | 187.0 |
| Glorieta SS | 7,980 | 112.9 | 235.2 | 87.1 | 188.8 |
| Yeso/San Ysidro | 8,370 | 117.3 | 243.2 | 91.1 | 196.0 |
| Yeso/Meseta Blanca | 8,620 | 119.2 | 246.5 | 93.6 | 200.6 |
| Abo | 9,360 | 127.5 | 261.5 | 101.2 | 214.2 |
| Madera Group/Bursum | 9,460 | 128.6 | 263.5 | 102.2 | 216.0 |
| Madera Group/Wild Cow | 9,910 | 132.8 | 271.0 | 106.8 | 224.3 |
| Madera Group/Los Moyos | 10,210 | 135.3 | 275.5 | 109.9 | 229.8 |
| Sandia | 10,240 | 135.6 | 276.1 | 110.2 | 230.3 |
| Arroyo Penasco | 10,240 | 135.6 | 276.1 | 110.2 | 230.3 |

At Site 3, given a heat flow of 85 *m*W/m², the average reservoir temperature is 112 °C at a depth of 7,800 ft in the middle of the Aqua Zarca-San Andres-Glorieta reservoir ($\delta$T+MAT column in Table 3.3). The BHT reservoir estimate is 86 °C and is 26 °C less than estimates using heat flow (BHT model column in Table 3.3).

Site 4 may overlie the distal and cooled discharge of the Valles geothermal system which leaks upward to discharge at Soda Dam, Jemez Springs, and Indian Springs; therefore a heat flow 105 *m*W/m² is used in table 3.4. Reservoir temperatures between 50 and 80 °C are possible. Site 4 does not have power production potential.

Table 3.4 Subsurface temperature model for 105 *m*W/m2 heat flow at Pueblo of Zia Site 4.

| RESERVOIR TEMPS | ZIA SITE #4 | | | | |
|---|---|---|---|---|---|
| Mean Annual Temp | 13.8 | °C | | | |
| Background Heat Flow | 105 | *m*W/m² | | | |
| Formation | Depth ft | δT + MAT °C | δT + MAT °F | BHT model uncorr °C | BHT model uncorr °F |
| Dakota | 150 | 15.3 | 59.5 | 15.3 | 59.6 |
| Morrison/Brushy Basin | 250 | 16.9 | 62.4 | 16.4 | 61.4 |
| Morrison/Salt Wash | 500 | 20.1 | 68.2 | 18.9 | 66.0 |
| Summerville | 650 | 22.2 | 71.9 | 20.4 | 68.8 |
| Todilto | 730 | 22.8 | 73.1 | 21.3 | 70.3 |
| Entrada | 860 | 24.0 | 75.2 | 22.6 | 72.6 |
| Chinle/Petrified Forest | 2,160 | 47.1 | 116.8 | 35.9 | 96.5 |
| Chinle/Aqua Zarca | 2,460 | 51.0 | 123.7 | 38.9 | 102.1 |
| San Andres LS | 2,460 | 51.0 | 123.7 | 38.9 | 102.1 |
| Glorieta SS | 2,560 | 51.8 | 125.2 | 39.9 | 103.9 |
| Yeso/San Ysidro | 2,950 | 57.2 | 135.0 | 43.9 | 111.1 |
| Yeso/Meseta Blanca | 3,200 | 59.5 | 139.1 | 46.5 | 115.7 |
| Abo | 3,940 | 69.8 | 157.6 | 54.0 | 129.3 |
| Madera Group/Bursum | 4,040 | 71.2 | 160.1 | 55.1 | 131.1 |
| Madera Group/Wild Cow | 4,490 | 76.3 | 169.4 | 59.6 | 139.4 |
| Madera Group/Los Moyos | 4,790 | 79.4 | 174.9 | 62.7 | 144.9 |
| Sandia | 4,820 | 79.8 | 175.7 | 63.0 | 145.4 |
| Arroyo Penasco | 4,820 | 79.8 | 175.7 | 63.0 | 145.4 |

### 3.4 Shallow Temperature Gradient Information

Additional subsurface temperature information can be derived from water well production temperatures and from temperature logs of shallow wells. The water well production temperatures provide qualitative information and tend to represent the temperature average or mixing from several producing intervals. On the otherhand, temperature logs can provide very detailed and reliable temperatures for the depth intervals that are measured. Water well temperature information in the Albuquerque basin is tabulated in Jiracek (1983), Plummer and others (2004) and Witcher (1988a).

Jiracek (1983) Reiter (1999a and 2003) present 143 temperature logs for shallow wells that are less than 500 m depth in the Albuquerque basin. This study does not utilize or interpret the water well production temperature data or the shallow temperature logs because the present study is confined to the Pueblo of Zia area and is concerned with evaluation of deep conductive geothermal subsurface conditions at depths greater than 2 km.

Shallow temperature data are very important to find and evaluate shallow convective geothermal systems such as those identified on the Albuquerque West Mesa by Jiracek (1983). However, shallow temperature measurements can be difficult to project to great depth due to the influence of ground water flow. Infact, Reiter (1999a and 2003) uses the disturbance on subsurface temperature by ground water flow to document and quantify vertical and horizontal flow velocities and formation hydraulic conductivities.

### 3.5 Deep Oil and Gas Exploration Bottom Hole Temperatures

Another approach to quantify deep subsurface reservoir temperatures uses bottom-hole temperatures (BHT) obtained during geophysical logging of deep oil and gas exploration boreholes that have been drilled in the Albuquerque basin. Appendix F contains a detailed tabulation of BHT for several deep oil and gas tests obtained from geophysical logs on file at the New Mexico Bureau of Geology and Mineral Resources. This tabulation includes several measurements taken at the same depth and records the time since drilling mud circulation was stopped. Mud weight is also noted in order to gain insight into borehole pressures at depth. Where several temperatures at the same depth are taken, the temperatures increase with time since mud circulation was stopped. Several approaches may be applied to correct these data to equilibrium formation temperatures (Schoepppel and Gilarranz, 1966; Fertl and Wichmann, 1977; Dowdle and Cobb, 1975; and Willett and Chapman, 1987). The BHT's range in depth from 10,371 ft to 21,296 ft and show non-equilibrium temperatures of 267 to 434 $^{o}$F respectively. No corrections are applied to the BHT data in this study.

Table 3.5 shows a summary tabulation of BHT that includes additional oil and gas test wells in the Albuquerque area without information on when the logs were run relative to when drilling mud circulation was stopped. These temperatures are minimum temperatures and are below actual formation temperatures due to the cooling affects of drilling mud circulation prior to reaching total depth. Figure 3.1 is a temperature depth plot for the data in Table 3.5. No attempt is made to correct the BHT data for equilibrium formation temperature. A temperature gradient of 33.5 $^{o}$C/km is obtained with a surface intercept temperature of 16.1 $^{o}$C. The actual mean annual temperature for the region is about 13.8 $^{o}$C.

Table 3.5. Bottom hole temperatures of oil and gas test wells in the Albuquerque basin.

| WELL NAME | DEPTH ft | DEPTH m | TEMP ºF | TEMP ºC |
|---|---|---|---|---|
| Shell 1 Laguna Wilson | 3989 | 1215.8 | 147 | 63.9 |
| | 11107 | 3385.4 | 292 | 144.4 |
| Shell Santa Fe Pacific 2 | 3189 | 972.0 | 111 | 43.9 |
| | 7011 | 2137.0 | 204 | 95.6 |
| | 8654 | 2637.7 | 224 | 106.7 |
| | 11238 | 3425.3 | 289 | 142.8 |
| | 14011 | 4270.6 | 347 | 175.0 |
| | 14305 | 4360.2 | 354 | 178.9 |
| Shell 1 Isleta Transocean | 5299 | 1615.1 | 156 | 68.9 |
| | 9175 | 2796.5 | 205 | 96.1 |
| | 10378 | 3163.2 | 267 | 130.6 |
| Shell Santa Fe Pacific 3 | 4705 | 1434.1 | 126 | 52.2 |
| | 8994 | 2741.4 | 208 | 97.8 |
| | 10276 | 3132.1 | 238 | 114.4 |
| Shell Santa Fe Pacific 1 | 6936 | 2114.1 | 190 | 87.8 |
| | 11045 | 3366.5 | 267 | 130.6 |
| Shell West Mesa | 17582 | 5359.0 | 342 | 172.2 |
| | 19350 | 5897.9 | 381 | 193.9 |
| Shell Isleta 1 Central | 5325 | 1623.1 | 178 | 81.1 |
| | 8080 | 2462.8 | 198 | 92.2 |
| | 8909 | 2715.5 | 219 | 103.9 |
| | 10250 | 3124.2 | 250 | 121.1 |
| | 12396 | 3778.3 | 288 | 142.2 |
| | 13675 | 4168.1 | 339 | 170.6 |
| | 14100 | 4297.7 | 328 | 164.4 |
| | 16346 | 4982.3 | 387 | 197.2 |
| Shell Isleta 2 | 5000 | 1524.0 | 138 | 58.9 |
| | 9926 | 3025.4 | 215 | 101.7 |
| | 14525 | 4427.2 | 315 | 157.2 |
| | 16254 | 4954.2 | 370 | 187.8 |
| | 18227 | 5555.6 | 390 | 198.9 |

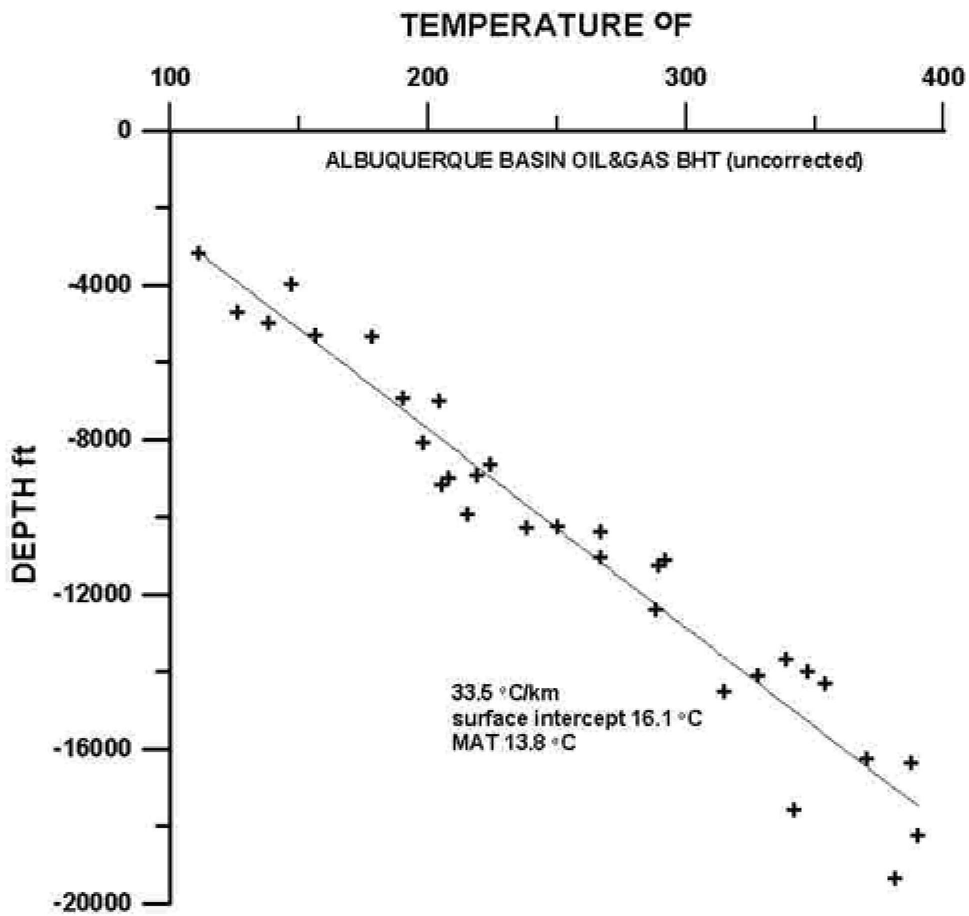


Figure 3.1. Temperature versus depth for oil and gas bottom hole temperature measurements in the Albuquerque basin.

### 3.6 Discussion and Use of Thermal Regime Data

The temperature estimates using BHT data from oil and gas data should be considered as average minimum temperatures. The BHT temperatures do not reflect true formation temperatures because of disturbance from drilling and drilling mud circulation. Temperature estimates with heat flow data are more reliable even though the thermal conductivities are estimated. Errors in the thermal conductivity will tend to cancel out when several interval estimates are involved because some thermal conductivity values will be too high and some will be too low. Application of heat flows that range from 75 to 85 $m\text{W/m}^2$ is conservative and represent best estimates for Sites 1 and 3 (See Appendix E).

## 5.0 DISCUSSION OF GEOTHERMAL AT SITES 1, 3, AND 4

A favorable geothermal reservoir underlies the Pueblo of Zia Site 1. The Triassic Aqua Zarca (Santa Rosa Sandstone)-Permian San Andres-Glorieta aquifers system may be as much as 400 ft composite thickness and have a transmissivity sufficient to produce up to 1,500 gpm of 137 °C water (heat flow 75 $m$W/m$^2$) from a depth between 9,500 to 10,200 ft.

Pueblo of Zia Site 3 taps 112 °C water (heat flow 85 $m$W/m$^2$) from 7,600 to 8,000 ft depth from the Triassic Aqua Zarca-Permian San Andres-Glorieta aquifer system and should be capable of 1,500 gpm production with a single production well and injection well couplet.

The temperature and potential production rates indicate favorability for small-scale (<5 MWe installed) electrical power production with cascaded direct-use for heating a greenhouse or other purposes. Detailed design of production and injection drilling program is a next phase task along with determining the spacing of the injection and production wells to prevent premature thermal breakthrough and modeling pump requirements and head losses for deep production after a test well is drilled. Because of the Pliocene-Quaternary fault density in the Albuquerque basin, a preliminary analysis of reservoir volume and potential compartmentalization, is required prior to designing a production and injection well field. This will require a detailed analysis of seismic data along with test results of a geothermal well into the Aqua Zarca-San Andres-Glorieta reservoir.

Pueblo of Zia Site 4 has little or no geothermal power production potential.

While drilling issues are not as severe as those associated with conventional geothermal wells drilled across fault zones with convective flow systems and associated hydrothermal alteration that forms very soft altered clay zones juxtaposed very hard silicified zones, stratigraphy of the subsurface shows potential for drilling problems associated with drilling across swelling clay and shale formations.

Good quality ground water will be available from the Santa Fe Group sands for drilling and for cooling tower use for binary power plant condensers at sites 1 and 3; but will require drilling dedicated water well at each site prior to geothermal test drilling.

