Evaluation of the Geothermal Potential in the Rio Grande Rift: Truth or Consequences, New Mexico

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ABSTRACT

In this article, we evaluate the geothermal potential of the city of Truth or Consequences. Truth or Consequences is located in Sierra County in the Palomas Basin and is famous for its hot mineral springs and baths which use geothermal waters with temperatures ranging from 104 to 110°F. The evaluation examined the existing literature and data and includes a discussion on the geology, tectonics, structure, geothermal resources, water resources and existing infrastructure of the site with respect to geothermal development. The geothermal resources at Truth or Consequences are relatively shallow and, based on a calculated geothermal gradient of 1.9 to 2.5°F/100ft, the 194°F isotherm would be expected to be encountered at depths between (5250 and 6890 ft). Hotter temperatures could be encountered at shallower depths if flow paths where hot water is flowing to the surface can be intercepted. Hillsboro Warm Springs is located approximately 30 miles southwest of Truth or Consequences and has estimated resource temperatures in the range of 250-300°F. Based on these temperatures a binary power plant is feasible at Hillsboro Warm Springs.

Cooling water is available from the Elephant Butte and Caballo reservoirs. The artesian wells in and around the region are primarily used for irrigation and domestic purposes. These wells can potentially be used as a source for cooling water. However, due to low flow rates, these wells may be unable to provide adequate amounts of water for both domestic and cooling purposes. Greenhouses, aquaculture, agriculture and district heating are other potential uses of the geothermal resources in the region.

Introduction

Truth or Consequences is located between Albuquerque and Las Cruces along U.S Interstate Highway 25 (Fig1). It is located along the Rio Grande in the south-central region of New Mexico in the Palomas Basin. Truth or Consequences is famous for its hot mineral springs and baths and draws a large number of tourists each year. The temperatures of the resources currently being utilized range from 104 to110°F and are obtained from shallow artesian wells (Witcher, 1995). These wells are a part of one of the first State Engineer declared ground water basins in New Mexico and have high priority water rights (Witcher, 1995). Around 200 acres of land in the area contains known geothermal reserves which are potentially available for development.

The Geronimo Springs Museum and the Carrie Tingley Veteran's Center use the geothermal resources for small scale space heating (Witcher, 1995). Resistance from the spa owners has hindered further geothermal development in the area. The Truth or Consequences Utility Department supplies electric power to the city and the electricity rates are low compared to other southern New Mexico communities. The local municipal utility also provides natural gas to the city.

The Hillsboro Warm Springs are located about (30 miles) southwest of the city of Truth or Consequences. Reservoir temperatures in the range of 250-300°F have been estimated at the

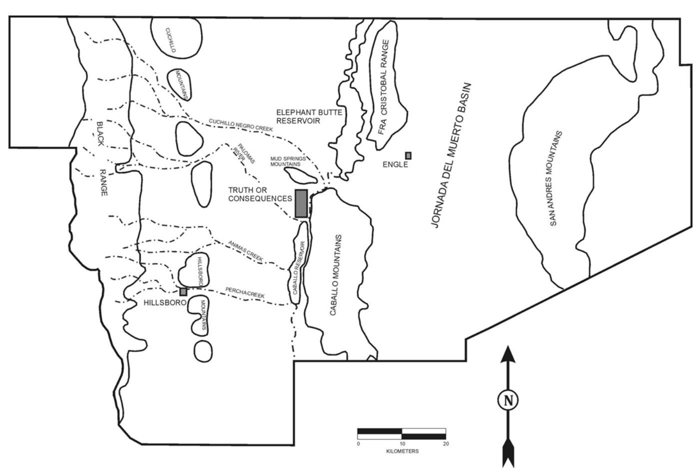

Figure 1. Map of Sierra County, New Mexico (modified from Cox and Reader, 1962).

springs (Fleischmann, 2006). In addition, the resource area has the advantage of being located near transmission lines.

