MILLENNIUM ENERGY LLC

FINAL REPORT
Manley, Alaska
Geothermal Project Scoping Assessment

Prepared for:
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
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Prepared by:
Millennium Energy LLC
PO Box 16073
Golden, CO 80403
(303) 526-2972
www.millennium-energy.net

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We have made honest efforts to secure accurate and up to date information. To the extent errors remain in the report, it is our responsibility. Please do not hesitate to contact us should you identify mistakes in this report.

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1 Introduction

Manley Hot Springs, Alaska is located about 90 miles northwest of Fairbanks, and is home to about 125 year-round residents. This remote area has a known geothermal resource, and a history of small projects that have utilized this hot water for direct use applications (i.e., space heating, greenhouse heating, and bathing). Recently, with the success of Chena Hot Springs in developing a similar geothermal resource for small scale power production, and with prevailing energy rates in the area of about 68 cents per kiloWatt-hour (kWh), the Alaska Energy Authority (AEA) applied for technical assistance from the US Department of Energy's GeoPowering the West (GPW) Initiative and the National Renewable Energy Laboratory (NREL) via its Task Ordering Agreement (TOA) mechanism to conduct a feasibility study of geothermal project opportunities for Manley.

AEA was successful in its application, and Millennium Energy LLC, a Colorado-based renewable energy consulting firm, was awarded a contract to work with AEA and Manley residents to review and assess both direct use and power production opportunities. Under the TOA agreement (#KLDJ-5-55050-05) with NREL, Millennium Energy was tasked to investigate the potential of geothermal development at Manley Hot Springs, including the following applications: district heating, greenhouse heating, lodge or resort development, swimming pool development, community cold storage, and/or power production. The first step in this investigation was to conduct a scoping study, or Phase I assessment, with Manley representatives to determine if a) all of the aforementioned applications should be looked at in a cursory, qualitative manner, or b) conducting a detailed technical and economic feasibility study on one application would be the best course of action. Specifically, Millennium was tasked to perform the following actions:

1. Contact the appropriate state and local authorities for background information on this project and site, starting with Alaska Energy Authority;
2. Summarize the resource information;
3. Conduct a site visit and project scoping meeting with local residents; and
4. Develop a brief scoping report delineating a statement of work developed by consensus among AEA, Manley, Sandia National Laboratory, NREL, and Millennium. The consensus-based statement of work would then form the basis for follow-on activities to be provided by Millennium under Phase II of the project.

This report summarizes the task actions completed under this Phase I assessment. Specifically, Section 2 details the geothermal resource characterization for the Manley Hot Springs area; Section 3 summarizes the site visit and community project scoping meeting conducted on August 23, 2006; and Section 4 provides conclusions and recommendations resulting from this Phase I study, including the recommended scope of work for Phase II activities under the NREL TOA agreement.

2 Background and Geothermal Resource Characterization

A trading post was established at Manley Hot Springs in 1881. The trading economy transitioned into support of mining and the site became the center of the Manley Hot Springs mining district around the beginning of the 20th Century with the discovery of gold in the area in 1898 (Mertie, 1937). In 1906, geothermal direct-use began with the heating of a 60-room hotel and spa. In addition, geothermal heating was applied to a dairy, hog and poultry farm. A decline in mining activity and the burning of the hotel and spa resulted in the end of early geothermal direct-use except for continued greenhouse heating and some small-scale space heating, which continues to this day.

The purpose of this study is to review the literature and past studies on Manley Hot Springs and provide an up to date synthesis of the geology and geothermal potential of the hot springs. It is anticipated that geothermal direct-use could be of substantial benefit to the current Manley Hot Springs community and the surrounding area. Also, a preliminary analysis of the geothermal reservoir potential for small-scale, binary cycle electrical power is presented along with recommendations and approaches to complete a detailed assessment of the geothermal resource.

2.1 LOCATION

Manley Hot Springs is located 90 miles west northwest of Fairbanks and 50 miles east southeast of the village of Tanana on the Yukon River (**Figure 1**). The Elliot Highway, Alaska Highway 2, connects Manley Hot Springs with Fairbanks. It is a partially paved two-lane road that is often closed for long periods of time in the winter.

The area lies within a region of discontinuous permafrost. Permanent snow elevation in the region is about 5,000 ft (Anderson, 1970). The climate at Manley Hot Springs is similar to Fairbanks. In Fairbanks, the annual precipitation is 10.34 inches. Fairbanks has 13,980 degree heating days with an 18° C reference temperature (NOAA).