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# APPENDIX A SUBSURFACE STRATIGRAPHY

Contents



| PUEBLO OF ZIA (NW ALBUQUERQUE BASIN RGR)<br>ZIA SITE 1 - ROBERTS TOWER AREA | | | |
|---|---|---|---|
| **AGE** | **UNIT** | **DEPTH ft** | **THICKNESS ft** |
| Tertiary | Sante Fe Group | 0 | **3,760** |
| Tertiary | volcanoclastic seds | 3,760 | **1,549** |
| Tertiary | Galisteo Fm | 5,309 | **1,136** |
| Cretaceous | Menefee Fm (or above Kds) | 6,442 | **1,100** |
| Cretaceous | Crevasse Canyon | 7,542 | **200** |
| Cretaceous | Mancos Fm | 7,742 | **900** |
| Cretaceous | Dakota SS | 8,642 | **310** |
| Jurassic | Morrison Fm | 8,952 | **350** |
| | Brushy Basin Mbr | 8,952 | **100** |
| | Salt Wash Mbr | 9,052 | **250** |
| Jurassic | Summerville Fm | 9,302 | **150** |
| Jurassic | Todilto Fm | 9,452 | **80** |
| Jurassic | Entrada SS | 9,532 | **130** |
| Triassic | Chinle Grp | 9,662 | **1,600** |
| | Petrified Forest Fm | 9,662 | **1,300** |
| | Aqua Zarca Fm | 10,962 | **300** |
| Permian | San Andres Fm | 11,262 | **112** |
| | San Andres Mbr | 11,262 | **12** |
| | Glorieta Mbr | 11,274 | **100** |
| | Yeso | 11,374 | **640** |
| | San Ysidro Mbr | 11,374 | **386** |
| | Meseta Blanca Mbr | 11,760 | **254** |
| Permian | Abo | 12,014 | **743** |
| Pennslyvanian | Madera Grp | 12,757 | **880** |
| | Bursum Fm | 12,757 | **100** |
| | Wild Cow Fm | 12,857 | **450** |
| | Los Moyos Fm | 13,307 | **300** |
| Pennslyvanian | Sandia Fm | 13,607 | **30** |
| Mississippian | Arroyo Penasco Fm | 13,637 | **<50** |
| | | TOTAL | **13,637** |

| Davis Petroleum Corp Tamara 1Y | | |
|---|---|---|
| UNIT | TOPS DEPTH ft | REMARKS |
| Sante Fe Group | 0 | Connell and others (2001) |
| Arroyo Ojito Fm | 0 | Connell and others (2001) |
| Zia Fm | 1,260 | Connell and others (2001) |
| volcanoclastics | 3,760 | Connell and others (2001) |
| Galisteo Fm | 5,309 | Connell and others (2001) |
| Menefee Fm | 6,442 | |
| Point Lookout | | **absent; Hosta Dalton 6,510 ft;** |
| Mancos Fm | | **not picked; Gallup 7,044 ft; Greenhorn 8,040 ft** |
| Dakota SS | 8,170 | |
| Morrison Fm | 8,330 | |
| Brushy Basin Mbr | | |
| Salt Wash Mbr | | **partial, faulted out** |
| Summerville Fm | | **faulted out** |
| Todilto Fm | 8,470 | |
| Entrada SS | 8,550 | |
| Chinle Grp | | |
| Petrified Forest Fm | 8,680 | **drilled incomplete section (TD 8,732 ft)** |
| Aqua Zarca Fm | | |
| San Andres Fm | | |
| San Andres Mbr | | |
| Glorieta Mbr | | |
| Yeso | | |
| San Ysidro Mbr | | |
| Meseta Blanca Mbr | | |
| Abo | | |
| Madera Grp | | |
| Bursum Fm | | |
| Wild Cow Fm | | |
| Los Moyos Fm | | |
| Sandia Fm | | |
| Arroyo Penasco Fm | | |
| | | **TD (8,732 ft reported in Chinle?)** |

| Shell, Santa Fe Pacific 1 | | |
|---|---|---|
| **UNIT** | **TOPS DEPTH ft** | **REMARKS** |
| Santa Fe Group | 0 | below 1,500 ft to top Galisteo,~2,000 ppm TDS |
| Galisteo Fm | 2,970 | >10,000 ppm TDS |
| Menefee Fm | 3,644 | 2956 ft of Cretaceous above the Dakota SS |
| Point Lookout | 4,378 | |
| Mancos Fm | 4,520 | faulted |
| Dakota SS | 6,600 | |
| Morrison Fm | 6,907 | thickness includes the Summerville Fm |
| Brushy Basin Mbr | | not picked |
| Salt Wash Mbr | | not picked |
| Summerville Fm | | not picked |
| Todilto Fm | 7,412 | |
| Entrada SS | 7,530 | |
| Chinle Grp | 7,726 | |
| Petrified Forest Fm | | |
| Aqua Zarca Fm | | not picked |
| San Andres Fm | 8,880 | |
| San Andres Mbr | | probably thin or absent |
| Glorieta Mbr | | |
| Yeso | 8,992 | |
| San Ysidro Mbr | 8,992 | |
| Meseta Blanca Mbr | 9,378 | |
| Abo | 9,632 | |
| Madera Grp | 10,375 | units below Abo Fm and above Precambrian |
| Bursum Fm | | not picked |
| Wild Cow Fm | | not picked |
| Los Moyos Fm | | not picked |
| Sandia Fm | | not picked |
| Arroyo Penasco Fm | | absent or not picked |
| Precambran | 10,955 | |
| TOTAL | | TD (11,045 ft) |

# APPENDIX B  RESERVOIR HYDRAULICS

Contents

1) Database of regional rock hydraulics.
2) Site 1 hydraulics calculations.
3) Site 3 hydraulics calculations.
4) Site 4 hydraulics calculations.
5) References for rock hydraulics database.

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | $ft^2/d$ | | | ft | | | |
| | | | | | | | | | | | | | | | | |
| Cretaceous | Point Lookout | sandstone | field | 13 | 2 | | | | | | | | | dst/core | 16 | Central Basin |
| Cretaceous | Point Lookout | sandstone | field | 17 | 2.5 | 15 | | | | | | | | dst/core | 17,18 | Cuervo Mesa Verde |
| **Cretaceous** | **Point Lookout** | **sandstone** | | **15** | **2.25** | **15** | | | | | | | | | | **median values** |
| | | | | | | | | | | | | | | | | |
| Cretaceous | Dakota | sandstone | field | 14 | 16.5 | 40 | | d | | | | | | dst/core | 8 | Barker Creek |
| Cretaceous | Dakota | sandstone | field | 7 | 0.15 | | | d | | | | | | dst/core | 8 | Basin/T=180°F |
| Cretaceous | Dakota | sandstone | field | 9 | 0.05 | | | d | | | | | | dst/core | 8 | Lindrith W/T=160°F |
| Cretaceous | Dakota | sandstone | field | 22 | 143 | | | d | | | | | | dst/core | 8 | Lone Pine |
| Cretaceous | Dakota | sandstone | field | 15 | 10 | | | d | | | | | | dst/core | 8 | Ute Dome |
| Cretaceous | Dakota | sandstone | field | 12 | 0.1 | | | d | | | | | | dst/core | 16 | Lindrith Dakota South |
| Cretaceous | Dakota | sandstone | field | 5 | 0.1 | 50 | | d | | | | | | dst/core | 16,1,18 | Basin Dakota (min) |
| Cretaceous | Dakota | sandstone | field | 10 | 0.25 | | | d,f | | | | | | dst/core | 16 | Basin Dakota, fracture |
| Cretaceous | Dakota | sandstone | field | 18.5 | 83 | 18 | | d | | | | | | dst/core | 17,18 | Lone Pine Dakota |
| Cretaceous | Dakota | sandstone | field | 9 | 0.05 | 41 | | d | | | | | | dst/core | 17,18 | Lindrith Dokata West |
| Cretaceous | Dakota | sandstone | field | 17 | 50 | 18 | | d | | | | | | dst/core | 17,18 | Marecelina Dakota |
| Cretaceous | Dakota | sandstone | field | 12 | 0.3 | 20 | | d | | | | | | dst/core | 17,18 | Middle Camru Dakota |
| Cretaceous | Dakota | sandstone | field | 10 | 0.25 | 45 | | d | | | | | | dst/core | 17,18 | Ojito Dakota |
| Cretaceous | Dakota | sandstone | field | 16 | 0.8 | 40 | | d | | | | | | dst/core | 17,18 | Salt Creek Dakota (max) |
| Cretaceous | Dakota | sandstone | field | 22 | 400 | 8 | | d,f? | | | | | | dst/core | 17,18 | Slick Rock Dakota (max) |
| Cretaceous | Dakota | sandstone | field | 20 | 200 | 12 | | d,f? | | | | | | dst/core | 17,18 | Table Mesa |
| Cretaceous | Dakota | sandstone | field | 15 | 10 | 30 | | d | | | | | | dst/core | 17,18 | Ute Dome Dakota |
| Cretaceous | Dakota | sandstone | field | 15 | 10 | 12 | | d | | | | | | dst/core | 17,18 | Straight Canyon Dakota |
| Cretaceous | Dakota | sandstone | field | 11 | 1 | 15 | | d | | | | | | dst/core | 17,18 | Whitewash Dakota |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | $ft^2/d$ | | | ft | | | |
| Cretaceous | Dakota | sandstone | field | 5 | 0.22 | 100 | | d | | | | | | dst/core | 17,18 | Wildhorse Dakota |
| Cretaceous | Dakota | sandstone | field | 14 | 16.5 | 40 | | d | | | | | | dst/core | 17,18 | Barker Creek Dakota |
| Cretaceous | Dakota | sandstone | field | 15 | 0.25 | 70 | | d | | | | | | dst/core | 17,18 | Basin Dakota (max) |
| Cretaceous | Dakota | sandstone | field | 11.8 | 7.23 | 12.6 | | d | | | | | | dst/core | 17,18 | Five lakes (ave) |
| Cretaceous | Dakota | sandstone | field | 11.8 | 0.68 | 12.6 | | d | | | | | | dst/core | 17,18 | Five lakes (min) |
| Cretaceous | Dakota | sandstone | field | 11.8 | 19.7 | 12.6 | | d | | | | | | dst/core | 17,18 | Five lakes (max) |
| Cretaceous | Dakota | sandstone | well | 7.8 | 0.09 | 71 | 59 | s | | | | | | dst/core | 19 | Tijeras Canyon #3 (median) |
| **Cretaceous** | **Dakota** | **sandstone** | | **12** | **0.9** | **25** | | | | | | | | | | **median values** |
| Cretaceous | Dakota | sandstone | well | | | | | s | 100 | 2000 | | | 20 | pump | 10 | Laguna Pueblo |
| Cretaceous | Dakota | sandstone | well | | | | | s | 0.06 | 19 | | | 317 | pump | 10 | Laguna Pueblo |
| Cretaceous | Dakota | sandstone | well | | | | | s | | 3.3 | | | | pump | 15 | Pueblo Test #3 |
| Cretaceous | Dakota | sandstone | well | | | | | s | | 36 | | | | pump | 12 | Frasnelli-Allison well |
| Cretaceous | Dakota | sandstone | well | | | | | s | | 45 | | | | recovery | 12 | Frasnelli-Allison well |
| Cretaceous | Dakota | sandstone | well | | | | | s | | 44 | 0.000057 | | | pump | 12 | Phillips Nose-Rock |
| Cretaceous | Dakota | sandstone | well | | | | | s | | 85 | 0.00004 | | | pump | 12 | Phillips Nose-Rock |
| **Cretaceous** | **Dakota** | **sandstone** | | | | | | | **0.06** | **40** | **0.000049** | | **317** | | | **median values (top value -2000 $ft^2/d$ not used)** |
| | | | | | | | | | | | | | | | | |
| Jurassic | Morrison | sandstone | well | | | | | s | 0.8 | 240 | | | 300 | pump | 10 | Laguna Pueblo |
| Jurassic | Morrison | sandstone | well | | | | | s | | 460 | | | | pump | 12 | Gulf/Mt Taylor |
| Jurassic | Morrison | sandstone | well | | | | | s | | 480 | | | | recovery | 12 | Gulf/Mt Taylor |
| Jurassic | Morrison | sandstone | well | | | | | s | | 126 | | | | pump | 12 | Gulf West Largo |
| Jurassic | Morrison | sandstone | well | | | | | s | | 210 | | | | recovery | 12 | Gulf West Largo |
| Jurassic | Morrison | sandstone | well | | | | | s | | 240 | | | | pump | 12 | Casamero Lake |
| Jurassic | Morrison | sandstone | well | | | | | s | | 270 | | | | recovery | 12 | Casamero Lake |
| Jurassic | Morrison | sandstone | well | | | | | s | | 123 | | | | pump | 12 | Gulf Mariano |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | $ft^2/d$ | | | ft | | | |
| Jurassic | Morrison | sandstone | well | | | | | s | | 286 | | | | recovery | 12 | Borego Pass School #3 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 370 | | | | recovery | 12 | 16T-513/includes Dakota SS |
| Jurassic | Morrison | sandstone | regional | | | | | s | | 300 | 0.0002 | | | model | 12 | Church Rock Mine/includes Dakota SS |
| Jurassic | Morrison | sandstone | well | | | | | s | | 296 | 0.003 | | | pump | 12 | Gallup-Munoz 1-A/includes Dakota SS |
| Jurassic | Morrison | sandstone | well | | | | | s | | 173 | 0.0007 | | | pump | 20 | no name |
| Jurassic | Morrison | sandstone | well | | | | | s | | 290 | | | | recovery | 12 | Crownpoint #6 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 190 | 0.00005 | | | observwell | 12 | Mobil 9u214 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 200 | 0.00014 | | | pump | 12 | Mobil TW-132 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 41 | | | | recovery | 12 | C&P Star Lake |
| Jurassic | Morrison | sandstone | well | | | | | s | | 35 | | | | recovery | 12 | C&P Star Lake |
| Jurassic | Morrison | sandstone | well | | | | | s | | 88 | | | | pump | 12 | Cherokee and Pittsburg Gallo |
| Jurassic | Morrison | sandstone | well | | | | | s | | 120 | | | | pump | 12 | Cherokee and Pittsburg Gallo |
| Jurassic | Morrison | sandstone | well | | | | | s | | 440 | | | | pump | 12 | Foshay Well |
| Jurassic | Morrison | sandstone | well | | | | | s | | 38 | | | | recovery | 12 | no name |
| Jurassic | Morrison | sandstone | well | | | | | s | | 2 | | | | recovery | 12 | no name |
| Jurassic | Morrison | sandstone | well | | | | | s | | 18 | | | | pump | 12 | New Red Rock well PM1 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 205 | | | | recovery | 12 | EPNG Burnham |
| Jurassic | Morrison | sandstone | well | | | | | s | | 87 | | | | recovery | 12 | 12M-25 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 107 | | | | pump | 12 | Sanostee PM3 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 40 | | | | recovery | 20 | Sanostee PM3 ??? |
| Jurassic | Morrison | sandstone | well | | | | | s | | 2.8 | | | | recovery | 12 | 12T-507 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 400 | | | | pump | 12 | LJ-205 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 380 | | | | recovery | 20 | LJ-205?? |
| Jurassic | Morrison | sandstone | well | | | | | s | | 25 | | | | pump | 12 | Sohio A-1 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 18 | | | | recovery | 12 | Sohio A-1 |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | ft²/d | | | ft | | | |
| Jurassic | Morrison | sandstone | well | | | | | s | | 35 | 0.0004 | | | observwell | 12 | Sohio A-1 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 58 | | | | recovery | 12 | MT-26 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 173 | 0.0002 | | | pump | 12 | Conoco JMW Test |
| Jurassic | Morrison | sandstone | well | | | | | s | | 200 | 0.00015 | | | pump | 12 | Conoco JMW Test |
| Jurassic | Morrison | sandstone | well | | | | | s | | 88 | 0.000042 | | | observwell | 12 | Phillips Nose Rock |
| Jurassic | Morrison | sandstone | well | | | | | s | | 9 | | | | pump | 12 | Pueblo Pintabo 5 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 15 | | | | pump | 12 | Pueblo Pintabo 4 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 12 | | | | recovery | 12 | Pueblo Pintabo 4 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 10 | | | | pump | 12 | 15R-302 (PM-1) |
| Jurassic | Morrison | sandstone | well | | | | | s | | 13 | | | | recovery | 12 | 15R-302 (PM-1) |
| Jurassic | Morrison | sandstone | well | | | | | s | | 7 | | | | recovery | 12 | Lake Valley |
| Jurassic | Morrison | sandstone | well | | | | | s | | 95 | | | | recovery | 12 | 12T-637 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 470 | | | | pump | 12 | 12T-520 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 2.7 | | | | recovery | 12 | 15T-339 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 8.5 | | | | recovery | 12 | 15K-340 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 112 | | | | pump | 12 | Mexican Springs #3 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 93 | | | | recovery | 12 | Mexican Springs #3 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 28 | | | | recovery | 12 | 14T-512 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 106 | | | | pump | 12 | Slickrock #3 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 76 | | | | recovery | 12 | Slickrock #3 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 114 | | | | pump | 12 | Slickrock #2 |
| Jurassic | Morrison | sandstone | well | | | | | s | | 135 | | | | pump | 20 | no name |
| Jurassic | Morrison | sandstone | well | | | | | s | | 100 | 0.0002 | | | pump | 20 | no name |
| Jurassic | Morrison | sandstone | well | | | | | s | 0.26 | 24 | 0.00018 | | 93 | pump | 21 | M2 |
| Jurassic | Morrison | sandstone | well | | | | | s | 0.39 | 47 | 0.00029 | | 121 | pump | 21 | M3 |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | ft²/d | | | ft | | | |
| Jurassic | Morrison | sandstone | well | | | | | s | 23 | 430 | 0.0021 | | 19 | pump | 21 | M4C |
| Jurassic | Morrison | sandstone | well | | | | | s | 0.025 | 2 | 0.00002 | | 81 | pump | 21 | M21 |
| Jurassic | Morrison | sandstone | well | | | | | s | 0.33 | 20 | 0.0001 | | 60 | slug | 21 | M25 |
| **Jurassic** | **Morrison** | **sandstone** | | | | | | | **0.39** | **103** | **0.0002** | | **121** | | | **median values** |
| | | | | | | | | | | | | | | | | |
| Jurassic | Bluff | sandstone | well | | | | | s | 0.86 | 450 | | | 523 | pump | 10 | Laguna Pueblo |
| **Jurassic** | **Bluff** | **sandstone** | | | | | | | **0.86** | **450** | | | **523** | | | **median values** |
| | | | | | | | | | | | | | | | | |
| Jurassic | Entrada | sandstone | field | 20 | 38 | | | d | | | | | | dst/core | 9 | Wilson Creek, CO/T=171°F |
| Jurassic | Entrada | sandstone | field | 16 | 30 | | | d | | | | | | dst/core | 9 | San Arroyo, UT |
| Jurassic | Entrada | sandstone | field | 24 | 762 | | | d | | | | | | dst/core | 9 | Westwater, UT |
| Jurassic | Entrada | sandstone | field | 23.8 | 361 | | | d | | | | | | dst/core | 16 | Southwest Media Entrada |
| Jurassic | Entrada | sandstone | field | 23.3 | 293 | 24 | | d | | | | | | dst/core | 17,18 | Media Entrada |
| Jurassic | Entrada | sandstone | field | 23.8 | 361 | 30 | | d | | | | | | dst/core | 17,18 | Media Entrada SW |
| Jurassic | Entrada | sandstone | field | 23.6 | 205 | 27 | | d | | | | | | dst/core | 17,18 | Ojo Encino Entrada |
| Jurassic | Entrada | sandstone | field | 26.1 | 290 | 37 | | d | | | | | | dst/core | 17,18 | Papers Wash |
| Jurassic | Entrada | sandstone | field | 24.9 | 665 | 35 | | d | | | | | | dst/core | 17,18 | Shake Eyes Entrada |
| Jurassic | Entrada | sandstone | field | 26 | 450 | 26 | | d | | | | | | dst/core | 17,18 | Eagle Mesa |
| Jurassic | Entrada | sandstone | well | 9.6 | 0.086 | 13 | 7 | s | | | | | | dst/core | 19 | Tijeras Canyon #2 (ave) |
| **Jurassic** | **Entrada** | **sandstone** | | **23.8** | **293** | **27** | | | | | | | | | | **median values** |
| Jurassic | Entrada | sandstone | well | | | | | s | 0.8 | 55 | | | 69 | pump | 10 | Laguna Pueblo |
| Jurassic | Entrada | sandstone | well | | | | | s | | 0.84 | | | | pump | 12 | 16T-591 |
| Jurassic | Entrada | sandstone | well | | | | | s | | 400 | | | | pump | 12 | Foshay well |
| Jurassic | Entrada | sandstone | well | | | | | s | | 5.4 | | | | pump | 12 | 21T-599 |
| **Jurassic** | **Entrada** | **sandstone** | | | | | | | **0.8** | **30.2** | | | **69** | | | **median values** |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | ft²/d | | | ft | | | |
| | | | | | | | | | | | | | | | | |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.16 | 70 | | | 438 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.17 | 108 | | | 635 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.07 | 25 | | | 357 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 23 | 6,000 | | | 261 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 62.5 | 16,000 | | | 256 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 1.2 | 542 | | | 452 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s,f,sp | 1040 | 200,000 | | | 192 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 1.2 | 300 | | | 250 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 26.4 | 1,400 | | | 53 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.0046 | 0.66 | | | 143 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.27 | 55 | | | 204 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.27 | 110 | | | 407 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 2.97 | 520 | | | 175 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 14.7 | 2,936 | | | 200 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.85 | 170 | | | 200 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | 0.82 | 200 | | | 244 | pump | 2 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | regional | | | | | s | 25 | 10,000 | | | 400 | model | 4 | Estancia/low |
| Permian | SanAndr/Glor | limestn/sndstn | regional | | | | | s | 50 | 30,000 | | | 600 | model | 4 | Estancia/high |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s,f,sp | | 330,000 | 0.00084 | | | observwell | 11 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s,f,sp | | 54,000 | | | | recovery | 11 | Grants/Bluewater area |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 5 | | | | recovery | 12 | TransWest#1/Glorieta Fm |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 64 | | | | pump | 12 | SmithLake Mutual Help |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 91 | | | | recovery | 12 | SmithLake Mutual Help |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 21 | | | | pump | 13 | Ft Wingate 340 |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | $ft^2/d$ | | | ft | | | |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 70 | | | | pump | 12 | Rehoboth Mission |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 30 | 0.000036 | | | observwell | 12 | Rehoboth Mission |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 32 | | | | recovery | 12 | Rehoboth Mission |
| Permian | SanAndr/Glor | limestn/sndstn | well | | | | | s | | 57 | | | | observwell | 12 | Rehoboth Mission |
| **Permian** | **SanAndr/Glor** | **limestn/sndstn** | | | | | | | **2.085** | **185** | **0.000438** | | **600** | | | **median values** |
| Permian | SanAndr/Glor | limestn/sndstn | regional | 3 | 0.1 | | | d | | | | | | dst/core | 14 | San Andres Fm SE NM low/non fracture-solution |
| Permian | SanAndr/Glor | limestn/sndstn | regional | 5 | 5 | | | d | | | | | | dst/core | 14 | San Andres Fm SE NM low non fracture-solution |
| **Permian** | **SanAndr/Glor** | **limestn/sndstn** | | **4** | **2.55** | | | | | | | | | | | **median values** |
| | | | | | | | | | | | | | | | | |
| Permian | De Chelly | sandstone | regional | 8 | 0.4 | | 2618 | d | | | | | | dst/core | 1 | Four Corners region |
| Permian | De Chelly | sandstone | regional | n/a | 0.96 | | 127 | d | | | | | | dst/core | 1 | Four Corners region |
| **Permian** | **De Chelly** | **sandstone** | | **8** | **0.68** | | | | | | | | | | | **median values** |
| | | | | | | | | | | | | | | | | |
| Penn | Madera | limestn/sndstn | well | | | | | s,f,sp | 105 | 2100 | 0.2 | | 20 | pump | 3 | Placitas area/fracture permeability |
| Penn | Madera | limestn/sndstn | well | | | | | s,f,sp | 108 | 2160 | 0.2 | | 20 | pump | 3 | Placitas area/fracture permeability |
| Penn | Madera | limestn/sndstn | well | | | | | s,f,sp | 66 | 1968 | 0.24 | | 30 | pump | 3 | Placitas area/fracture permeability |
| Penn | Madera | limestn/sndstn | well | | | | | s,f,sp | 62 | 1869 | 0.26 | | 30 | pump | 3 | Placitas area/fracture permeability |
| Penn | Madera | limestn/sndstn | regional | | | | | s | 0.01 | 30 | | 0.005 | 3000 | model | 4 | Estancia/silty zone low |
| Penn | Madera | limestn/sndstn | regional | | | | | s | 0.10 | 300 | | 0.01 | 3000 | model | 4 | Estancia/silty zone high |
| Penn | Madera | limestn/sndstn | regional | | | | | s | 0.50 | 500 | | 0.005 | 1000 | model | 4 | Estancia/low zone low |
| Penn | Madera | limestn/sndstn | regional | | | | | s | 2 | 1000 | | 0.03 | 500 | model | 4 | Estancia/low zone high |
| Penn | Madera | limestn/sndstn | regional | | | | | s,f,sp | 10 | 15000 | | 0.03 | 1500 | model | 4 | Estancia/high zone low |
| Penn | Madera | limestn/sndstn | regional | | | | | s,f,sp | 20 | 30000 | | 0.03 | 1500 | model | 4 | Estancia/high zone high |
| Penn | Madera | limestn/sndstn | well | | | | | s,f, | 27 | 400 | 0.00015 | | 15 | pump | 5 | early fracture TBMW26 aquifer B |
| Penn | Madera | limestn/sndstn | well | | | | | s,f | 0.87 | 13 | 0.00009 | | 15 | pump | 5 | late matrix TBMW26 aquifer B |