Physiography

As mentioned above, Truth or Consequences is located in Sierra County in the Palomas Basin. The Palomas Basin, located in the southern portion of the Rio Grande Rift in New Mexico, is approximately 35 miles long and12 miles wide and has a general north-south orientation. It is at an elevation of 4,820 ft above mean sea level and is flanked by the Caballo Mountains on the east and the Black Range Mountains on the west.

Truth or Consequences has an arid and mild climate. The National Weather Service records indicate that the average annual precipitation is around nine inches, the average relative humidity is around 20% and that the average low temperature in January is 27°F and the average high temperature for July is 93°F with an annual average temperature of 61.7°F. Land in the area is primarily utilized for agricultural activities including farming and ranching (Witcher, 1995).

Geology

A nearly complete rock record in the Caballo Mountains was reported by Silver in 1955. He identified twenty-five formations that may be analogous to the formations within the basin itself. The formations identified include: Quaternary: gravel and other deposits (Palomas Gravel); Tertiary: Santa Fe, Thurman, Pal Park and McRae formations; Cretaceous: Mesaverde Group, Mancos Formation and Dakota Sandstone; Permian: Manzano Group consisting of the San Andres, Yeso and Abo Formations; Pennsylvanian: Magdalena Group, consisting of the Madera Limestone and Sandia Formation; Mississippian: Lake Valley Formation; Devonian: Percha Shale; Silurian: Fusselman Dolomite; Ordovician: Montoya Group (Cutter, Aleman, Upham Formations and Cable Canyon Sandstone) and El Paso Group (Bat Cave Formation and Sierrite Limestone); Cambrian: Bliss Formation; and Precambrian granites, gneisses and schists. A stratigraphic column and generalized cross-section are shown in Figures 2 and 3 below, respectively.

Hawley (1965) reported that the current surface of the Palomas Valley is dominated by flood plain deposits which frequently preserve underlying ancient flood plain terraces. He notes that the valley floor is home to many smaller arroyos which cut down as far as 250 ft below the basin surface, and that it has small creeks with drainage areas as large as 100 mi^2.

Figure 2. Generalized section of rocks in Truth or Consequences area (Murray, 1959).

ERA	System	Series	Formation		Commonly Reported Thickness (meters)	Character of Rocks
Cenozoic	Quaternary	Recent	Flows and sediments		No Data	Basalts, terrace gravels, and alluvium
		Pleistocene	Palomas Gravel		275	Poorly cemented conglomerate
	Tertiary	Pliocene and Miocene	Santa Fe Formation		610	Buff to reddish clays, sands, silts, and gravels
		Oligocene	Eruptives		305 - 1220	Andesite, latite, and rhyolite
		Oligocene (?) and Eocene	Galisteo (?) Sandstone		No Data	Red shale and sandstone
Mesozoic	Cretaceous	Upper Cretaceous	Mancos Shale and Mesaverde Formation		305	Gray shales and sandstone
			Dakota (?) Sandstone		30	Cross-bedded sandstone and shale
Paleozoic	Permian		Manzano Group	San Andres Formation	150 - 200	Gray limestone, etc.
				Yeso Formation	60 - 90	Shales and evaporites
				Abo Formation	60 - 245	Red sandstone and shale
	Permian (?) Carbon-iferous	Permian (?) and Pennsylvanian (upper and middle)	Magdalena Group	Madera Limestone	120 - 305	Gray limestone, etc.
				Sandia Formation	No Data	Limestone, conglomer-ate, and shale
		Mississippian (middle and lower)	Lake Valley Limestone		15 - 65	Gray limestone, etc.
	Devonian	Upper Devonian	Percha Shale		50 - 75	Dark gray and tan shale
	Silurian		Fusselman Limestone		15 - 60	Gray limestone, etc.
	Ordovician	Upper Ordovician	Montoya Group		15 - 120	Gray limestone, etc.
		Lower Ordovician	El Paso Group		45 - 120	Gray limestone, etc.
	Cambrian		Bliss Sandstone		15 - 30	Sandstone, quartzite (ferruginous)
Precambrian					No Data	Granite, gneiss, schist, etc.