The area overlies the boundary of the western Yukon-Tanana Upland and northern Tanana-Kuskowin Lowland physiographic provinces of Alaska (Wahrhaftig, 1994). Quadrangle maps Tanana A-2 and Kantishna River D-2 cover the area. Manley Hot Springs is located at the southern margin of the Tanana A-2 quadrangle map. The Manley Hot Springs lie at the base of the Manley Hot Springs Dome, a local high elevation area on Bean Ridge, adjacent to the Tanana River Valley and the Hot Springs Slough (**Figure 2**). The Manley Hot Springs Dome has a maximum elevation of about 2,485 ft and the Tanana River Valley adjacent to Manley Hot Springs has an elevation of about 275 ft.

Figure 1. Location map of the Manley Hot Springs, Alaska area (modified from The National Geographic Society).

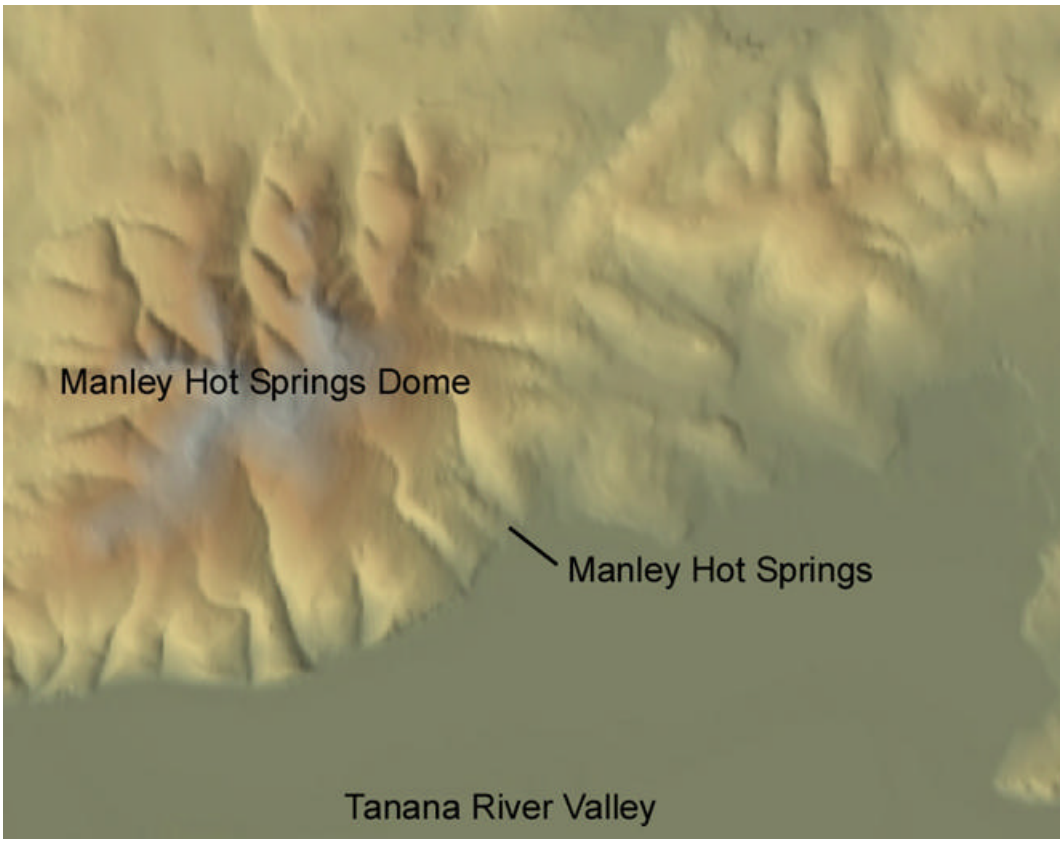

Figure 2. Local digital elevation model of Manley Hot Springs (National Elevation Dataset from US Geological Survey).

2.2 PREVIOUS STUDIES OF MANLEY HOT SPRINGS REGION

Several reconnaissance studies have been conducted on Manley Hot Springs (formerly called Baker Hot Springs and Karshner Hot Springs). A bibliography of past studies is included as Appendix A to this report. The earliest studies are those of Waring (1917). In the 1970's and 1980's several studies covered Manley Hot Springs (ADGGS, 1983; East, 1982; Forbes and others, 1974; Gassaway and Abramson, 1977; Miller, 1973; Miller and others, 1973 and 1975). Statewide summaries of Alaska geothermal resources are found in ADGGS, 1983 and Miller, 1994. A bibliography of Alaska geothermal resources is found in Liss and others (1987). East (1982) provides the only synthesis specific to Manley Hot Springs. The East (1982) study discusses additional hot spring water chemistry, a shallow temperature survey, soil mercury and helium surveys, and shallow EM (electromagnetic) geophysical surveys.

Geologic maps for the area are found in Chapman and others (1975 and 1982), Chapman and Yeend (1981), Patton and others (1989), Pinney (1998), Reifenstuhl and others (1998), and Wilson and others (1998). Regional analysis of geology includes Dover (1994), Dusel-Bacon (1994), Mertie (1937), Nokelberg and others (1994), Pewe (1975), Plafker and Berg (1994), and Silberling and others (1994).