| AGE | UNIT | LITHOLOGY | SCALE | POR | PERM | PAY | #MEAS | DEPTH | HCOND | TRANS | STORAT | SYIELD | PAY | METHOD | REF | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % | mD | ft | | | ft/d | $ft^2/d$ | | | ft | | | |
| Penn | Madera | limestn/sndstn | well | | | | | s,f | 36 | 540 | 0.00031 | | 15 | pump | 5 | early fracture IHMW19 aquifer B |
| Penn | Madera | limestn/sndstn | well | | | | | s,f | 0.93300 | 14 | 0.014 | | 15 | pump | 5 | late matrix IHMW19 aquifer B |
| Penn | Madera | limestn/sndstn | well | | | | | s,f | 12 | 310 | | | 26 | pump | 5 | IHW18 aquifer C |
| Penn | Madera | limestn/sndstn | well | | | | | s,f | 56.67 | 850 | | | 15 | pump | 5 | early fracture IHMW17 aquifer B |
| Penn | Madera | limestn/sndstn | well | | | | | s,f | 1.066 | 16 | | | 15 | pump | 5 | late matrix IHMW17 aquifer B |
| Penn | Madera | limestn/sndstn | well | | | | | s,f, sp | | 168500 | 0.005 | | | pump | 6 | note high vertical h cond |
| **Penn** | **Madera** | **limestn/sndstn** | | | | | | | **15** | **1434.5** | **0.2** | **0.02** | **265** | | | **median values** |
| Penn | Madera | limestn/sndstn | field | 8 | 15.1 | | | d | | | | | | dst/core | 7 | Alkali Gulch (Paradox) |
| Penn | Madera | limestn/sndstn | field | 9 | 94 | | | d | | | | | | dst/core | 7 | Tocito Dome |
| Penn | Madera | limestn/sndstn | field | 4 | 0.5 | | | d | | | | | | dst/core | 7 | Ute Dome (Paradox) |
| Penn | Madera | limestn/sndstn | regional | 9.1 | 0.46 | | 299 | d | | | | | | dst/core | 1 | regional sandstone only |
| Penn | Madera | limestn/sndstn | field | 14 | 13.1 | 16 | | d | | | | | | dst/core | 17,18 | Parajito Pennslyvanian |
| Penn | Madera | limestn/sndstn | field | 8.6 | 94 | 17 | | d | | | | | | dst/core | 17,18 | Tocito Dome Penn "D" |
| Penn | Madera | limestn/sndstn | field | 3.5 | 0.5 | 116 | | d,m | | | | | | dst/core | 17,18 | Ute Dome (Paradox)(matrix) |
| Penn | Madera | limestn/sndstn | field | 10 | 3 | 50 | | d | | | | | | dst/core | 17,18 | Cone Paradox (max) |
| Penn | Madera | limestn/sndstn | field | 7 | 34.1 | 24 | | d | | | | | | dst/core | 17,18 | Four Corners Paradox Ismay zone (ave) |
| Penn | Madera | limestn/sndstn | field | 11 | 51 | 6 | | d | | | | | | dst/core | 17,18 | Big Gap Penn |
| Penn | Madera | limestn/sndstn | regional | 2.4 | 0.01 | | 194 | d | | | | | | core | 1 | Hermosa/Four Corners region |
| **Penn** | **Madera** | **limestn/sndstn** | | **8.6** | **13.1** | **20.5** | | | | | | | | | | **median values** |

| # | REFERENCE |
|---|---|
| 1 | Geldon (2003) |
| 2 | White and Kelly (1989) |
| 3 | Johnson (1999) |
| 4 | Shafike and Flanigan (1999) |
| 5 | Drakos and Lazarus (1997) |
| 6 | Jenkins and Prentice (1982) |
| 7 | Whitehead (1993a) |
| 8 | Whitehead (1993b) |
| 9 | Morgan (1993) |
| 10 | Risser and Lyford (1983) |
| 11 | Gordon (1961) |
| 12 | Stone and others (1983) |
| 13 | Shomaker (1971) |
| 14 | Kinney (1969) |
| 15 | Dinwiddie and Motts (1964) |
| 16 | Gautier and others (1995) |
| 17 | Fassett and others (1978) |
| 18 | Fassett and others (1983) |
| 19 | Files, NMBGMR |
| 20 | Dam and others (1990) |
| 21 | Risser and others (1984) |

| CORE/DST | matix permeability | | est | est | min est | core | core | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|---|---|---|
| AGE | RESERVOIR | LITH | THICK | TEMP | TDS | POR | PERM k | HCOND K | TRANS T |
| | | | ft | °F | mg/L | % | mD | ft/d | $ft^2/d$ |
| CRETACEOUS | CREVASSE CAN/DALTON SS | SAND | 200 | 208 | 10,000 | 15 | 2.8 | 0.027 | 5.40 |
| CRETACEOUS | DAKOTA | SAND | 310 | 232 | 10,000 | 12 | 0.9 | 0.010 | 3.10 |
| JURASSIC | MORRISON (SALT WASH) | SAND | 250 | 238 | 10,000 | | | | |
| JURASSIC | ENTRADA | SAND | 130 | 243 | 10,000 | 23.8 | 293.0 | 3.427 | 445.56 |
| TRIASSIC/PERMIAN | AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 278 | 15,000 | 4 | 2.6 | 0.036 | 14.58 |
| PERMIAN | DECHELLY/MESETA BLANCA | SAND | 250 | 289 | 15,000 | 8 | 0.7 | 0.010 | 2.49 |
| PENNSYLVANIAN | MADERA | LIME/SAND | 300 | 315 | 15,000 | 8.6 | 13.1 | 0.215 | 64.41 |

| PUMP TEST | w/fracture permeability | | est | est | min est | pump test | calculated | pump test | pump test | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AGE | RESERVOIR | LITH | THICK | TEMP | TDS | STOR | PERM k | HCOND K | TRANS T | HCOND K | TRANS T |
| | | | ft | °F | mg/L | | mD | ft/d | $ft^2/d$ | ft/d | $ft^2/d$ |
| CRETACEOUS | CREVASSE CAN/DALTON SS | SAND | 200 | 208 | 10,000 | | | | | | |
| CRETACEOUS | DAKOTA | SAND | 310 | 232 | 10,000 | 0.000049 | 24.6 | 0.060 | 40.0 | 0.264 | 81.99 |
| JURASSIC | MORRISON (SALT WASH) | SAND | 250 | 238 | 10,000 | 0.0002 | 147.8 | 0.360 | 100.0 | 1.634 | 408.58 |
| JURASSIC | ENTRADA | SAND | 130 | 243 | 10,000 | | 328.4 | 0.800 | 30.2 | 3.722 | 483.81 |
| PERMIAN | AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 278 | 15,000 | 0.00438 | 492.6 | 1.200 | 140.0 | 6.555 | 2,687.40 |
| PERMIAN | DECHELLY/MESETA BLANCA | SAND | 250 | 289 | 15,000 | | | | | | |
| PENNSYLVANIAN | MADERA | LIME | 300 | 315 | 15,000 | 0.014 | 205.3 | 0.500 | 695.0 | 3.206 | 961.83 |