Tectonics and Structure

The Palomas basin, bounded on the western and eastern sides by the Caballo and Animas fault blocks respectively, is part of a system divided by the Mud Spring uplift that separates it from the Engle basin to the north and is referred to by Kelley (1952) as the Rio Grande Depression. He also notes that the Palomas Basin ends to the north at Mud Springs, and is connected to the Engle Basin by means of the Cuchillo channel.

In 1955, Kelley discussed the region's tectonics beginning with the Caballo uplift describing it as a, north-northwesterly trending, eastward-tilted uplift that is approximately 28 miles long and as much as 10 miles wide. Along the western edge of the uplifted block is the Caballo fault system. Numerous small high angle faults occur within the fault block as well as Tertiary-aged overturned fold belts. Kelley (1952) also noted that the Animas uplift generally trends eastward, that it has several cross faults, and that the Mud Spring uplift trends 15-50 degrees northwest. The Engle basin to the north is a half graben having its deeper end to the east along the Hot Springs fault. The basin thickness in this area is estimated to be 2,300 ft or more (Lozinsky, 1987).

Geothermal

The geothermal resources currently being utilized in the vicinity of Truth or Consequences are shallow and low temperature. The temperatures of the geothermal resources observed to date are in the range of 100 to 115°F. The depth of existing geothermal wells range from less than 15 m to 76 m. Witcher (1995) also indicates that there may be a potential for intermediate temperature 194°Fresources at shallow depths for the Hillsboro Warm Springs area.

Reiter et al. (1986) presented the results of eighteen well tests performed in the southern Rio Grande Rift, including the Palomas Basin. He published that the heat flow values in this area are between 95-117 milliwatts per square meter (mW/m^2), and data suggest that a simple model of crustal thinning, with possible groundwater advection for the locations of higher heat flow, can be used to characterize the areas. Thermal conductivities for seven sites were included in this paper, and can be found in Table 1. It should be noted that the reported heat flow measurements are limited and may be inadequate to provide sufficient detail regarding heat flow in the area. However, assuming that the heat flow values are representative, and assuming an average thermal conductivity of 2.6 milliwatt per meter×Kelvin (mW/m-K), thermal gradients of approximately 1.9 to 2.5°F/100ft are calculated. These gradients result in the 194°F (90°C) isotherm being reached at depths on the order of approximately 5,360 to 6,890 ftand the 356°F (180°C) isotherm at depths of 11,920 to 15,325 ft.

Table 1. Thermal Conductivity measurements (Reiter et al., 1986).

Location	Interval (m)	Thermal Conductivity, W m^{-1} K^{-1}		Difference %
		Measured	Estimated	
Chapita Federal 15-2	762 - 2771	2.19 ± 1.29	2.76	-26
Clear Creek	2075 - 4083	2.57 ± 0.19	2.62	-2
	4083 - 4535	3.49 ± 0.35	3.09	11
Ah Des Pi Ah	1837 - 3580	2.22 ± 1.01	2.49	-12
Santa Fe No. 2	972 - 2565	2.44 ± 0.15	2.71	-11
Sierra K	612-2393	3.23 ± 1.29	3.1	4
Centauro	2496 - 3915	3.04 ± 0.60	2.78	9
	3915 - 4942	3.19 ± 0.45	2.99	6
	4942 - 5146	4.14 ± 0.32	4.68	-13
Sapallo	2047 - 4595	3.09 ± 1.28	2.97	4
	4595 - 5323	2.96 ± 0.86	3.11	-5