Regional geophysical (aeromagnetic) surveys with pertinence to Manley Hot Springs include (Burns, 1996 and 1997) and Meyer and Saltus (1995). Neotectonic analyses of the region include Gedney and others (1972), and Plafker and others (1994).

Topical studies that are mainly concentrated on the mineral resources of the area that may have useful information on Manley Hot Springs include Maloney (1971), McDal and others (1988), Mertie (1932), Moxman (1964), Southworth (1982), Szumigala and others (2004), Wayland (1961), and Yeend (1990).

GEOLOGY

Central Alaska represents a complex collage of terranes or microplates added to the North American continent as a result of Paleozoic through Tertiary interactions and collisions of the North American tectonic plate (mostly continental crust) with various outboard oceanic plates (such as the current collision and subduction of the Pacific Plate) on the west, south, and southwest of Alaska (Dover, 1974; Dusel-Bakon, 1994; Nokleberg and others, 1994; and Plafker and Berg, 1994). Some of the outboard dominantly oceanic crust plates transported continental crust fragments into tectonic plate collision and accretion. In other cases, ripped off continental crust and island arcs of the North American plate from other locations were pasted to the North American continent in Alaska. In other areas, upper parts of the oceanic crust were tectonically shaved at the plate boundary and later pasted (accreted) to the continent in Alaska. Each of the terranes is defined by packages of rocks that internally record their unique internal depositional, structural, and tectonic history (Dover, 1974; Dusel-Bacon, 1994; Nokleberg and others, 1994 Patton and others, 1989; Reifenstuhl and others, 1998; Silbering and others, 1994; and Wilson and others, 1998). These packages of rocks are bound together and/or merged by complexes of high angle strike slip and reverse faults along with relatively flat and imbricate overriding thrust faults.

A package of variously deformed, but largely unmetamorphosed clastic rocks (flysch deposits) underlies the Manley Hot Springs region. The flysch sediments were deposited in a Cretaceous and Jurassic submarine fan basin and comprise the Manley or Beaver Creek terrane of rocks and structures (Silbering and others, 1994; and Dover, 1994). Older metamorphosed terranes of Paleozoic to Mesozoic age are found to the north and are sliced by south-vergent and imbricated thrust faults (Dusel-Bacon, 1994; Nokleberg and others, 1994; Patton and others, 1989; Reifenstuhl and others, 1998; Silbering and others, 1994; and Wilson and others, 1998). To the south, a metamorphic terrane of Precambrian to Mesozoic age protoliths is transported on north-vergent thrust faults (**Figure 3**). All of the terranes are cut by high angle faults, many with major strike slip components. The Kaltag and Stevens Creek faults and associated splays are among the more important, if not larger, high angle faults in the area.