ZIA SITE 1

| CORE/DST | matix permeability | | est | est | min est | core | core | T-TDScorr HCOND | T-TDScorr |
|---|---|---|---|---|---|---|---|---|---|
| AGE | RESERVOIR | LITH | THICK | TEMP | TDS | POR | PERM k | K | TRANS T |
| | | | ft | °F | mg/L | % | mD | ft/d | $ft^2/d$ |
| CRETACEOUS | DAKOTA | SAND | 150 | 183 | 10,000 | 12 | 0.9 | 0.008 | 1.15 |
| JURASSIC | MORRISON (SALT WASH) | SAND | 500 | 190 | 10,000 | | | | |
| JURASSIC | ENTRADA | SAND | 130 | 195 | 10,000 | 23.8 | 293.0 | 2.680 | 348.40 |
| TRIASSIC/PERMIAN | AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 234 | 15,000 | 4 | 2.6 | 0.029 | 11.90 |
| PERMIAN | DECHELLY/MESETA BLANCA | SAND | 250 | 247 | 15,000 | 8 | 0.7 | 0.008 | 2.06 |
| PENNSYLVANIAN | MADERA | LIME/SAND | 300 | 276 | 15,000 | 8.6 | 13.1 | 0.181 | 54.33 |

| PUMP TEST | w/fracture permeability | | est | est | min est | pump test | calculated | pump test HCOND | pump test | T-TDScorr HCOND | T-TDScorr TRANS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AGE | RESERVOIR | LITH | THICK | TEMP | TDS | STOR | PERM k | K | TRANS T | K | T |
| | | | ft | °F | mg/L | | mD | ft/d | $ft^2/d$ | ft/d | $ft^2/d$ |
| CRETACEOUS | DAKOTA | SAND | 150 | 183 | 10,000 | 0.000049 | 24.6 | 0.060 | 40.0 | 0.210 | 31.50 |
| JURASSIC | MORRISON (SALT WASH) | SAND | 500 | 190 | 10,000 | 0.0002 | 147.8 | 0.360 | 100.0 | 1.272 | 635.88 |
| JURASSIC | ENTRADA | SAND | 130 | 195 | 10,000 | | 328.4 | 0.800 | 30.2 | 2.910 | 378.31 |
| PERMIAN | AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 234 | 15,000 | 0.00438 | 492.6 | 1.200 | 140.0 | 5.608 | 2,299.28 |
| PERMIAN | DECHELLY/MESETA BLANCA | SAND | 250 | 247 | 15,000 | | | | | | |
| PENNSYLVANIAN | MADERA | LIME | 300 | 276 | 15,000 | 0.014 | 205.3 | 0.500 | 695.0 | 2.704 | 811.30 |

ZIA SITE 3

| CORE/DST | matix permeability | | est | est | min est | core | core | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|---|---|---|
| AGE | RESERVOIR | LITH | THICK | TEMP | TDS | POR | PERM k | HCOND K | TRANS T |
| | | | ft | °F | mg/L | % | mD | ft/d | $ft^2/d$ |
| TRIASSIC/PERMIAN | AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 124 | 15,000 | 4 | 2.6 | 0.013 | 5.46 |
| PERMIAN | DECHELLY/MESETA BLANCA | SAND | 250 | 139 | 15,000 | 8 | 0.7 | 0.004 | 1.06 |
| PENNSYLVANIAN | MADERA | LIME/SAND | 300 | 175 | 15,000 | 8.6 | 13.1 | 0.108 | 32.39 |

| PUMP TEST | w/fracture permeability | | est | est | min est | pump test | calculated | pump test | pump test | T-TDScorr | T-TDScorr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AGE | RESERVOIR | LITH | THICK | TEMP | TDS | STOR | PERM k | HCOND K | TRANS T | HCOND K | TRANS T |
| | | | ft | °F | mg/L | | mD | ft/d | $ft^2/d$ | ft/d | $ft^2/d$ |
| PERMIAN | AQUAZAR/SAN ANDRES/GLOR | LIME/SAND | 410 | 124 | 15,000 | 0.00438 | 492.6 | 1.200 | 140.0 | 2.573 | 1,054.95 |
| PERMIAN | DECHELLY/MESETA BLANCA | SAND | 250 | 139 | 15,000 | | | | | | |
| PENNSYLVANIAN | MADERA | LIME | 300 | 175 | 15,000 | 0.014 | 205.3 | 0.500 | 695.0 | 1.612 | 483.64 |

ZIA SITE 4

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# APPENDIX C HEATFLOW

Contents

1) Published Zia region heatflow.

| SITE | LAT | LON | ELEV | TOP | BOT | INTV | GRAD | TC | HF | REF |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | m | m | m | m | $^{o}$C/km | W/mK | mWm$^{2}$ | |
| GALISTEO | 35.4167 | 106.0000 | 1870 | 40 | 200 | 160 | 30.94 | 2 | 62 | Reiter and others (1975) |
| CERRILLOS #1 | 35.4500 | 106.1000 | 1866 | 70 | 150 | 80 | 24.06 | 2.09 | 50 | Edwards and others (1978) |
| CERRILLOS #2 | 35.4500 | 106.1000 | 1884 | 81 | 129 | 48 | 26.39 | 2.08 | 55 | Edwards and others (1978) |
| TURQUOISE MTN #1 | 35.5000 | 106.1000 | 1918 | 40 | 120 | 80 | 28.18 | 1.97 | 55 | Edwards and others (1978) |
| CERRILLOS #3 | 35.4500 | 106.1167 | 1829 | 80 | 184 | 104 | 24.86 | 2.06 | 51 | Edwards and others (1978) |
| CERRILLOS | 35.4667 | 106.1167 | 1880 | 90 | 280 | 190 | 24.45 | 2.08 | 51 | Decker (1969) |
| TURQUOISE MTN #2 | 35.5167 | 106.1167 | 1918 | 60 | 110 | 50 | 21.21 | 1.99 | 42 | Edwards and others (1978) |
| TURQUOISE MTN #2 | 35.5167 | 106.1167 | 1918 | 110 | 160 | 50 | 23.68 | 2.16 | 51 | Edwards and others (1978) |
| ORTIZ MTN #3 | 35.3000 | 106.1667 | 2218 | 130 | 280 | 150 | 16.03 | 3.27 | 52 | Edwards and others (1978) |
| ORTIZ MTN #3 | 35.3000 | 106.1667 | 2218 | 370 | 420 | 50 | 22 | 2.66 | 59 | Edwards and others (1978) |
| ORTIZ MTN #2 | 35.3167 | 106.1667 | 2399 | 140 | 720 | 580 | 18.18 | 3.06 | 56 | Edwards and others (1978) |
| SAN PEDRO 4AL | 35.2500 | 106.1833 | 2165 | 190 | 410 | 220 | 22.74 | 2.62 | 59 | Edwards and others (1978) |
| SAN PEDRO #1 | 35.2500 | 106.1833 | 2160 | 30 | 160 | 130 | 19.04 | 2.95 | 56 | Reiter and others (1975) |
| SAN PEDRO #3 | 35.2500 | 106.1833 | 2160 | 40 | 80 | 40 | 15.84 | 2.72 | 43 | Reiter and others (1975) |
| SAN PEDRO #3 | 35.2500 | 106.1833 | 2160 | 80 | 160 | 80 | 23.05 | 2.34 | 54 | Reiter and others (1975) |
| SAN PEDRO #3 | 35.2500 | 106.1833 | 2160 | 180 | 270 | 90 | 21.57 | 2.61 | 56 | Reiter and others (1975) |
| SAN PEDRO #3 | 35.2500 | 106.1833 | 2160 | 310 | 490 | 180 | 19.92 | 2.62 | 52 | Reiter and others (1975) |
| ORTIZ MTN. | 35.3330 | 106.1833 | 2560 | 230 | 350 | 120 | 27.9 | 2.59 | 72 | Reiter and others (1975) |
| ARROYO TETILLA | 35.6667 | 106.1833 | 2050 | 100 | 180 | 80 | 48.89 | 2.23 | 109 | Edwards and others (1978) |
| GOLDEN #1 | 35.2667 | 106.2000 | 2037 | 80 | 150 | 70 | 27.44 | 3.89 | 107 | Edwards and others (1978) |
| GOLDEN #1 | 35.2667 | 106.2000 | 2037 | 150 | 250 | 100 | 18.83 | 2.75 | 52 | Edwards and others (1978) |
| TETILLA PEAK | 35.5833 | 106.2167 | 1889 | 70 | 140 | 70 | 39.57 | 2.12 | 84 | Edwards and others (1978) |
| SAN FELIPE/EAST | 35.3000 | 106.2500 | 1920 | 70 | 120 | 50 | 22.33 | 2.4 | 54 | Reiter and others (1975) |
| SAN FELIPE/EAST | 35.3000 | 106.2500 | 1920 | 120 | 180 | 60 | 31.48 | 2.27 | 72 | Reiter and others (1975) |
| SAN FELIPE/EAST | 35.3000 | 106.2500 | 1920 | 170 | 260 | 90 | 36.58 | 2.31 | 85 | Reiter and others (1975) |
| HOLWEG | 35.1500 | 106.2667 | 2090 | 60 | 140 | 80 | 23.33 | 2.83 | 66 | Reiter and others (1975) |
| ALBUQUERQUE | 35.0500 | 106.5167 | 1650 | 140 | 180 | 40 | 19.71 | 2.29 | 45 | Reiter and others (1975) |
| ALBUQUERQUE SE #1 | 34.9333 | 106.5500 | 1820 | 20 | 130 | 90 | 19.7 | 3.31 | 65 | Reiter and others (1975) |
| ALBUQUERUQE SE #2 | 34.9333 | 106.5500 | 1820 | 30 | 130 | 100 | 17.5 | 3.41 | 60 | Reiter and others (1975) |
| ISLETA NO.3 | 34.9333 | 106.6500 | 1605 | 1616 | 2793 | 1177 | 20 | 2.65 | 53 | Reiter and others (1986) |
| ISLETA NO.3 | 34.9333 | 106.6500 | 1605 | 2793 | 3162 | 2793 | 98.6 | 2.72 | 268 | Reiter and others (1986) |
| ISLETA NO.3 | 34.9333 | 106.6500 | 1605 | 1616 | 3162 | 1546 | 38.7 | 2.66 | 103 | Reiter and others (1986) |
| SANTA FE NO.1 | 35.3500 | 106.6667 | 1748 | 2115 | 3365 | 1250 | 32.8 | 2.35 | 77 | Reiter and others (1986) |
| ISLETA NO.2 | 34.9167 | 106.7500 | 1563 | 1524 | 4428 | 2904 | 28.5 | 2.17 | 62 | Reiter and others (1986) |
| ISLETA NO.2 | 34.9167 | 106.7500 | 1563 | 4428 | 5557 | 1129 | 48.9 | 2.36 | 115 | Reiter and others (1986) |
| ISLETA NO.2 | 34.9167 | 106.7500 | 1563 | 5557 | 6484 | 927 | 30.8 | 2.18 | 67 | Reiter and others (1986) |
| ISLETA NO.2 | 34.9167 | 106.7500 | 1563 | 1524 | 6484 | 4960 | 36.7 | 2.24 | 82 | Reiter and others (1986) |
| ISLETA NO.4 | 34.8500 | 106.7667 | 1538 | 2463 | 3125 | 662 | 43.8 | 2.02 | 88 | Reiter and others (1986) |
| ISLETA NO.4 | 34.8500 | 106.7667 | 1538 | 3125 | 3781 | 656 | 27.8 | 2.64 | 73 | Reiter and others (1986) |
| ISLETA NO.4 | 34.8500 | 106.7667 | 1538 | 3784 | 4299 | 515 | 23.6 | 2.1 | 50 | Reiter and others (1986) |
| SANTA FE NO.3 | 35.3333 | 106.8667 | 1915 | 1435 | 2735 | 1300 | 32.5 | 2.26 | 73 | Reiter and others (1986) |
| SANTA FE NO.2 | 34.7167 | 106.9500 | 1584 | 972 | 2565 | 1593 | 39.9 | 2.71 | 108 | Reiter and others (1986) |
| SANTA FE NO.2 | 34.7167 | 106.9500 | 1584 | 972 | 2565 | 1593 | 39.9 | 2.44 | 97 | Reiter and others (1986) |
| SANTA FE NO.2 | 34.7167 | 106.9500 | 1584 | 972 | 2138 | 1166 | 42.9 | 2.79 | 120 | Reiter and others (1986) |
| SANTA FE NO.2 | 34.7167 | 106.9500 | 1584 | 972 | 2138 | 1166 | 42.9 | 2.44 | 105 | Reiter and others (1986) |
| SANTA FE NO.2 | 34.7167 | 106.9500 | 1584 | 2138 | 4272 | 2134 | 40.8 | 2.86 | 117 | Reiter and others (1986) |
| LAGUNA WILSON | 35.0167 | 106.9667 | 1645 | 1215 | 3386 | 2171 | 32.3 | 2.41 | 78 | Reiter and others (1986) |
| SAN YSIDRO | 35.5167 | 106.9667 | 1808 | 335 | 595 | 260 | 39.4 | 1.82 | 72 | Reiter and others (1979) |
| SANTA FE PACIFIC | 34.7500 | 106.9833 | 1546 | 1686 | 2228 | 542 | 40.1 | 2.67 | 107 | Reiter and others (1986) |
| SANTA FE PACIFIC | 34.7500 | 106.9833 | 1546 | 2228 | 3709 | 1481 | 40 | 2.6 | 104 | Reiter and others (1986) |
| RIO PUERCO #2 | 35.2000 | 107.0167 | 1750 | 60 | 140 | 80 | 30.83 | 2.37 | 73 | Reiter and others (1975) |
| RIO PUERCO #2 | 35.2000 | 107.0167 | 1750 | 160 | 190 | 30 | 55.78 | 2.1 | 117 | Reiter and others (1975) |
| RIO PUERCO #1 | 35.2167 | 107.0167 | 1740 | 60 | 120 | 60 | 37.39 | 2.31 | 86 | Reiter and others (1975) |
| RIO PUERCO #1 | 35.2167 | 107.0167 | 1740 | 140 | 180 | 40 | 56.18 | 2.33 | 131 | Reiter and others (1975) |
| RIO PUERCO #1 | 35.2167 | 107.0167 | 1740 | 180 | 210 | 30 | 75.23 | 2.25 | 170 | Reiter and others (1975) |
| RIO PUERCO #3 | 35.2000 | 107.0833 | 1830 | 60 | 120 | 60 | 35.66 | 2.39 | 85 | Reiter and others (1975) |
| RIO PUERCO #3 | 35.2000 | 107.0833 | 1830 | 120 | 150 | 30 | 49.12 | 2.34 | 115 | Reiter and others (1975) |
| RIO PUERCO #3 | 35.2000 | 107.0833 | 1830 | 150 | 170 | 20 | 60.01 | 2.24 | 134 | Reiter and others (1975) |
| CARRIZO | 34.8000 | 107.1333 | 1886 | 50 | 350 | 300 | 24.84 | 2.42 | 60 | Edwards and others (1978) |
| CARRIZO | 34.8000 | 107.1333 | 1886 | 350 | 820 | 470 | 35.91 | 2.29 | 82 | Edwards and others (1978) |
| MARQUEZ/SE | 35.2500 | 107.2167 | 1970 | 100 | 130 | 30 | 21.12 | 3.52 | 74 | Reiter and others (1975) |
| MARQUEZ/SE | 35.2500 | 107.2167 | 1970 | 130 | 180 | 50 | 33.91 | 2.3 | 78 | Reiter and others (1975) |
| MARQUEZ/SE | 35.2500 | 107.2167 | 1970 | 160 | 300 | 140 | 32.34 | 2.73 | 88 | Reiter and others (1975) |
| LITTLE BEAR MTN | 34.2833 | 107.2500 | 1902 | 60 | 210 | 150 | 20.13 | 2.95 | 59 | Edwards and others (1978) |
| LITTLE BEAR MTN | 34.2833 | 107.2500 | 1902 | 200 | 290 | 90 | 29.15 | 2.47 | 72 | Edwards and others (1978) |
| MARQUEZ | 35.2833 | 107.2500 | 2120 | 70 | 130 | 60 | 51.98 | 1.72 | 90 | Reiter and others (1975) |