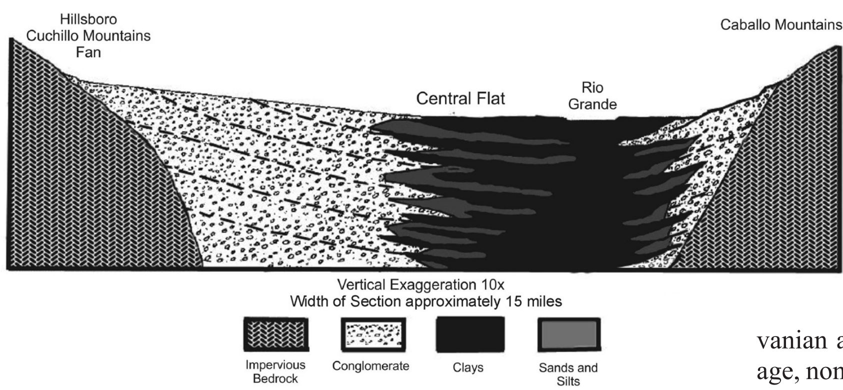

Figure 3. Cross section of Rio Grande south of Truth or Consequences (modified from Murray, 1959).

Water Resources

The Elephant Butte Dam is located four miles east of Truth or Consequences. The dam stores the spring runoff water of the Rio Grande resulting in formation of a large lake. The Elephant Butte Reservoir can store approximately 2 million acre-ft of water (Witcher, et al., 2004). The Caballo Dam is located twenty miles south of Truth or Consequences and forms a smaller reservoir with a capacity of 343,990 acre-ft capacity (Witcher, et al., 2004). Hydroelectric power is generated from the Caballo Dam. The total estimated flow from this system is 1,314 acre/ft per year. The water supplies for the city are obtained from the Hot Springs Water Basin. The city also supplies fresh water to surrounding geothermal development sites.

Groundwater is believed to occur in three general conditions in the Rio Grande Valley in the Palomas Basin and in the region of Truth or Consequences: thermal water in the Magdalena Group of Pennsylvanian and Permian age and overlying alluvium of Quaternary age, non- thermal artesian water in the Santa Fe Group of middle Miocene to Pleistocene age and unconfined water in alluvium of Quaternary age (Cox & Reeder, 1962).

An artesian development area extends from Mud Springs Draw, south of Truth or Consequences to Arrey, 18 miles farther south. The primary developments are in Mud Springs Draw, Animas Creek, and Percha Creek. However, there are a number of artesian wells along the Rio Grande Valley. The water occurs in sand, gravel, and silt of the poorly consolidated Tertiary and Quaternary deposits that fill the Rio Grande structural depression and dip eastwardly toward the Rio Grande (Murray, 1959). Although most of the wells in the area are used for combined domestic and irrigation purposes, the artesian wells in the Mud Springs Draw are primarily used for municipal water supply for the city of Truth or Consequences (Murray, 1959). Water enters the aquifers from west of the area of artesian development and flows through the aquifers towards the Rio Grande. Water is discharged indirectly to the river by upward percolation through imperfect confining beds to the overlying, shallow water aquifers. The well yields in the Mud Springs Draw area are on the order of a few hundred gallons per minute. However, other area wells yield as little as a few tenths of a gallon per minute (Murray, 1959).

Water quality in the region varies considerably from area to area and well to well. Sodium, calcium, chloride, and bicarbonate are the most common anions and cations in the water (Murray, 1959). The average values of dissolved solids and hardness are 550 and 200 parts per million (ppm) respectively, but can go as high as 850 and 350 ppm (Murray, 1959).

More water from the wells equipped with valves in the Mud Springs Draw is used during the summer for city and irrigation purposes (Murray, 1959). Recharge of the aquifers is believed to be from three main sources: direct rainfall penetration on the edges of the aquifers, infiltration into the outcropping edges of the aquifers from flash floods in the arroyos, and infiltration into the outcropping edges of the aquifers from the perennial streams that occupy the upper reaches of some of the arroyo-like valleys (Murray, 1959).

Murray (1959) estimated 11,000 gallons per day per foot as the maximum rate of transmission of water through the aquifers. He concluded that 600,000 gallons per day is transmitted by the part of the aquifer from which the wells in the Mud Springs Draw area are located.