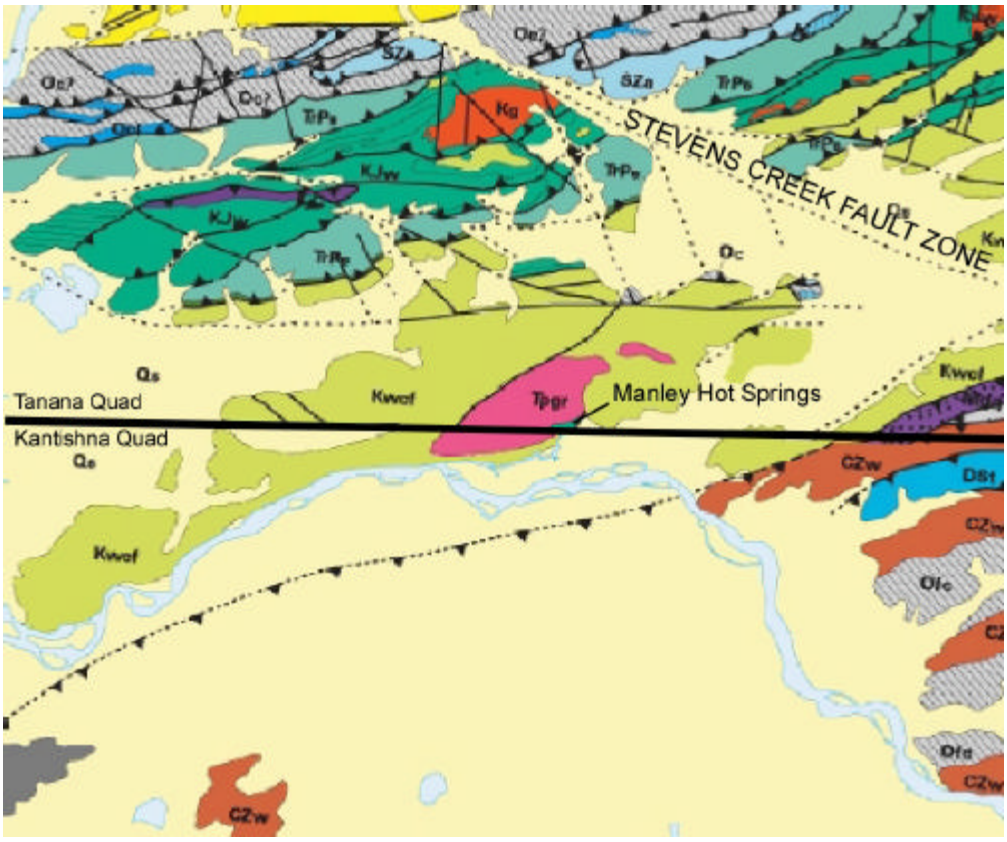

Figure 3. Geologic map of Manley Hot Springs region. Yellow represents Quaternary deposits; green shades are Mesozoic rocks of the Manley terrane; brown and blue shades are Precambrian and Paleozoic rocks. Red is granite of Hot Springs Dome pluton. Lines and dotted lines with barbs are thrust faults; barbs point to the allochthon or hanging wall. Other solid and dotted lines are high angle and strike slip faults (geology from Wilson and others, 1998).

At Manley Hot Springs the Manley terrane consists of the Lower Cretaceous (Albian) Wilber Creek unit (not a formal formation name) (Figure 4). The Wilber Creek unit consists of thin-bedded, and frequently graded deposits of dark, poorly sorted, argillaceous, lithic sandstone, siltstone and shale. Locally, the unit may also contain gray, dense, lithic quartzite (Reifenstuhl and others, 1998). The Wilber Creek unit is intruded by the Hot Springs pluton (58 million years old) (Reifenstuhl and others 1997). The Hot Springs pluton consists of medium- to coarse-grained biotite granite. The Wilber Creek unit shows hornfels contact metamorphism adjacent to the Hot Springs pluton. The north side of the pluton is in high angle fault contact with the Wilber Creek unit while contact relationships for the southern side of the intrusion are poorly known. While hornfels metamorphism gives information on the approximate location of the contact, the nature of the contact shape is unknown (i.e., is the contact at high angle or low angle, etc?). Reifenstuhl and others (1998) point out that the pluton has “extremely low magnetic susceptibility.” This could be important to understand the southern shape of the pluton if the magnetic susceptibility of the Wilber Creek units or the hornfels areole is substantially higher than the Hot Springs pluton.

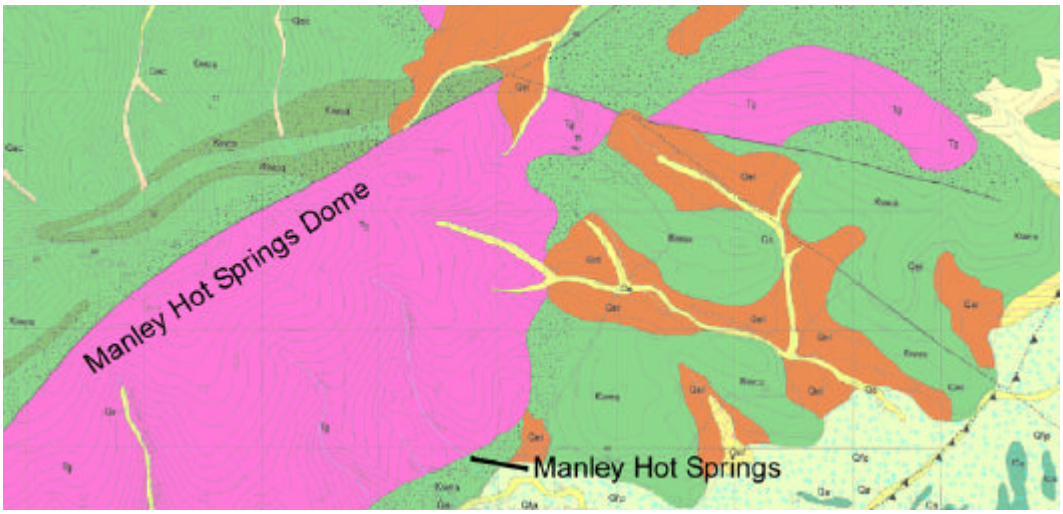

Figure 4. Local geologic map of Manley Hot Springs and Hot Springs Dome. Green is the Lower Cretaceous Wilbur Creek unit (stippled areas are hornfels); purple is Paleocene Hot Spring Dome pluton (biotite granite), brown is Quaternary loess, others units are Quaternary swamp and river deposits (geology from Reifenstuhl and others, 1998). Faults have same symbols as Figure 3.