# APPENDIX D  SUBSURFACE TEMPERATURE MODELS

Contents

| Mean Annual Temp | 13.8 | °C | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Background Heat Flow | 85 | mW/m² | | | | | | | | |
| Formation | Thickness ft | Thickness m | Depth ft | est Tcond W/m°K | Tgrad °C/km | dT °C | dT + MAT °C | dT + MAT °F | BHT model uncorr °C | BHT model uncorr °F |
| Upper Santa Fe | 1,500 | 457.2 | 1,500 | 2.00 | 42.5 | 19.4 | 33.2 | 91.8 | 29.1 | 84.4 |
| Lower Santa Fe | 2,260 | 688.8 | 3,760 | 2.20 | 38.6 | 26.6 | 59.8 | 139.7 | 52.2 | 125.9 |
| Tertiary volcanic sediment | 1,550 | 472.4 | 5,310 | 2.20 | 38.6 | 18.3 | 129.9 | 265.8 | 68.0 | 154.4 |
| Galisteo | 1,136 | 346.3 | 4,896 | 2.30 | 37.0 | 12.8 | 90.9 | 195.6 | 63.8 | 146.8 |
| Menefee | 1,100 | 335.3 | 5,996 | 1.80 | 47.2 | 15.8 | 106.7 | 224.1 | 75.0 | 167.0 |
| Crevasse Canyon | 200 | 61.0 | 6,196 | 2.50 | 34.0 | 2.1 | 108.8 | 227.8 | 77.1 | 170.7 |
| Mancos | 900 | 274.3 | 7,096 | 1.80 | 47.2 | 13.0 | 121.8 | 251.2 | 86.3 | 187.3 |
| Dakota | 310 | 94.5 | 7,406 | 3.20 | 26.6 | 2.5 | 124.3 | 255.7 | 89.4 | 193.0 |
| Morrison/Brushy Basin | 100 | 30.5 | 7,506 | 2.00 | 42.5 | 1.3 | 125.6 | 258.0 | 90.4 | 194.8 |
| Morrison/Salt Wash | 250 | 76.2 | 7,756 | 2.50 | 34.0 | 2.6 | 128.2 | 262.7 | 93.0 | 199.4 |
| Summerville | 150 | 45.7 | 7,906 | 2.30 | 37.0 | 1.7 | 129.8 | 265.7 | 94.5 | 202.1 |
| Todilto | 80 | 24.4 | 7,986 | 4.00 | 21.3 | 0.5 | 130.4 | 266.6 | 95.3 | 203.6 |
| Entrada | 130 | 39.6 | 8,116 | 3.50 | 24.3 | 1.0 | 131.3 | 268.4 | 96.7 | 206.0 |
| Chinle/Petrified Forest | 1,300 | 396.2 | 9,416 | 1.80 | 47.2 | 18.7 | 150.0 | 302.1 | 109.9 | 229.9 |
| Chinle/Aqua Zarca | 300 | 91.4 | 9,716 | 2.50 | 34.0 | 3.1 | 153.1 | 307.7 | 113.0 | 235.4 |
| San Andres LS | 10 | 3.0 | 9,726 | 3.10 | 27.4 | 0.1 | 153.2 | 307.8 | 113.1 | 235.6 |
| Glorieta SS | 100 | 30.5 | 9,826 | 4.00 | 21.3 | 0.6 | 153.9 | 309.0 | 114.1 | 237.4 |
| Yeso/San Ysidro | 390 | 118.9 | 10,216 | 2.30 | 37.0 | 4.4 | 158.3 | 316.9 | 118.1 | 244.6 |
| Yeso/Meseta Blanca | 250 | 76.2 | 10,466 | 3.50 | 24.3 | 1.9 | 160.1 | 320.2 | 120.7 | 249.2 |
| Abo | 740 | 225.6 | 11,206 | 2.30 | 37.0 | 8.3 | 168.5 | 335.2 | 128.2 | 262.8 |
| Madera Group/Bursum | 100 | 30.5 | 11,306 | 2.30 | 37.0 | 1.1 | 169.6 | 337.2 | 129.2 | 264.6 |
| Madera Group/Wild Cow | 450 | 137.2 | 11,756 | 2.80 | 30.4 | 4.2 | 173.7 | 344.7 | 133.8 | 272.9 |
| Madera Group/Los Moyos | 300 | 91.4 | 12,056 | 3.10 | 27.4 | 2.5 | 176.2 | 349.2 | 136.9 | 278.4 |
| Sandia | 30 | 9.1 | 12,086 | 2.30 | 37.0 | 0.3 | 176.6 | 349.9 | 137.2 | 279.0 |
| Arroyo Penasco | 0 | 0.0 | 12,086 | 3.00 | 28.3 | 0.0 | 176.6 | 349.9 | 137.2 | 279.0 |
| TD | 13,636 | | | | total | 162.8 | | | | |

| RESERVOIR TEMPS | ZIA SITE #1 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mean Annual Temp** | **13.8** | **ºC** | | | | | | | | |
| **Background Heat Flow** | **75** | **mW/m²** | | | | | | | | |
| **Formation** | **Thickness ft** | **Thickness m** | **Depth ft** | **est Tcond W/mºK** | **Tgrad ºC/km** | **dT ºC** | **dT + MAT ºC** | **dT + MAT ºF** | **BHT model uncorr ºC** | **BHT model uncorr ºF** |
| Upper Santa Fe | 1,500 | 457.2 | 1,500 | 2.00 | 37.5 | 17.1 | 30.9 | 87.7 | 29.1 | 84.4 |
| Lower Santa Fe | 2,260 | 688.8 | 3,760 | 2.20 | 34.1 | 23.5 | 54.4 | 130.0 | 52.2 | 125.9 |
| Tertiary volcanic sediment | 1,550 | 472.4 | 5,310 | 2.20 | 34.1 | 16.1 | 114.6 | 238.3 | 68.0 | 154.4 |
| Galisteo | 1,136 | 346.3 | 4,896 | 2.30 | 32.6 | 11.3 | 81.8 | 179.3 | 63.8 | 146.8 |
| Menefee | 1,100 | 335.3 | 5,996 | 1.80 | 41.7 | 14.0 | 95.8 | 204.4 | 75.0 | 167.0 |
| Crevasse Canyon | 200 | 61.0 | 6,196 | 2.50 | 30.0 | 1.8 | 97.6 | 207.7 | 77.1 | 170.7 |
| Mancos | 900 | 274.3 | 7,096 | 1.80 | 41.7 | 11.4 | 109.1 | 228.3 | 86.3 | 187.3 |
| Dakota | 310 | 94.5 | 7,406 | 3.20 | 23.4 | 2.2 | 111.3 | 232.3 | 89.4 | 193.0 |
| Morrison/Brushy Basin | 100 | 30.5 | 7,506 | 2.00 | 37.5 | 1.1 | 112.4 | 234.3 | 90.4 | 194.8 |
| Morrison/Salt Wash | 250 | 76.2 | 7,756 | 2.50 | 30.0 | 2.3 | 114.7 | 238.5 | 93.0 | 199.4 |
| Summerville | 150 | 45.7 | 7,906 | 2.30 | 32.6 | 1.5 | 116.2 | 241.1 | 94.5 | 202.1 |
| Todilto | 80 | 24.4 | 7,986 | 4.00 | 18.8 | 0.5 | 116.6 | 242.0 | 95.3 | 203.6 |
| Entrada | 130 | 39.6 | 8,116 | 3.50 | 21.4 | 0.8 | 117.5 | 243.5 | 96.7 | 206.0 |
| Chinle/Petrified Forest | 1,300 | 396.2 | 9,416 | 1.80 | 41.7 | 16.5 | 134.0 | 273.2 | 109.9 | 229.9 |
| Chinle/Aqua Zarca | 300 | 91.4 | 9,716 | 2.50 | 30.0 | 2.7 | 136.7 | 278.1 | 113.0 | 235.4 |
| San Andres LS | 10 | 3.0 | 9,726 | 3.10 | 24.2 | 0.1 | 136.8 | 278.3 | 113.1 | 235.6 |
| Glorieta SS | 100 | 30.5 | 9,826 | 4.00 | 18.8 | 0.6 | 137.4 | 279.3 | 114.1 | 237.4 |
| Yeso/San Ysidro | 390 | 118.9 | 10,216 | 2.30 | 32.6 | 3.9 | 141.3 | 286.3 | 118.1 | 244.6 |
| Yeso/Meseta Blanca | 250 | 76.2 | 10,466 | 3.50 | 21.4 | 1.6 | 142.9 | 289.2 | 120.7 | 249.2 |
| Abo | 740 | 225.6 | 11,206 | 2.30 | 32.6 | 7.4 | 150.3 | 302.5 | 128.2 | 262.8 |
| Madera Group/Bursum | 100 | 30.5 | 11,306 | 2.30 | 32.6 | 1.0 | 151.3 | 304.3 | 129.2 | 264.6 |
| Madera Group/Wild Cow | 450 | 137.2 | 11,756 | 2.80 | 26.8 | 3.7 | 154.9 | 310.9 | 133.8 | 272.9 |
| Madera Group/Los Moyos | 300 | 91.4 | 12,056 | 3.10 | 24.2 | 2.2 | 157.1 | 314.8 | 136.9 | 278.4 |
| Sandia | 30 | 9.1 | 12,086 | 2.30 | 32.6 | 0.3 | 157.4 | 315.4 | 137.2 | 279.0 |
| Arroyo Penasco | 0 | 0.0 | 12,086 | 3.00 | 25.0 | 0.0 | 157.4 | 315.4 | 137.2 | 279.0 |
| TD | 13,636 | | | | total | 143.6 | | | | |

| RESERVOIR TEMPS | ZIA SITE #3 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mean Annual Temp** | **13.8** | **°C** | | | | | | | | |
| **Background Heat Flow** | **85** | **mW/m²** | | | | | | | | |
| **Formation** | **Thickness ft** | **Thickness m** | **Depth ft** | **est Tcond W/m°K** | **Tgrad °C/km** | **dT °C** | **dT + MAT °C** | **dT + MAT °F** | **BHT model uncorr °C** | **BHT model uncorr °F** |
| Upper Santa Fe | 1,250 | 381.0 | 1,250 | 2.00 | 42.5 | 16.2 | 30.0 | 86.0 | 26.6 | 79.8 |
| Lower Santa Fe | 1,300 | 396.2 | 2,550 | 2.20 | 38.6 | 15.3 | 45.3 | 113.5 | 39.8 | 103.7 |
| Tertiary volcanic sediment | 800 | 243.8 | 3,350 | 2.20 | 38.6 | 9.4 | 109.7 | 229.5 | 48.0 | 118.4 |
| Galisteo | 250 | 76.2 | 3,600 | 2.30 | 37.0 | 2.8 | 57.5 | 135.6 | 42.4 | 108.3 |
| Menefee | 600 | 182.9 | 4,200 | 1.80 | 47.2 | 8.6 | 66.2 | 151.1 | 48.5 | 119.3 |
| Crevasse Canyon | 200 | 61.0 | 4,400 | 2.50 | 34.0 | 2.1 | 68.2 | 154.8 | 50.6 | 123.0 |
| Mancos | 900 | 274.3 | 5,300 | 1.80 | 47.2 | 13.0 | 81.2 | 178.2 | 59.7 | 139.5 |
| Dakota | 300 | 91.4 | 5,600 | 3.20 | 26.6 | 2.4 | 83.6 | 182.5 | 62.8 | 145.1 |
| Morrison/Brushy Basin | 100 | 30.5 | 5,700 | 2.00 | 42.5 | 1.3 | 84.9 | 184.9 | 63.8 | 146.9 |
| Morrison/Salt Wash | 250 | 76.2 | 5,950 | 2.50 | 34.0 | 2.6 | 87.5 | 189.5 | 66.4 | 151.5 |
| Summerville | 150 | 45.7 | 6,100 | 2.30 | 37.0 | 1.7 | 89.2 | 192.6 | 67.9 | 154.3 |
| Todilto | 100 | 30.5 | 6,200 | 4.00 | 21.3 | 0.6 | 89.9 | 193.7 | 68.9 | 156.1 |
| Entrada | 80 | 24.4 | 6,280 | 3.50 | 24.3 | 0.6 | 90.4 | 194.8 | 69.8 | 157.6 |
| Chinle/Petrified Forest | 1,300 | 396.2 | 7,580 | 1.80 | 47.2 | 18.7 | 109.2 | 228.5 | 83.0 | 181.5 |
| Chinle/Aqua Zarca | 300 | 91.4 | 7,880 | 2.50 | 34.0 | 3.1 | 112.3 | 234.1 | 86.1 | 187.0 |
| San Andres LS | 0 | 0.0 | 7,880 | 3.10 | 27.4 | 0.0 | 112.3 | 234.1 | 86.1 | 187.0 |
| Glorieta SS | 100 | 30.5 | 7,980 | 4.00 | 21.3 | 0.6 | 112.9 | 235.2 | 87.1 | 188.8 |
| Yeso/San Ysidro | 390 | 118.9 | 8,370 | 2.30 | 37.0 | 4.4 | 117.3 | 243.2 | 91.1 | 196.0 |
| Yeso/Meseta Blanca | 250 | 76.2 | 8,620 | 3.50 | 24.3 | 1.9 | 119.2 | 246.5 | 93.6 | 200.6 |
| Abo | 740 | 225.6 | 9,360 | 2.30 | 37.0 | 8.3 | 127.5 | 261.5 | 101.2 | 214.2 |
| Madera Group/Bursum | 100 | 30.5 | 9,460 | 2.30 | 37.0 | 1.1 | 128.6 | 263.5 | 102.2 | 216.0 |
| Madera Group/Wild Cow | 450 | 137.2 | 9,910 | 2.80 | 30.4 | 4.2 | 132.8 | 271.0 | 106.8 | 224.3 |
| Madera Group/Los Moyos | 300 | 91.4 | 10,210 | 3.10 | 27.4 | 2.5 | 135.3 | 275.5 | 109.9 | 229.8 |
| Sandia | 30 | 9.1 | 10,240 | 2.30 | 37.0 | 0.3 | 135.6 | 276.1 | 110.2 | 230.3 |
| Arroyo Penasco | 0 | 0.0 | 10,240 | 3.00 | 28.3 | 0.0 | 135.6 | 276.1 | 110.2 | 230.3 |
| TD | 10,240 | | | | total | 121.8 | | | | |

| RESERVOIR TEMPS | ZIA SITE #4 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mean Annual Temp** | **13.8** | **°C** | | | | | | | | |
| **Background Heat Flow** | **105** | **mW/m²** | | | | | | | | |
| **Formation** | **Thickness ft** | **Thickness m** | **Depth ft** | **est Tcond W/m°K** | **Tgrad °C/km** | **dT °C** | **dT + MAT °C** | **dT + MAT °F** | **BHT model uncorr °C** | **BHT model uncorr °F** |
| Dakota | 150 | 45.7 | 150 | 3.20 | 32.8 | 1.5 | 15.3 | 59.5 | 15.3 | 59.6 |
| Morrison/Brushy Basin | 100 | 30.5 | 250 | 2.00 | 52.5 | 1.6 | 16.9 | 62.4 | 16.4 | 61.4 |
| Morrison/Salt Wash | 250 | 76.2 | 500 | 2.50 | 42.0 | 3.2 | 20.1 | 68.2 | 18.9 | 66.0 |
| Summerville | 150 | 45.7 | 650 | 2.30 | 45.7 | 2.1 | 22.2 | 71.9 | 20.4 | 68.8 |
| Todilto | 80 | 24.4 | 730 | 4.00 | 26.3 | 0.6 | 22.8 | 73.1 | 21.3 | 70.3 |
| Entrada | 130 | 39.6 | 860 | 3.50 | 30.0 | 1.2 | 24.0 | 75.2 | 22.6 | 72.6 |
| Chinle/Petrified Forest | 1,300 | 396.2 | 2,160 | 1.80 | 58.3 | 23.1 | 47.1 | 116.8 | 35.9 | 96.5 |
| Chinle/Aqua Zarca | 300 | 91.4 | 2,460 | 2.50 | 42.0 | 3.8 | 51.0 | 123.7 | 38.9 | 102.1 |
| San Andres LS | 0 | 0.0 | 2,460 | 3.10 | 33.9 | 0.0 | 51.0 | 123.7 | 38.9 | 102.1 |
| Glorieta SS | 100 | 30.5 | 2,560 | 4.00 | 26.3 | 0.8 | 51.8 | 125.2 | 39.9 | 103.9 |
| Yeso/San Ysidro | 390 | 118.9 | 2,950 | 2.30 | 45.7 | 5.4 | 57.2 | 135.0 | 43.9 | 111.1 |
| Yeso/Meseta Blanca | 250 | 76.2 | 3,200 | 3.50 | 30.0 | 2.3 | 59.5 | 139.1 | 46.5 | 115.7 |
| Abo | 740 | 225.6 | 3,940 | 2.30 | 45.7 | 10.3 | 69.8 | 157.6 | 54.0 | 129.3 |
| Madera Group/Bursum | 100 | 30.5 | 4,040 | 2.30 | 45.7 | 1.4 | 71.2 | 160.1 | 55.1 | 131.1 |
| Madera Group/Wild Cow | 450 | 137.2 | 4,490 | 2.80 | 37.5 | 5.1 | 76.3 | 169.4 | 59.6 | 139.4 |
| Madera Group/Los Moyos | 300 | 91.4 | 4,790 | 3.10 | 33.9 | 3.1 | 79.4 | 174.9 | 62.7 | 144.9 |
| Sandia | 30 | 9.1 | 4,820 | 2.30 | 45.7 | 0.4 | 79.8 | 175.7 | 63.0 | 145.4 |
| Arroyo Penasco | 0 | 0.0 | 4,820 | 3.00 | 35.0 | 0.0 | 79.8 | 175.7 | 63.0 | 145.4 |
| TD | 4,820 | | | | total | 66.0 | | | | |