Total dissolved solids for the geothermal resources around the region range from 2,300 to 2,500 ppm. The flow rates of geothermal fluids produced in the region range from ten to several hundred gallons per minute (Fischer et al., 1990).In addition, low resistivity areas and steep resistivity gradients have been observed (Jiracek and Mahoney, 1981) giving an indication of TDS concentrations at various locations.

Existing Infrastructure

The Truth or Consequences Utility Department supplies electric power to the city and the electricity rates are low compared to other southern New Mexico communities. The local municipal utility also provides natural gas to the city (Fischer et al., 1990). Elephant Butte Dam has a hydroelectric power plant (Witcher, et al., 2004). This is a base load power plant and has an installed capacity of 27,945 kW (U.S Department of the Interior, Bureau of Reclamation, 2009). Two transmission networks of 115 kV and 230-345 kV exist in the region that run through the City of Truth or Consequences. Truth or Consequences is located on the U.S Interstate Highway I-25. El Paso International Airport and Albuquerque International Airport are the major airports near Truth or Consequences. Figure 4 shows the available roads and transmission lines around Truth or Consequences.

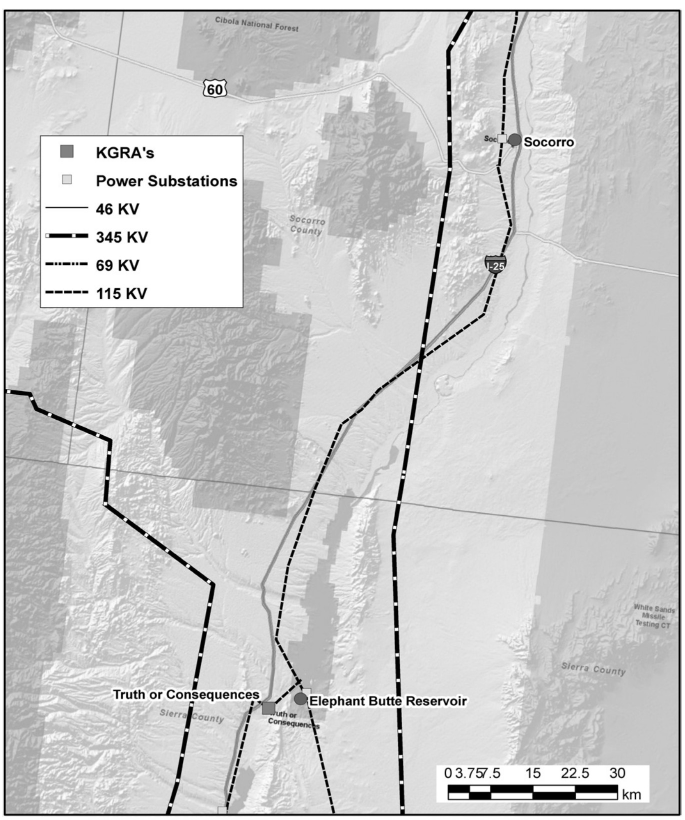

Figure 4. Infrastructure in the vicinity of Truth or Consequences.

Geothermal Binary Power Plant Assessment

Geothermal binary power plants using Organic Rankine Cycle (ORC) are commonly used to generate electricity from low temperature resources (Wang et al., 2012). The working principle of ORC is similar to Clausius Rankine cycle but uses an organic working fluid instead of water. ORC installations can be found worldwide and is a very popular choice to generate electricity from low temperature geothermal resources. A conceptual study is presented here to evaluate the amount of power that can be generated using the available resources at Truth or Consequences. As previously mentioned in this article, temperatures in the range of 250 - 300°F have been observed at Hillsboro Warm Springs. For the proposed evaluation, geothermal brine having a temperature of 250°F was chosen. It is assumed that ORC will be a subcritical cycle and therefore, a working fluid having a critical temperature higher than the resource temperature was chosen. Refrigerant R245fa (1, 1,1,3,3 – pentafluoropropane) has critical temperature and pressure of 310°F and 528 psia respectively and was chosen as the working fluid. Aspen HYSYS® process simulator was used to simulate and predict the performance of the ORC.A modular ORC system with a gross power output of 125kW was assumed for this study. All the heat transfer processes are assumed to be isobaric. The ORC is assumed to be operating in the subcritical region and therefore, the maximum pressure in the system is chosen below the critical pressure of the working fluid. All heat transfer processes are assumed to be isobaric. The cycle was optimized using optimizer tool from Aspen HYSYS®.