Bedrock is generally mantled by thin deposits of locally-derived colluvium. In scattered areas, especially in topographic drainage, Pleistocene deposits of loess are observed mostly filling in the depressions (Reifenstuhl and others, 1998). The Tanana Valley floor is underlain by fluvial gravel and sand channel deposits and associated finer-grained overbank deposits (Reifenstuhl and others, 1998). Local organic-rich swamp deposits rest within and on top of the river deposits at scattered locations.

HYDROGEOLOGY

A hot spring system requires a deep circulation path after surface recharge in order to sweep up heat in the subsurface and concentrate that heat at or near the surface. Recharge can occur many miles distance and over a very large area. The overall flow path may only allow seepage at low rates through a large volume of rock. However, at the upflow or discharge end of the flow path, the flow must be of sufficient volume and rate to transport the heat upward without loosing most of the heat by conduction to the surrounding country rock. In other words, the process of convection or advective heat transfer must overwhelm the process of conductive heat transfer in the upflow portion of a hot spring system. Good vertical fracture permeability is required. Also, the vertical fracture system must have sufficient open fracture surface area at great depth to collect or divert incoming seepage from low permeability rock.

At Manley Hot Springs, the large volume low permeability country rock may consist of the Wilber Creek unit. Fault zones could provide the vertical permeability "window" for hot water discharge. However, the location of the hot springs on or adjacent to the Hot Springs pluton and its hornsfel alteration areole suggests that fracture permeability in either the contact zone or the pluton provides the "upflow discharge window." Regionally, there exist sufficient elevation differences to force ground water seepage to great depth. The location of the springs adjacent the Tanana Valley floor also points to an advective-type geothermal system with an upflow in fractured granite or hornfels.

The association of Manley Hot Springs with a granitic pluton is a common hydrogeologic setting with practically all of the hot spring systems in central Alaska (Miller and others, 1975 and Miller, 1994).

REGIONAL HEAT FLOW

There is a substantial lack of heat flow measurements in the interior of Alaska. In fact, there are no measurements within a radius of several 100 km of Manley Hot Springs (Sass and others, 1981; Blackwell others, 1991; and Blackwell and Steele, 1992; and Blackwell and others, 2004). However, all of the above compilations and maps indicate a probable heat flow between 80 and 90 mW/m^2 in the region around Manley Hot Springs. Certainly, this estimate has potential for error. However, heat flow can be roughly characterized for "thermal" provinces using some of the criteria discussed by Morgan and Sass (1984) and Morgan and Gosnold (1989). Age since last magmatism, crustal heat production, crustal thickness, and tectonic style and magnitude of activity can all play roles. On local scales, regional and local ground water flow may complicate regional assumptions.

Thermal conductivity of graywacke (flysch sediments) ranges from about 2.70 to 3.35 W/m^{o}K (Blackwell and Steele (1989). Therefore, conductive temperature gradients in the Manley (Beaver Creek) tectonostragraphic terrane are likely to range between 25 and 35 ^{o}C/km with the estimated regional heat flow of 80 to 90 mW/m^2.

NEOTECTONICS

While regional heat flow and local vertical permeability are important in determining geothermal potential, neotectonics can play a very important role. Certainly, Pleistocene magmatism, especially that associated with large volumes of dacitic and rhyolitic eruptions, can be of major significance (Smith and Shaw, 1978 and Wohletz and Heiken, 1992). Unfortunately, no Neogene (less than 10 million years old) rhyolitic or basaltic volcanism is known to occur within 50 km or more of the Manley Hot Springs area (Plafker and others, 1994).

Sustaining fracture permeability and fractured reservoir volumes can be very important for geothermal resources. Because of elevated temperatures and long flow paths, geothermal fluids become mineralized and fractures in the outflow paths can seal with minerals such as quartz when the fluids cool. Seismicity and active faulting can be very important to periodically break and reopen healed fractures or create new fractures. Seismicity may also contribute to forcing very deep-seated hot fluids toward shallow depth (Sibson, 1990).

Gedney and others (1972) and Plafker and others (1994) show that several structures in the Manley Hot Springs region are suspected of having movement in the last million years. These include the Kaltag, Stevens Creek, and Minook Creek fault zones. Historic earthquake epicenters (>2.0 in magnitude) mapped in the region by Gedney and others (1972) from 1968 to 1971 show at least 3 epicenters within a couple of miles of Manley Hot Springs. On the other hand, Page and others (1991) do not show any epicenters (>1.0 in magnitude) in the immediate Manley Hot Springs vicinity from 1982 to 1985. One speculative hypothesis to explain the near universal occurrence of hot springs adjacent granitic plutons in central Alaska is that the plutons focus or enhance regional stress to allow local periodic brittle strain release (fracturing and small (<1 or 2 in magnitude) earthquake swarms) and open favorable pathways for geothermal circulation.

HOT SPRING CHEMISTRY AND GEOTHERMOMETRY

Water chemistry for thermal waters at Manley Hot Springs is compiled in Tables 1a and 1b from Waring (1917), Miller and others (1975), East (1982) and the online US Geological Survey NWIS database (http://nwis.waterdata.usgs.gov/nwis). Included in the compilation are cold water samples from East (1982).