# APPENDIX E BHT DEEP OIL AND GAS WELLS

Contents

1) Bottom hole temperature table.

| WELL NAME | DEPTH ft | DEPTH m | TEMP ºF | TEMP ºC |
|---|---|---|---|---|
| Shell 1 Laguna Wilson | 3989 | 1215.8 | 147 | 63.9 |
| | 11107 | 3385.4 | 292 | 144.4 |
| Shell Santa Fe Pacific 2 | 3189 | 972.0 | 111 | 43.9 |
| | 7011 | 2137.0 | 204 | 95.6 |
| | 8654 | 2637.7 | 224 | 106.7 |
| | 11238 | 3425.3 | 289 | 142.8 |
| | 14011 | 4270.6 | 347 | 175.0 |
| | 14305 | 4360.2 | 354 | 178.9 |
| Shell 1 Isleta Transocean | 5299 | 1615.1 | 156 | 68.9 |
| | 9175 | 2796.5 | 205 | 96.1 |
| | 10378 | 3163.2 | 267 | 130.6 |
| Shell Santa Fe Pacific 3 | 4705 | 1434.1 | 126 | 52.2 |
| | 8994 | 2741.4 | 208 | 97.8 |
| | 10276 | 3132.1 | 238 | 114.4 |
| Shell Santa Fe Pacific 1 | 6936 | 2114.1 | 190 | 87.8 |
| | 11045 | 3366.5 | 267 | 130.6 |
| Shell West Mesa | 17582 | 5359.0 | 342 | 172.2 |
| | 19350 | 5897.9 | 381 | 193.9 |
| Shell Isleta 1 Central | 5325 | 1623.1 | 178 | 81.1 |
| | 8080 | 2462.8 | 198 | 92.2 |
| | 8909 | 2715.5 | 219 | 103.9 |
| | 10250 | 3124.2 | 250 | 121.1 |
| | 12396 | 3778.3 | 288 | 142.2 |
| | 13675 | 4168.1 | 339 | 170.6 |
| | 14100 | 4297.7 | 328 | 164.4 |
| | 16346 | 4982.3 | 387 | 197.2 |
| Shell Isleta 2 | 5000 | 1524.0 | 138 | 58.9 |
| | 9926 | 3025.4 | 215 | 101.7 |
| | 14525 | 4427.2 | 315 | 157.2 |
| | 16254 | 4954.2 | 370 | 187.8 |
| | 18227 | 5555.6 | 390 | 198.9 |

# PUEBLO OF ZIA GEOTHERMAL RESERVOIR CHARACTERIZATION
# PART 2
# CONVECTIVE GEOTHERMAL RESERVOIRS
# SITE 2, SOUTHEASTERN COLORADO PLATEAU, NEW MEXICO

**FINAL TECHNICAL REPORT**

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**Prepared**
**for**
**Pueblo of Zia**
**and**
**USDOE Contract DE-EE00005628**
**Pueblo of Zia Renewable Energy Development Feasibility Study**

**August 2013**

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**APPENDICES**



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## 1.0 INTRODUCTION

A group of convective geothermal systems in the southern Jemez Mountains region are located on or adjacent Jemez Pueblo and Pueblo of Zia lands on the southern flanks of the Nacimiento uplift. During the 1970's, one of the geothermal systems was designated as the San Ysidro Known Geothermal Resources Area (KGRA). However, a KGRA status does not necessarily indicate high geothermal resource potential and may only indicate that competing interests have filed for leases in an area (Godwin and others, 1971). The San Ysidro KGRA was dropped in the 1980's, probably the result of unsuccessful exploration for shallow high-temperature resources in the Rio Grande rift.

Nearby geothermal systems in the central Jemez Mountains are among the best characterized in the world. These systems have spacial, temporal, and genetic associations to the volcanism and tectonism of the Pleistocene Valles caldera (Goff and Grigsby, 1982; Goff and others, 1989; and Laughlin, 1981). The Valles caldera, the type example of a resurgent caldera (Smith and Bailey, 1968), is the only large Neogene ignimbrite volcanic center in the Rio Grande rift (Baldridge and others, 1984).

### 1.1 Purpose

This report describes the geology and hydrogeology of convective the systems on the southern flanks of the Nacimiento uplift on the Colorado Plateau and Rio Grande rift western boundary. A region on Pueblo of Zia adjacent the Kaseman wells, also called “Zia hot wells, hot springs, or warm springs,” is the main focus of this study and the region around the wells is designated as Pueblo of Zia Site 2.

A qualitative hypothesis for the evolution of the geothermal systems on the southern flanks of the Nacimiento uplift is outlined in relation to regional hydrogeology, evolution of the Valles geothermal system, and Neogene unroofing of regional aquitards. Predictions of subsurface temperature and host reservoirs are discussed.

### 1.2 Previous Studies

Compilations of chemical, isotopic, and physical characteristics (temperature and flow rate) of thermal springs and wells in the Jemez region are found in (Craigg, 1984; Mariner and others, 1977; Norman and Bernhardt, 1982; Shevenell and others, 1987; and Summers, 1976; and Vautaz and Goff, 1986; Witcher, 1988a and 1988b; Witcher, 1990, 1991, 1995, and 2004; and Witcher and others, 1992).

Several studies have investigated the hydrodynamics of geothermal systems in the Jemez region with geochemical and isotopic approaches. These studies include Goff and others (1982), Goff and others (1988), Shevenell and others (1987), Trainer (1974, 1975, 1978 and 1984), Trainer and Lyford (1979), Trainer and others, 2000, Vuataz and Goff (1986), White (1986).

Geology of the southern Nacimiento uplift is well characterized by geologic maps at 1:24,000 scale (Formento-Trigilio and others, 1998b; Woodward and Martinez, 1974; Woodward and Ruetschilling, 1976; Woodward and Schumacher, 1973; and Woodward and others, 1977). Flesch (1974), Flesch and Wilson, 1974), Formento-Trigilio and Pazzaglia (1996, Formento-Trigilio and others (1998a), and Woodward (1987) provides discussions of stratigraphy and structure in the area. Early studies by Clark (1929), Harrington (1948), and Renick (1931) provide additional information on travertine and tuffa deposits that occur on the southwestern tip of the Nacimiento uplift. Investigations of the travertine depositional history at Soda Dam adjacent the Valles Caldera to the north by Goff and Shevenell (1987) provides insight into the possible hydrodynamic importance of the travertine deposits found in the southern Nacimiento uplift area.

Drilling and plugging history, driller's formation logs and discharge temperature data on the Kaseman 2 well or ("warm springs") are found in Clark (1929) and Renick (1931).

## 2.0 GEOLOGY

### 2.1 Regional Setting

The Pueblo of Zia Site 2 overlies Colorado Plateau near the intersection of three major physiographic provinces, the Colorado Plateau, the Southern Rocky Mountains and the southern Basin and Range Province (Woodward, 1987). The Rio Grande rift, a tectonic province, is superimposed on the Southern Rocky Mountains and the southern Basin and Range physiographic provinces.

The Colorado Plateau is structurally low compared to the Southern Rocky Mountains and the western margin of the Southern Basin and Range. The Colorado Plateau preserves Paleozoic and most of the Mesozoic sedimentary strata.

The underlying portions of the southern Basin and Range and Southern Rocky Mountains Provinces are structurally high and form the western margin of the Rio Grande rift tectonic province. In the Nacimiento Mountains, most or all of the Paleozoic and Mesozoic strata are eroded and missing.

All three physiographic provinces in the vicinity of the study area show evidence of Pleistocene faulting; high regional heat flow; hundreds of meters of regional Neogene uplift; and significant Pliocene and Pleistocene drainage incision and erosion to create important topographic relief. All of these dynamic processes are associated with the Rio Grande rift tectonism and associated thermal regimes and hydrogeologic processes.

This area is also located within the domain of a major regional northeast linear trend of young, Pliocene and Pleistocene magmatism called the Jemez zone or lineament, which extends from east-central Arizona to northeast New Mexico (Aldrich, 1986, Mayo, 1958, and Laughlin, 1981). Pueblo of Zia Site 2 is located 20 miles south-southwest of the center of the Valles caldera, the largest silicic volcanic center along the Jemez zone and Rio Grande rift.

## 2.2 Hydrostratigraphy

Several major aquifer systems and aquitards comprise the hydrostratigraphy of the area. Basement plutonic and metamorphic rocks provide a mostly low-permeability floor beneath the regions aquifers. Basement rocks are probably aquifers only in fault zones and weathered zones.

A basal carbonate aquifer, comprised mostly of the Pennslyvanian Madera Formation, is overlain by a red bed sandstone aquifer system in the Permian Abo, Yeso, Glorieta Formations, and the Triassic Agua Zarca Member of the Chinle Formation. The red bed sandstone aquifer system is actually a composite of several sandstone aquifers separated by confining siltstone and shale. Both the carbonate and the red bed sandstone units are about 1,800 ft thick (Woodward and Ruetschilling, 1976). The carbonate and the red bed sandstone aquifer system is confined by the shales of the Petrified Forest Member of Chinle Formation. The Triassic Petrified Forest Member, over 1,000 ft thick, forms the Chinle aquitard (Woodward and Ruetschilling, 1976).

Distribution of the Chinle aquitard is key to understanding hydrodynamics and thermal regime of the geothermal systems in the southern Nacimiento uplift. In structurally low areas, the aquifers are deep seated and are capped by the low thermal conductivity Chinle aquitard which provides an effective thermal blanket with relatively higher temperature gradients. The aquitard also provides a barrier to rapid vertical discharge of deep-seated regional ground water-flow.

Other aquifers (and aquitards) occur in the area, but none act as geothermal reservoirs or directly confine deep-seated potential reservoir hosts. On the adjacent Colorado Plateau, just west of the study area, the 100 ft thick Entrada Formation (Woodward and Ruetschilling, 1976) forms a sandstone aquifer above the Chinle aquitard. The Entrada aquifer is overlain by the 100 feet thick Todilto Formation (Woodward and Ruetshilling, 1976), a gypsum aquitard. The gypsum aquitard is overlain by a series of Jurassic and Lower Cretaceous sandstone aquifers, interbedded with confining shales and siltstones, in the Morrison and Dakota Formations. The Mesozoic sandstone aquifers may be capped by more than 300 ft thickness of Mancos Shale on western Pueblo of Zia land (Woodward and Ruetschilling, 1976). Several sandstone bodies within the Mancos aquitard provide minor local aquifers.

Regional discussions of hydrogeology of the San Juan Basin and southeastern Colorado Plateau that are applicable to the Puebo of Zia Site 2 include Levings and others (1996) and Stone and others (1983).

## 2.3 Structure

Thermal and structural framework of the Pueblo of Zia region is dominated by four major tectonic events: 1) the Late Cretaceous to Eocene Laramide Orogeny, 3) a mid-Tertiary volcano-tectonic disturbance, 4) a late Tertiary rifting event, and 5) the formation the Valles caldera, a locally important consequence of the rifting event and associated magmatism. It should be noted that structures created by these tectonic events largely conform to or have reactivated the structural grain preserved in the Precambrian crust. Northeast and north-south grains are prominent.

Laramide deformation in the area is expressed in the Nacimiento Mountains and its western slopes. Baltz (1967), Chapin and Cather (1981) and Woodward (1987) provide in-depth discussion of this deformation and associated sedimentation. On a regional scale, northeast-directed compression elevated the asymmetric basement-cored Nacimiento uplift along the west-vergent Nacimiento reverse-fault system. Rather than acting in a purely reverse-fault fashion, a significant amount of right-lateral transpression may have also occurred along the Nacimiento fault, allowing the Colorado Plateau to move relatively northward (Baltz, 1967). Because the Nacimiento uplift acted as a buttress, en echelon and northwest-plunging folds formed west of the Nacimiento fault. These northwest-plunging folds provide the main evidence for right-lateral movements. East of the Nacimiento uplift, the Eocene Galisteo Formation is deposited in a complementary Laramide basin (Chapin and Cather, 1981).

Much of the region, from the Oligocene to mid-Miocene, was heated by a profound thermal disturbance of the crust that resulted in several ten-thousand cubic kilometers of ash-flow tuff to be erupted (McIntosh and others, 1986); Elston, 1984; and Steven and Lipman, 1976). Most volcanism was confined to the San Juan Mountains of Colorado and Datil-Mogollon area in New Mexico. In some areas, broad basins formed, catching volcaniclastic detritus from the volcanic centers (Seager and others, 1984); Morgan and Golombek, 1984); and Chamberlin, 1983). In the Pueblo of Zia region, the Zia Sand Formation may fill such a basin or the Zia Sand may simply represent the distal alluvial aprons and eolian fields surrounding the Oligocene-Miocene volcanic fields north and south of the Pueblo of Zia.

At about 13 million years before present (Ma), the region east of San Ysidro began to rift apart and subside along north-striking normal faults as the underlying crust stretched and collapsed to form the Albuquerque basin. Thermal disturbance, asthenosphere upwarp, and isostatic readjustments resulted in uplift on the flanks of the rift on the Colorado Plateau margins and in the Nacimiento Mountains west of San Ysidro. Most faulting and rifting probably occurred from 12 to 7 Ma. Reactivation of Laramide faults in the Nacimiento uplift may have also occurred (Woodward, 1987). Quaternary displacements are also observed on many normal faults indicating continued rifting. Significant volcanism, in the Jemez volcanic field, accompanied the late Tertiary rifting in the region north of the Pueblo of Zia. Keres Group volcanics, which comprise approximately half the eruptive volume within the volcanic field, accompanied the intense rifting between 12 and 7 Ma (Gardner and Goff, 1984). Between 7 and 4 Ma there was a cessation of basaltic volcanism (Gardner and Goff, 1984). Basaltic eruptions again ensued after 4 Ma. Volcanism culminated in the Jemez volcanic field with the catastrophic eruption of the Bandelier ash-flow tuff from a shallow silicic magma chamber at about 1.12 Ma. The Bandelier eruptions were accompanied by collapse into the vacated top of the magma chamber to form the circular Valles caldera (Smith and others, 1970). Volatile-depleted Valles Rhyolite has subsequently squeezed out along the caldera ring fractures. A young Valles Rhyolite, the Banco Bonito flow (0.13 Ma) Marvin and Dobson, 1979), on the southwest margin of the caldera at Battleship Rock is indicative of continuing silicic magmatism that provides the heat necessary to drive the high-temperature Valles (or Baca) geothermal system.

## 3.0 THERMAL REGIME

### 3.1 Regional Conductive Heat Flow

Lithospheric extension, accompanied by asthenosphere upwarp, and magma intrusion into the upper mantle, and locally at crustal depths, gives the Rio Grande rift and immediately adjacent Colorado Plateau enhanced thermal energy (Baldridge and others, 1984; Lachenbruch and Sass, 1978; and Reiter and others, 1979). Typical higher heat flows in the rift averages about 107 milli-watts per meter squared ($m$W/m$^2$) (Morgan, 1982; and Reiter and others, 1979).