In Figure 5 we present a schematic diagram of a binary power plant using ORC geothermal brine from the production well is circulated through the evaporator where it transfers heat to the working fluid. The geothermal brine exiting out of the evaporator is reinjected back into the ground using injection pumps. The working fluid is evaporated in the evaporator by the heat extracted from the geothermal brine. The working fluid vapors at high temperature and pressure are expanded over the turbine. The turbine is coupled to a generator to generate electricity. These expanded vapors from the exit stream of the turbine are completely condensed in the condenser before they are fed to the pump. The working fluid pump increases the pressure of the working fluid and circulates it back to the evaporator. The geothermal brine and working fluid stay in two separate loops and there is no physical contact between them.

In Table 2 we list the design condition assumed for the modeling of the ORC system. Modeling of the ORC system revealed that an approximate flow rate of 128 gpm is required at 250°F to operate the system at full capacity of 125 kW. The flow rate of geothermal fluid was based on assumption of 50 °F temperature drop across the evaporator. The ORC model was optimized to maximize the thermal efficiency by varying pump output pressure and mass flow rate of working fluid. The number of ORC modules that could be installed will be determined based on the available geothermal flow rate. A graph of power produced against the required geothermal resource flow rate was generated and is shown in Figure 6. It can be observed that the ORC power increases with an increase in the geothermal flow rate and temperature. Multiple ORC units can be installed depending on the geothermal resource availability.

The output power of the ORC is governed by the temperature and flow-rate of geothermal resource and cooling media. The option of air cooling is considered here due to limited availability of cooling water. The temperature varies over the year and it affects the amount power produced by the ORC. In Figure 7 we show the temperature entropy diagram of R245fa displaying the operation conditions of the ORC.

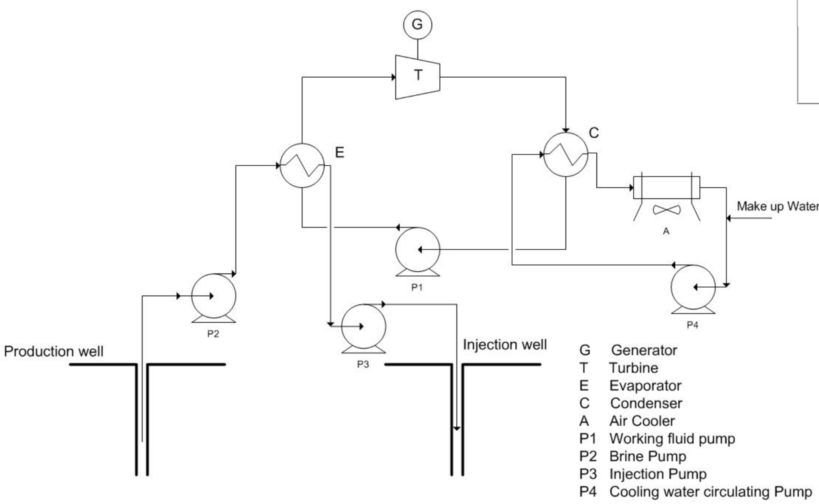

Figure 5. Schematic of a binary geothermal power plant using organic Rankine cycle.

Table 2. Design conditions for the ORC system.