Table 1a. Table of Manley Hot Springs water chemistry supplemental information.
Red indicates TDS estimated from specific conductance.

#	Site	Date	Temp	pH	Cond	TDS	Flow	Reference
	Manley HS		°C		uS/cm	mg/L	gpm	
1	650018150375401	10/1/1954		6.5	684	391		USGS NWIS
2	650018150375401	1/14/1970		7.8	623	389		USGS NWIS
3	650018150375401	5/30/1972	57					USGS NWIS
4	650018150375401	7/9/1976	47.5	7.6	540	372	203	USGS NWIS
5			59	7.7				Miller and others (1975)
6			56	7.7				Miller and others (1975)
7	650018150375401	8/5/1915	52				110	Waring (1917)
8	A-1		59.5	8.2	850	527		East (1982
9	A-2		58.7	8.4	810	502		East (1982
10	B-1		32	7.1	650	403		East (1982
11	C-5		33.1	7.7	615	381		East (1982
12	D-1		25.4	6.6	520	322		East (1982
13	HW-1		29.1		540	334		East (1982
14	CS-1		1.5	6.4	32	20		East (1982
15	CW-4		15					East (1982

Table 1b. Table of Manley Hot Springs water chemistry.
Red indicates TDS is estimated from specific conductance.

#	Temp	pH	EC	TDS	Na	K	Ca	Mg	HCO_3	SO_4	Cl	F	SiO_2	B	Li
	°C		uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L
1		6.5	684	391	117	6.8	9.1	0	83	41	124		52		
2		7.8	623	389	120	5.3	8.2	0.4	82	38	116	6.3	54		
3	57									45	133				
4	47.5	7.6	540	372	110	4	9.3	0.4	92	36	110		56	960	230
5	59	7.7			130	4.5	4	1	89.6	54	134	8.5	65	130	280
6	56	7.7			130	4.8	6.8	0.29	90.7	51	132	8.2	65	120	280
7	52				121	8.2	9.1	0.9	86	48	120		59		
8	59.5	8.2	850	527	145	4.6	8.2	0.11	90		153	8.3	65		290
9	58.7	8.4	810	502	148	4.7	7.6	0.06	93		192	8.6	65		300
10	32	7.1	650	403	123	3.57	8.4	0.74	81		182	7.2	59		210
11	33.1	7.7	615	381	111	2.98	11.2	1.11	99		134	6.5	47		170
12	25.4	6.6	520	322	101	2.95	12.2	1.34	68		147	4.4	50		0.2
13	29.1		540	334	109	3.11	2.2	0.16	40		192	5.9	3		0.2
14	1.5	6.4	32	20	2.9	0.24	3	0.5	10		<37	0.1	20		
15	15				12.6							1			

The waters have low total dissolved solids (TDS), ranging from 322 to 527 mg/L. The range in TDS suggests that mixing with shallow ground water is occurring. Figure 5 shows a plot of Na versus Cl. A general upward to the right trend confirms that mixing is occurring. However, there is a lot of scatter in the data, indicating that the mixing is apparently more complicated than simple mixing of two end members. Figure 6 shows the relationship between the mole concentration ratios of Na and Cl versus SiO2 in mg/L. Clearly, two types of thermal water may be juxtaposed at shallow depth. One group (A) of thermal waters show mole concentration Na/Cl ratios between 0.61 and 0.67 and the other group (B) of thermal waters show Na/Cl ratios between 0.44 and 0.54. The lower ratios are generally associated with the cooler sampled thermal waters. Halite (rock salt) has a ratio of 0.6485. The lower ratio waters have more chloride than is required for salt balance with halite. This may indicate that geochemical processes other than mixing may also be occurring. Anthropogenic sources are possible considering that a hog and poultry farm once existed in the area. Analytical error is also possible because Cl seems to be the only anomalous ion. Since there is no sulfate analysis reported for the East (1982) data it is not possible to check the analysis for charge balance or check TDS against specific conductance for mass balance error.