Reiter and others (1979) measure a 72.3 $m$W/m$^2$ heat flow 15 miles southwest San Ysidro on the Colorado Plateau margin. The San Ysidro heat flow is similar to heat flow in the Albuquerque basin area and the adjacent southern Colorado Plateau; however, it is about 10 to 40 $m$W/m$^2$ less than typical values measured elsewhere in the rift.

Temperature logs of two Bureau of Indian Affairs (BIA) ground-water monitor wells on Pueblo of Zia east and north of the Jemez River provide background temperature gradient information (Witcher, 1988a). These wells, the Backstop and Windmill sites, had temperature gradients of 31.6 and 32.3 degrees Celsius per kilometer ($^o$C/km), respectively.

### 3.2 Local Convective Geothermal Heat Fluxes

The Valles caldera is a localized, but very intense, thermal anomaly within the rift. Heat flow across the Valles caldera probably exceeds 500 $m$W/m$^2$ (Kolstad and McGetchin, 1978; Sass and Morgan, 1988; and Tomczck and Morgan, 1987). Mostly crystallized latest Pleistocene-to-Recent magma bodies beneath the caldera and in the ring fractures are the heat sources. Heat from these intrusions drives the Valles (Baca) geothermal system (Dondanville, 1978; Smith and Shaw, 1979). Lateral outflow from the Valles geothermal system transfers heat and fluids to areas outside and adjacent the southwest margin of the caldera (Faust and others, 1984; and Goff and others, 1988).

Temperature logs and reported temperature gradients for 15 boreholes across the southern flanks of the Nacimiento uplift allow evaluation of the possible extension of the outflow plume of the Baca geothermal system and generally characterize the thermal regime across the region (Figure 4.1).

Gradient measurements NC-3 and NC-5, reported by (Witcher, 1988a and Trainer, 1978), are adjacent to the structure that controls the Salado Warm

Springs discharge and they are slightly anomalous as warm gradients up to 44.2 to 55.2 $^{o}$C/km in the Mancos Formation. The North Ponderosa, Guadalupe Box, and Guadalupe Mesa measurements, reported in (Witcher, 1988a and Trainer, 1978) are also anomalously warm and may indicate a southern subsurface extension of the Valles geothermal system outflow plume or a conductive thermal aureole from Pliocene-to-Pleistocene magmatism in the subsurface.

An apparently narrow band of high heat flow extends from Salado Warm Springs northward to the Kaseman 2 flowing well. Temperature discharges (42.2$^{o}$C) reported by (Renick, 1931) at 129.5 m depth during drilling of the Kaseman 2 well indicate a near surface heat-flow exceeding 400 mW/m$^2$, using an estimated 1.89 watts per meter degree Kelvin (W/m$^{o}$K) for the thermal conductivity of the Chinle Formation and a near-surface mean annual air temperature (MAT) of 14.5 $^{o}$C. Temperatures reported by (Renick, 1931) within the producing zones of the Kaseman 2 well at depths greater than 130 m indicate average temperature gradients of about 80 $^{o}$C/km and are more than twice the normal values expected for this area.

While no temperature gradient measurements are available, heat flow in the Indian Springs area is definitely above normal as indicated by the results of Jemez Pueblo 1 test well (53 $^{o}$C at 80 m depth) (Witcher, 1991).

## 4.0 CONVECTIVE GEOTHERMAL SYSTEMS IN AREA

### 4.1 Introduction

Four convective geothermal system discharge areas are delineated on the basis of their hydrogeologic settings (Figure 4.1). The Indian Springs system just south of the Jemez Pueblo and the Zia Hot Well-Arroyo Penasco Warm Springs system along Highway 44 have sufficiently different fluid chemistry and structural associations as to be labeled end-member systems. The Salado and San Ysidro Warm Springs systems appear to have geochemical and hydrogeological attributes of the both end-member systems. All systems are co-located with travertine deposits that are variably extensive. However, the bulk of the travertine represents paleo or extinct spring discharges and only limited volumes of travertine are associated with current spring discharge sites.

### 4.2 Indian Springs System

Indian Springs form a series of seeps and very small springs that discharge thermal water along the banks of the Jemez River about 2 miles south of the Jemez Pueblo. The highest temperature reported for the springs is 53 $^{o}$C (Summers, 1976). Gas bubbles rising to the surface of the river are interpreted to indicate that additional discharges of thermal water occur directly into the river channel. Mixing with shallow Jemez River underflow is indicated by variations in total dissolved solids among the seeps and springs. Chloride contents vary between 1,165.9 and 1,328 mg/L. The springs discharge sodium-bicarbonate-chloride type water.

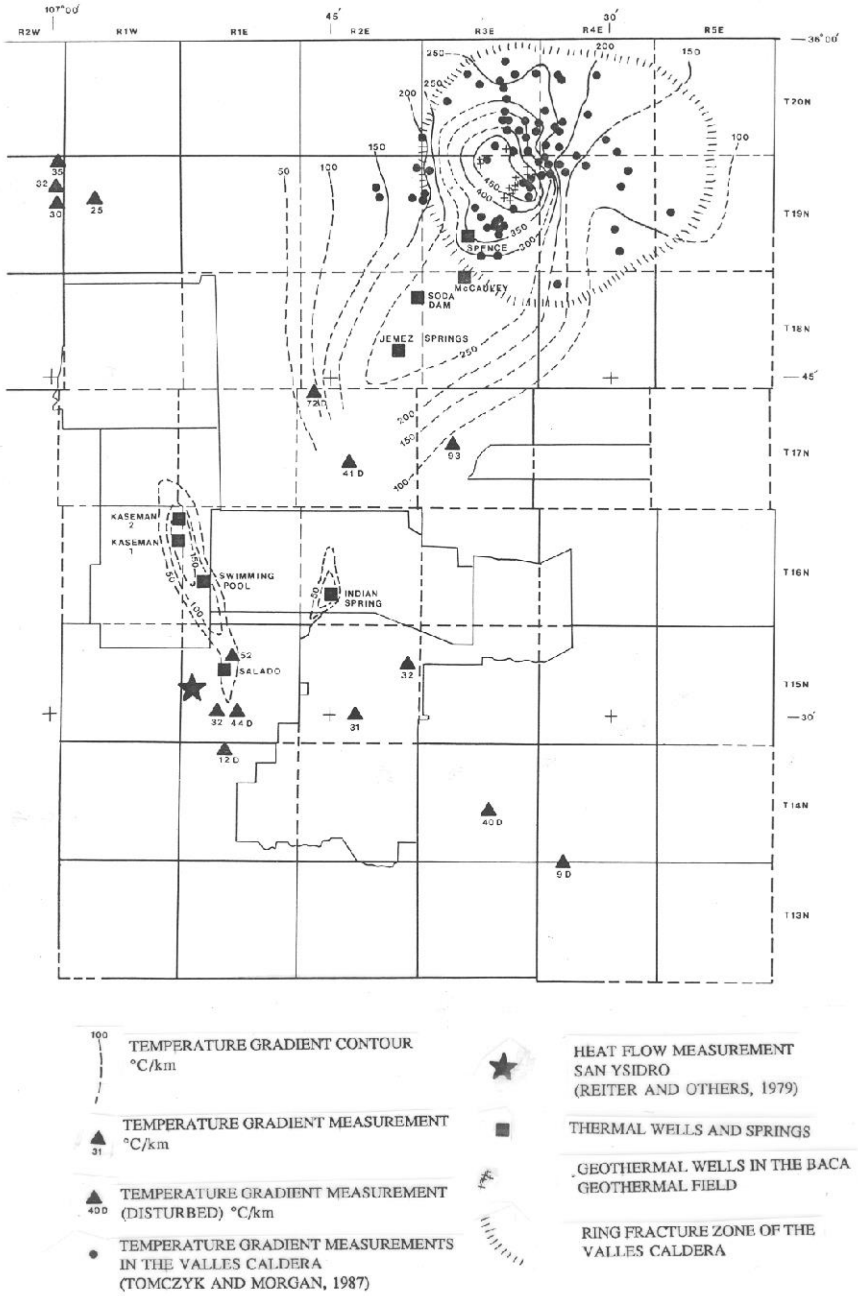



Figure 4.1 Temperature gradient map and locations of convective geothermal systems in the Pueblo of Zia region.

Witcher (1988b) reports a natural discharge of the Indian Springs geothermal system of 0.66 cubic feet per second (cfs) or about 296 gallons per minute (gpm) in 1991 using a chloride mass balance applied to a downstream flow measurement of the Jemez River with chloride measurements upstream and downstream of the springs and the chloride content of the spring discharge.

A seepage survey conducted by the U. S. Geological Survey on 1 March, 1984 between the Jemez Pueblo bridge and Highway 4 bridge north of San Ysidro shows the Jemez River gains 7 cfs of flow and 26 mg/L (Craigg, 1984). A chloride balance for the Jemez River, using these data show that 0.93 cfs or 416 gpm of geothermal water leaves the geothermal reservoir to ultimately leak into the river. These flow interpretations indicate an overall increase in discharge. Because the Jemez River is a gaining stream in the stretch between flow measurements, the differences in geothermal discharges into the river between estimates may reflect the location of the measurements or other non-thermal sources for chloride. In any case, the minimum natural discharge of the Indian Springs system is about 300 gpm.

### 4.3 Salado Warm Springs

Salado Warm Springs are a series of small springs and seeps at the northern end of the Tierra Amarillo anticline at the southwest termination of the Nacimiento Mountains. Salado Warm Spring discharges 9,608 mg/L TDS, sodium-sulfate-chloride water from the summit crater of a travertine mound. Water overflowing the summit vent has a 25 $^{o}$C temperature and an estimated flow rate less than 10 gpm (Witcher, 1988a). In addition, numerous adjacent seeps and small springs form an extensive marshy area on the south side of the Rio Salado.

Southward at elevations, ranging nearly 400 ft higher than the present day Salado Warm Springs, a significant volume of travertine rests upon the Petrified Forest Member of the Chinle Formation along the Tierra Amarillo anticline axis. This area of travertine probably has a thickness no greater than 50 to 100 ft along an area nearly 9,000 ft long by 1,000 to 1,400 ft wide along the Tierra Amarillo anticline axis. However, more than 250 million cubic ft of travertine exist if an average thickness of 30 ft is assumed (Witcher, 1988a).

Small faults and fractures in the Petrified Forest Member along the anticline axis apparently allow vertical seepage of fluids under artesian pressure from the underlying Aqua Zarca - Madera aquifer system. While present-day discharge may occur along the anticline at elevations much higher than the current spring discharges at Salado Warm Springs, such flows remain hidden beneath the travertine deposits and are not observed.

The Salado Warm Springs system probably has a long history of active discharge and the associated travertine deposits may provide important records of Quaternary hydrology and climate.

### 4.4 San Ysidro Warm Springs

Small 18 to 25 $^{o}$C temperature springs and seeps discharge sodium-sulfate-chloride water along the north side of Highway 44 at the southern end of the Nacimiento upift. These springs are located in an area one to two miles northeast of Salado Warm Springs. Small travertine deposits are associated with active springs. Woodward and Ruetschilling (1976) map numerous small travertine occurrences on the southern slope of the Naciemento uplift in the north and northeast of San Ysidro Warms Springs. These travertine deposits are found at elevations more than 600 ft above the current San Ysidro Warm Springs. Nearly all of these paleo spring deposits are mapped as residing upon the Petrified Forest Member of the Chinle Formation, an aquitard, and near the contact with the underlying Aqua Zarca Member, an aquifer. Proximity and identical geologic relationships to the present day San Ysidro Warm Springs suggests a genetic relationship for the travertine deposits and indicates the San Ysidro Warm Springs system has a long-lived history.

### 4.5 Zia Hot Well-Arroyo Penasco Warm Springs

Two oil and gas test wells, Kaseman 1 and Kaseman 2 (Zia hot well of Goff and Shevenell (1987), thermal springs in Arroyo Penasco (Phillips Springs of Renick,1931), and very large deposits of travertine indicate a geothermal system in the Cuchillo Arroyo and Penasco Arroyo area. This system is located west of the Nacimiento fault along the "Rio Salado anticline" of Renick (1931).

The Zia hot well or Kaseman 2 well, total 2,008 ft depth, discharges 10,720 mg/L TDS sodium-sulfate-chloride water at 53 $^{o}$C. Drilled in 1926 with cable tool equipment, this well had an artesian flow of 5.5 cfs or 2,468 gpm in 1927 and was highly charged with non-flammable gas. More recent work by Norman and Bernhardt (1982) and Goff and Shevenell (1987) indicates that most of the gas is predominantly carbon dioxide with some nitrogen. An attempt to plug and abandon this well failed in 1927 (Clark, 1929). By 1973, the flow rate had decreased to 85 gpm (Summers, 1976). The casing in this well has no doubt been destroyed by corrosion and attempts to plug the hole that included “dynamite” blasting. The decreased flow rates are probably the combined result of a collapsing borehole in shale zones, and carbonate scaling and not reservoir pressure decline.

An additional well, the Kaseman 1 well, total 550 ft depth, was plugged and abandoned after encountering salty hot (115 $^{o}$F) water. Renick (1931) reports that the Kaseman 1 well flowed 2,450 gpm with much non-flammable gas evolution in 1926 and the TDS was 11,120 mg/L.

Hot water was first encountered in the Kaseman wells after the drilling had penetrated clay beds to depths of 500 ft (Kaseman 1) and 425 ft depth (Kaseman 2) (Renick, 1931). The clay beds noted in drillers logs no doubt represent strata of the Petrified Forest Member of the Chinle Formation. The Kaseman 2 well apparently penetrated the Madera limestone at 1,880 feet depth before reaching a total depth of 2,008 ft (Renick, 1931).

Thermal springs in the Arroyo Penasco drainage (Penasco 1, 2, 3, 4 and Swimming Pool Spring) and Big Crater Spring are associated with an extensive area of large active and extinct travertine mounds with large circular spring vents. In the top of the extinct mounds, the spring vents appear as craters tens to over a hundred feet across and up to 100 ft deep. Harrington (1948) reports that early Spanish explorers were so impressed with the "crater" springs that they named one of the springs El Ojo del Espirutu Santo or "Spring of the Holy Spirit." The

Spanish land grant which covered this area carries the name El Ojo del Espirutu Santo.

The highest extinct travertine vents are at elevations over 6,240 ft and more than 200 ft higher than the Kaseman 2 site at 6,025 ft elevation. For comparison, artesian head values reported for the Kaseman wells range from 57.5 ft (25 psi) to 517 ft (225 psi) (Renick, 1931 and Clark, 1929). Based upon this limited information, head existing in 1926 may have been sufficient to drive flow to the highest elevation mounds with the proper subsurface plumbing. Clark (1929) and Harrington (1948) postulate that mounds grow until hydrostatic pressures force flow breakouts at the base of the mounds, resulting in repeated generation of lower elevation parasitic travertine mounds and a drying up of the parent mound discharge vents. Field relationships tend to support this hypothesis. On the other hand, mound growth may simply be stopped by travertine sealing of the vent feeder plumbing. Also, the weight of a growing travertine mass could cause the clays in the underlying Petrified Forest Member to shift or slide, thereby sealing feeder plumbing or even creating new plumbing.

Over long time scales, fluctuations in the artesian head of the regional aquifer system due to climate changes and regional erosive landscape denudation probably play a roles in determining travertine vent elevation growth, stabilization, and collapse. Progressive removal of confining units by erosion in the discharge areas and tectonic opening of new discharge sites may also change overall hydraulic head of the regional aquifer system.