Geothermal fluid temperature	250°F
Geothermal fluid flow rate	128gpm
Cooling media temperature	62 °F
Working fluid	R245fa
Working fluid flow rate	8.34lbm /sec
Gross power	125kW
Thermal efficiency	12%

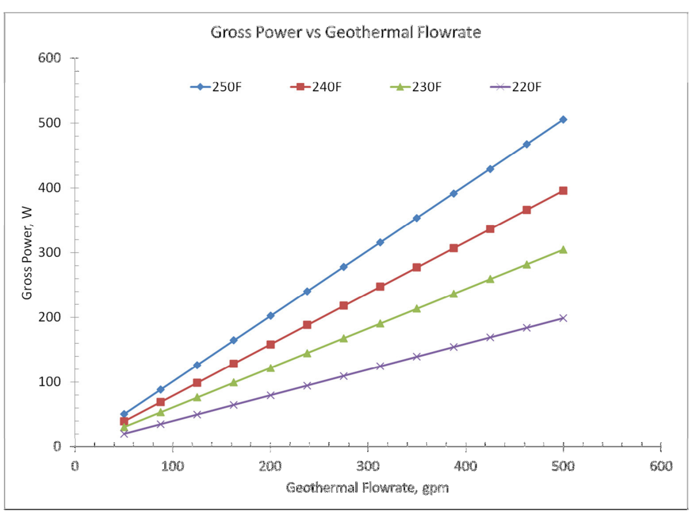

Figure 6. Variation of gross power from ORC plant as a function of geothermal flowrate.

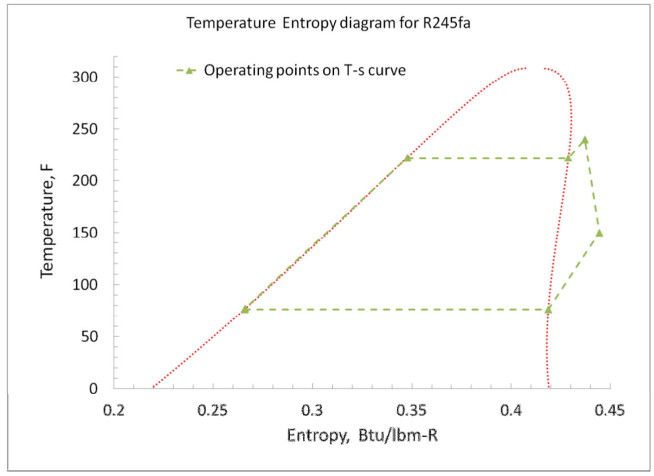

Figure 7. Temperature Entropy Diagram for R-245fa for the ORC binary power plant.

Economic Modeling of ORC

Economics of the ORC system was evaluated by varying the capital cost of plant and selling price of electricity. In Table 3, we list some of the criteria assumed for the economic modeling of the binary power plant. The cost price of the equipment was chosen based on some of the estimates obtained from ORC vendors and are subject to vary. Therefore, an approximate cost of the equipment was assumed for the economic analysis. The sale price of electricity was based on the price rates from the region. The city of Truth or Consequences utilities department reports the electricity price of \$.1043 per kWh.

Table 3. Criteria used for economic modeling of the ORC.

Criteria	Value	Explanation
Operating hours	8400 hrs per year	350 ´ 24
Annual revenue	\$105,000	\$0.1/kW ´ 125kWh ´ 8400
Equipment cost	\$375,000	\$3000 ´ 125 kW
Project life	20 years	
Recovery period	5 years	Alternative energy property
Depreciation method	MACRS 200%	3, 5, 7,10 year recovery period *
Supplies	2% of the total project cost	Assumed
Federal income tax	34% of yearly revenue	Average income tax for income from \$100,000 to \$335,000 [1]
Utilities	2.5% of total project cost	Assumed

Cash flow for the binary power plant was studied. In Figure 8, we show the effect of that variations in the selling price of electricity has on the plant economics. The point where the curve intersects the x axis is the payback time for each case. It is observed that increasing the selling price decreases the payback time. In Figure 9, we show that increasing the capital cost of the plant increases the payback time.