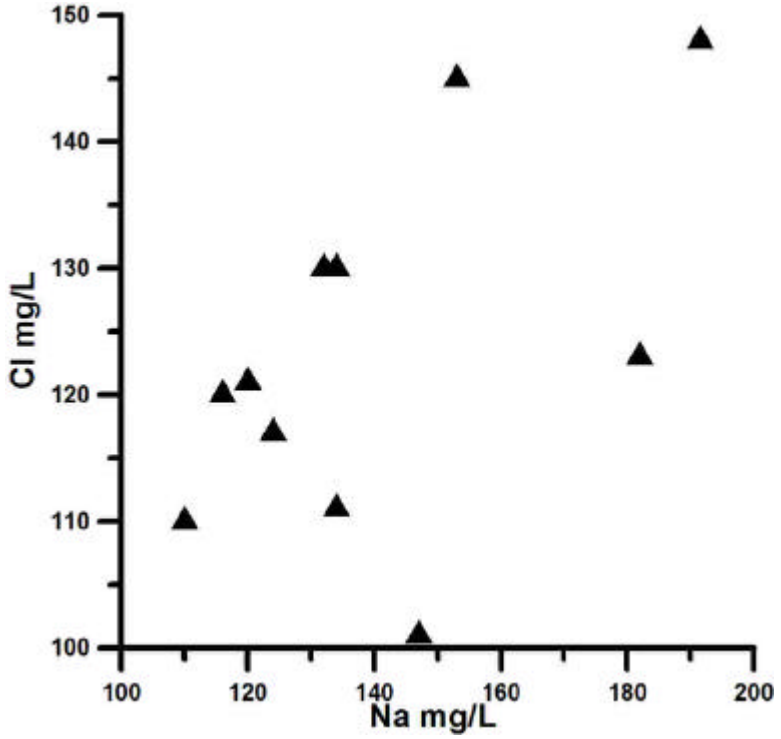

Figure 5. Chloride (Cl) versus sodium (Na) for Manley Hot Springs waters.

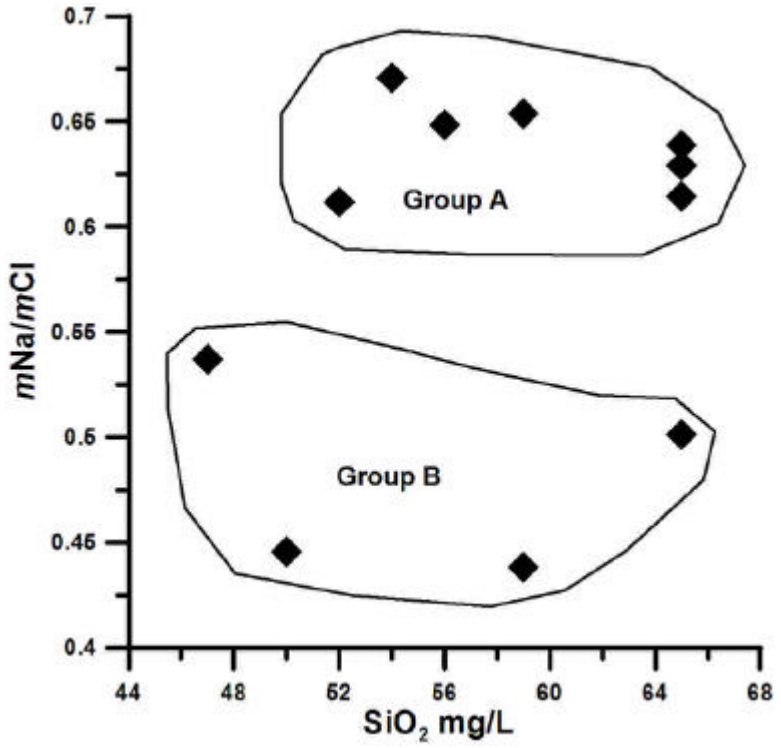

Figure 6. Mole concentration ratios of sodium and chloride versus silica (SiO_2).

Figure 7 shows a plot of Cl versus SiO2 delineating two apparent mixing trends. Geothermometry analysis will use only the upper end member waters in the mixing trend derived from samples with the higher Na/Cl ratio (Group A). For the purposes of this analysis the mixing is assumed to occur at very shallow depth (<200 ft) and that the upper end member chemistry reflects largely unmixed geothermal fluids. The lower Na/Cl ratio water will not be evaluated for geothermometry as there is some uncertainty as to the reliability or origin of this water. However, it is possible that this water could represent a geothermal flow with a different flow path or mixing history than the waters with the higher Na/Cl ratio.