## 5.0 GEOCHEMISTRY

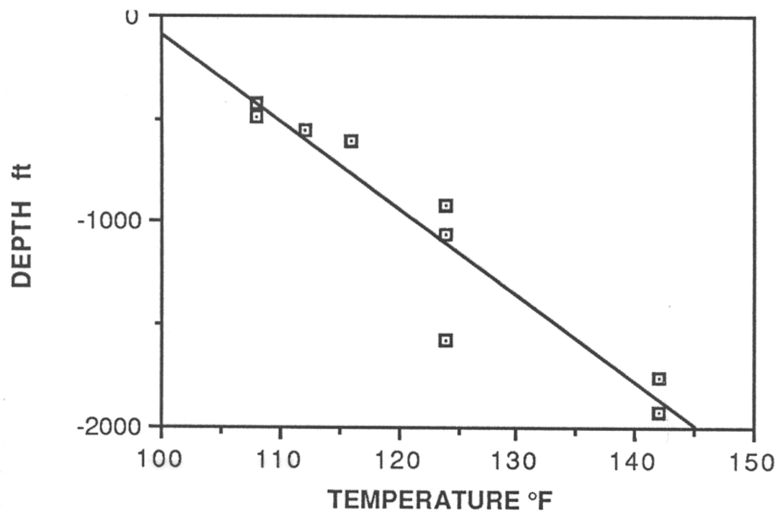
### 5.1 End Member Sources and Mixing

The hydrochemistry of thermal and non-thermal waters in the area provides information of the fluid source, flow paths, subsurface storage, discharge rates, temperatures and possible mixing or intermingling. Appendix A lists major cation and anion chemistry of Kaseman 2 hot well (from Witcher, 1995).

Goff and others (1988) used the ratios of conservative ions, such lithium, boron, and chloride, and stable isotopes, deuterium and oxygen, in geothermal waters to track the mixing and flow of the outflow plume from the Valles (Baca) geothermal system in the Jemez Mountains. The Indian Springs appears to represent a distal leakage of the Valles system outflow plume along the Jemez fault, which may also transmit outflow plumes of geothermal fluids beneath San Ysidro and the location of the Pueblo of Zia Site 4 (see Part 1 report). Ratio plots of conservative dissolved constituents show three general end-member waters. The first is shown by the Baca geothermal wells from the Redondo Creek area of the Jemez Mountains. The Kaseman 2 hot well on the Pueblo of Zia represents the second geothermal end member. Cold non-thermal springs and wells form a third end member. Mixing of cold non-thermal waters with two geothermal end-members waters gives two broad mixing trends.

### 5.2 Geothermometry Estimates of Reservoir Temperatures

Silica geothermometers are used to estimate possible reservoir temperatures (Fournier, 1977 and Fournier and Potter, 1979). The chalcedony geothermometer is probably most suitable for the low temperature (<80 ºC) springs and well discharges sampled for chemical analysis. The Na/K, Na/K/Ca, and Na/K/Ca/Mg geothermometers are not applicable. These cation geothermometers are based temperature dependent equilibria of dissolved cations with solid phase aluminosilicate minerals. The presence of soluble gypsum and anhydrite in the potential Paleozoic aquifers will increase dissolved calcium faster than equilibrium reactions with aluminosilicate solids can proceed at lower temperatures (<100 to 150 ºC). Also, precipitation of travertine or calcite removes dissolved calcium faster than aluminosilicate equilibrium can be established.




| DEPTH ft | TEMPERATURE °F |
|---|---|
| 425.0 | 108.0 |
| 490.0 | 108.0 |
| 550.0 | 112.0 |
| 610.0 | 116.0 |
| 910.0 | 124.0 |
| 1060.0 | 124.0 |
| 1570.0 | 124.0 |
| 1760.0 | 142.0 |
| 1920.0 | 142.0 |

Figure 5.1 Water temperature at various depths while drilling Kaseman 2 well.

The chalcedony geothermometer for the Kaseman 2 fluids is 54 $^{o}$C in close agreement with the observed artesian discharge temperature at 53 $^{o}$C. The Quartz geothermometer for the Kaseman 2 fluids is 85 $^{o}$C. Projection of systematic temperature increases for produced fluids during the drilling of the Kaseman 2 well into the lower Madera Formation gives an independent estimate of around 80 $^{o}$C (Figure 5.1).

## 7.0 DISCUSSION

Deeply circulating sodium-sulfate-chloride water, beneath the eastern San Juan Basin on the Colorado Plateau, is heated by the background geotherm. These fluids flow southeast as part of a regional ground water flow system in Triassic Aqua Zarca sandstone and Paleozoic redbed aquifers, including the Madera limestone. Structure on the eastern Colorado Plateau and the Nacimiento uplift force flow toward the surface. Maps of Formento-Triglio and others (1998a,b), Woodward and Martinez (1974), Woodward and Ruetschilling, Woodward and Schumacker (1973) and Woodward (1987) show favorable sites to explore for the regional geothermal underflow. Several northwest-plunging synclines and anticlines appear to provide good permeability on fold axes. Selection of fold-axis drill sites closest to the Nacimiento Mountain front may decrease the drilling depth required for reaching the productive reservoir.

Great care in production drilling is required due to the potential for very high artesian water pressures in aquifers beneath confining aquitard clays and silts. First, the depths will be at least a couple of thousand ft. Second, at least two cemented casing strings will have to be installed. The first will be the surface casing, used to mount BOPE equipment. The second or intermediate casing string will provide well integrity to the top of the geothermal aquifers below the Petrified Forest Member of the Chinle. Because of salinities in excess of 10,000 mg/l total dissolved solids (TDS) are likely to be encountered, high-temperature resin fiberglass production well casings and screens in both production and injection wells may be good options if fiberglass casings of adequate mechanical strength for deep well installation are available.

Maximum temperatures will probably not exceed 85 to 90 $^{o}$C and the best resource may be direct-use instead of electrical power generation. Production rates of 1,500 to 2,000 gpm are likely with a properly constructed well.

Direct-use applications may include geothermal heating for commercial greenhouses and aquaculture. Geothermal heat may also have important use as a source of heat for desalinization of saline water to provide potable water supply to the western Pueblo of Zia lands.

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# APPENDIX A  PUEBLO OF ZIA SITE 2 GEOTHERMAL WATER CHEMISTRY

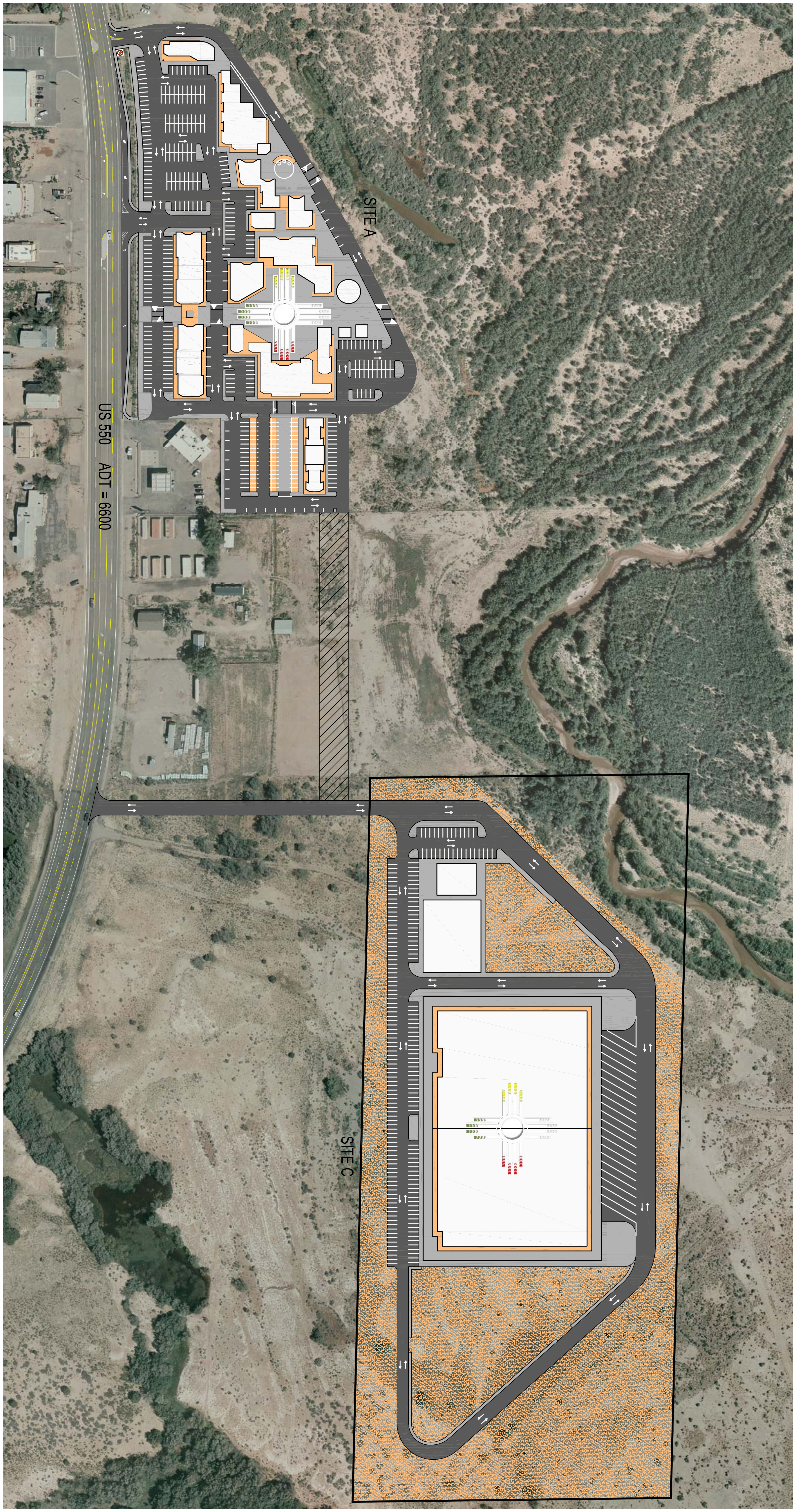
1) Chemical analyses of water from the Kaseman 2 well.

| SITE ID | SAMPLE | NAME | TMP C | pH field | pH lab | COND uS/cm | TDS mg/L | TDS (sum ) | Na mg/L | K mg/L | Ca mg/L | Mg mg/L | Li mg/L | Sr mg/L | HCO3 mg/L | SO4 mg/L | Cl mg/L | F mg/L | Br mg/L | B mg/L | SiO2 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SA20 | 247 | Kaseman #2 Well | 54.4 | 7.3 | | 15300 | | 11888 | 3600 | 88 | 350 | 56 | | | 1460 | 3300 | 3000 | 2.8 | 0 | 0 | 31 |
| SA20 | 252 | Kaseman #2 Well | 52.0 | 6.8 | | 15700 | | 11859 | 3500 | 88 | 350 | 61 | | | 1410 | 3300 | 3100 | 3.4 | 8.1 | 7.5 | 30 |
| SA20 | 88TDI1 | Kaseman #2 Well | 53.0 | 7.31 | 6.70 | | 10720 | 11339 | 3006 | 66.8 | 291.5 | 50.3 | 3.55 | 8 | 1667 | 3283 | 2920 | 2.97 | | 6.25 | 33.9 |
| SA20 | E | Kaseman #2 Well | 52.0 | | 6.87 | | 11300 | 12229 | 3720 | 92.7 | 417.8 | 73.4 | | | 1464 | 3343 | 3067 | 4.8 | | 6.96 | 37.9 |
| SA20 | VA-125 | Kaseman #2 Well | 53.0 | 6.98 | | 15700 | 11400 | 11351 | 3080 | 63.4 | 364 | 62.8 | 5.2 | 8.7 | 1398 | 3338 | 2984 | 2.47 | 3.4 | 7.8 | 33 |
| SA20 | VA-34 | Kaseman #2 Well | 56.0 | 6.29 | | 16600 | 12200 | 11343 | 2650 | 66.7 | 302 | 90 | 6.7 | 9 | 1440 | 3740 | 3000 | 2.4 | | 6.52 | 30 |
| SA20 | VA-53 | Kaseman #2 Well | 54.0 | 6.53 | | 16000 | 11700 | 11667 | 3440 | 77 | 321 | 61 | 6 | 4.8 | 1068 | 3430 | 3210 | 4.51 | 4.2 | 7.41 | 33 |
| SA20 | VA-67 | Kaseman #2 Well | 53.0 | 6.72 | | 15800 | 11300 | 11311 | 3180 | 64 | 320 | 71.5 | 6.3 | 9.6 | 1400 | 3280 | 2930 | 3.8 | 4.2 | 6.6 | 35 |
| SA20 | VA-74 | Kaseman #2 Well | 53.0 | 6.40 | | 15600 | 12800 | 12897 | 3700 | 54 | 354 | 21.8 | 5.52 | 6.9 | 1400 | 4100 | 3210 | 2.67 | 1.1 | 6.9 | 34 |

| SITE ID | SAMPLE | NAME | REFERENCE |
|---|---|---|---|
| SA20 | 247 | Kaseman #2 Well | USGS water quality file |
| SA20 | 252 | Kaseman #2 Well | USGS water quality file |
| SA20 | 88TDI1 | Kaseman #2 Well | Witcher (1988a) |
| SA20 | E | Kaseman #2 Well | Swanberg (1980) |
| SA20 | VA-125 | Kaseman #2 Well | Shevenell and others (1987) |
| SA20 | VA-34 | Kaseman #2 Well | Shevenell and others (1987) |
| SA20 | VA-53 | Kaseman #2 Well | Shevenell and others (1987) |
| SA20 | VA-67 | Kaseman #2 Well | Shevenell and others (1987) |
| SA20 | VA-74 | Kaseman #2 Well | Shevenell and others (1987) |

# Appendix N - Overall Site Plan Zia Enterprise Zone Master Plan

LAST MODIFIED: Apr 19, 2011 - 4:37pm BY USER: jalford
DWG. LOCATION: I:\ZIA Pueblo\Master Plan Update\Civil\Figures\
DWG. NAME: FIGURE 6-1 Overall Site Plan.dwg




MOLZENCORBIN

Pueblo of Zia, New Mexico

**Zia Enterprise Zone Masterplan**

**FIGURE 6-1 Overall Site Plan**

LAST MODIFIED: Apr 20, 2011 - 9:30am BY USER: jalford
DWG. LOCATION: I:\ZIA Pueblo\Master Plan Update\DWGS\
DWG. NAME: FIGURE 3-1 MASTERPLAN SITE A.dwg


| Group | Title | Square Footage |
|---|---|---|
| **Grocery/Learning Complex** | | |
| A1 | Diner | 3400 |
| A2 | Classroom | 600 |
| A3 | Grocery w/ Bakery | 9700 |
| A4 | Trading Post w/Art Studios | 8600 |
| A5 | Art Studios - High Bay | 2600 |
| A6 | Regional Visitors Center | 1600 |
| **Retail Complex** | | |
| B1 | Laundry | 2500 |
| B2 | Specialty Food | 1000 |
| B3 | Retail Store | 2300 |
| B4 | Personal Services | 1200 |
| B5 | Bank Branch | 1000 |
| B6 | Upper Offices - Personal Services | 3000 |
| B7 | Upper Offices - Personal Services | 3000 |
| B8 | Cell Phone | 1000 |
| B9 | Hardware | 2500 |
| B10 | Copy/Digital Services Shop | 2000 |
| B11 | Café | 1200 |
| B12 | Retail Space | 1100 |
| B13 | Professional Offices | 12500 |
| **Cultural Complex** | | |
| Z1 | Cultural/ConfCenter w/ Gift Shop | 4700 |
| Z2 | Gallery/Museum/Office | 14400 |
| Z3 | Replica Village | 1500 |
| Z4 | Studio Space | 2700 |
| Z5 | Zia Offices | 1500 |
| **Festival Complex** | | |
| Z6 | Pavilion | 5100 |
| | Farmer's Open Air Market Space | |
| | Total Square Footage | 90700 |

PLANNING AREAS - SITE A

| | |
|---|---|
| SITE A - COMMERCIAL/RETAIL AREA= | 9.35 AC |
| SITE B - LOW IMPACT AREA= | 36.63 AC |
| SITE C - MANUFACTURING/LIGHT INDUSTRIAL AREA= | 22.71 AC |
| WASTE WATER TREATMENT AREA= | 50 AC +/- |

LEGEND

SIDEWALK
ROADWAY
BUILDING PAD
SHADE STRUCTURE
SITE BOUNDARY
TRAFFIC CIRCULATION SIGNAGE
TREES & SHRUBS

0 10' 20' 50' 100'

NORTH

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Pueblo of Zia, New Mexico

**Zia Enterprise Zone Masterplan**
**Figure 3-1 Master Plan Site A**

# Appendix R - References


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