Assessment and Conclusions

As mentioned in the introduction, hydrothermal waters at Truth or Consequences are already used for small scale space heating and spas. While larger scale district heating and direct use may be feasible, it is anticipated that such proposals would meet strong resistance from existing spa owners.

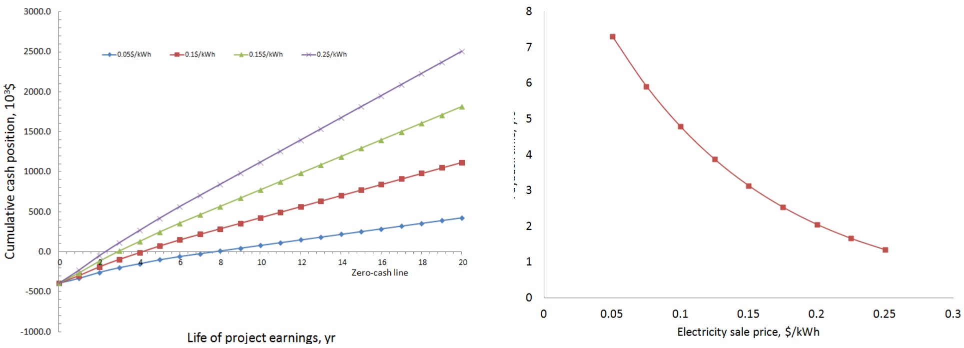

Figure 8. Cumulative Cash flow as a function of selling price.

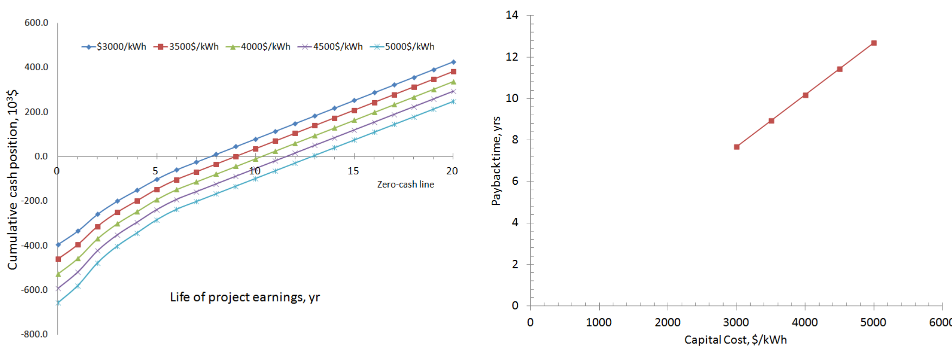

Figure 9. Cumulative Cash flow as a function of capital cost.

Based on the estimated geothermal gradients presented above, the 194°F (90°C) isotherm would be expected to be encountered at depths of between 5,360 and 6,890 ft, and the 356°F (180°C) isotherm would be at depths from approximately 11,920 to 15,325 ft. Hotter temperatures could be encountered at shallower depths if flow paths of hot water flowing to the surface can be intercepted by production wells. Based on the estimated resource temperature at Hillsboro Warm Springs and as shown by the ORC model and economic evaluation, it is feasible that a binary power plant can be installed.

Cooling water is available from the Elephant Butte and Caballo reservoirs. The artesian wells in and around the region are primarily used for irrigation and domestic purposes. These wells could possibly be used as a source for cooling water, however due to low flow rates, these wells may be unable to provide adequate amounts of water for both domestic and cooling purposes. Other cooling options including air cooling or a combination of air cooling and water cooling can be explored. Greenhouses, district heating, agriculture and aquaculture could be other potential uses of geothermal resources in the region. Mineral extraction from the geothermal fluids may also be possible due to the occurrence of porphyry copper deposit at Copper Flat 2 miles east of the Hillsboro Warm Springs (Witcher, 1995).

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