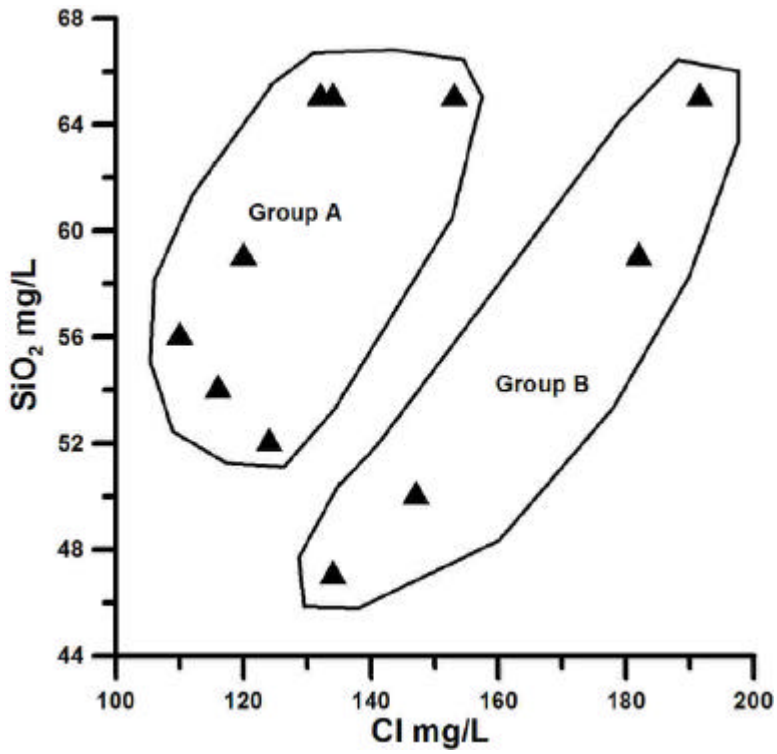

Figure 7. Silica versus chloride.

Chemical geothermometers comprise two basic types, silica and cation ratio geothermometers. Silica geothermometers (especially chalcedony) are perhaps the most reliable in lower temperature geothermal systems. With higher temperatures and reservoir rocks comprised of intermediate to silicic volcanic and plutonic rocks, the cation geothermometers tend to give reliable subsurface temperature estimates. Cation geothermometers which use ion ratios in the calculations may show only small affects if shallow mixing with non-thermal water occurs. On the other hand, mixing can modify silica geothermometers. Table 2 lists geothermometer estimates for Manley Hot Springs.

Table 2. Geothermometer estimates for subsurface reservoirs at Manley Hot Springs.

SAMPLE # (Table 1a,1b)	5	6	
GEOTEMPERATURE	^{o}C	^{o}C	REFERENCE
Measured at surface	59	56	Miller and others (1973)
Na/K	107.2	111.6	Arnorsson and others (1983)
Na/K/Ca (4/3)	102.5	113.6	Fournier and Truesdell (1973)
K/Mg	75.6	92.8	Giggenbach (1988)
Li/Mg	92	109.3	Kharaka and Mariner (1989)
Chalcedony	92.6	90.4	Arnorsson and others (1983)
Qrtz	114.5	114.5	Fournier and Rowe (1966)

Fournier and others (1974) discuss the assumptions for the use of geothermometers. The main assumptions are: 1) Temperature-dependent reactions occur at depth; 2) All constituents involved in a temperature-dependent reaction are sufficiently abundant; 3) Water-rock equilibration occurs at the reservoir temperature; 4) Little or no re-equilibration or change in composition occurs at lower temperatures as the water flows from the reservoir to the surface; and 5) The hot water coming from deep in the system does not mix with cooler shallow ground water. Clearly assumption #5 is not valid at Manley Hot Springs. However, if the mixing is at shallow depth, then the least mixed hot water component may reliably predict deep conditions. Other more rigorous mixing models are discussed in Fournier and Truesdell (1974); but not applied in this analysis.

The chalcedony and K/Mg geothermometers probably best characterize the reservoir in the upper parts of the upflow zone. Temperatures between 76 and 93° C appear to be very reasonable. Quartz and the other cation geothermometers probably reflect conditions at great depth in the Manley Hot Springs flow path. Deep maximum temperatures in the Manley Hot Springs system probably do not exceed 115° C.

2.3 DISCUSSION AND RECOMMENDATIONS

East (1982) reports that the composite flow for the main group of hottest springs at Manley totals about 1,418 L/min (about 375 gpm). The total convective output is more when all the others areas with warm seeps and wells are taken into account. Ground temperature surveying by East (1982) shows an elongated area of elevated thermal soil about 2,500 ft by 1,250 ft that is oriented in a northeast trend. Several very small and intense thermal anomalies are superimposed on the larger thermal anomaly. The most intense anomalies are located along Karshner Creek. Northeast and northwest trends are apparent. It is not known if this reflects possible bedrock fracture control on flow or local near surface hydrology controlled by geomorphic features such as Karshner Creek. In any case, the centers for the intense anomalies are very small (less than 50 ft to 100 ft across). It is not recommended that drilling be done over the centers of the temperature anomalies. Because these sites may represent spring upflow and unstable ground, well integrity may not be possible. For good well integrity, a well must have a properly cemented and installed surface casing, especially if hot water with positive artesian head is encountered during drilling.

Soil geochemical surveys (Hg and He) reported by East (1982) show some correlations with mapped shallow soil temperature. However, it is not clear that the data provide adequate information to site a well for the purpose of intersecting fractures at depth that may carry hot geothermal upflow. Also, the soil gas technique may only be useful to survey areas without permafrost as ice may effectively seal vertical soil gas permeability.

A shallow EM (electromagnetic) survey gives results that correlate very well with the shallow temperature survey (East, 1982). Unfortunately, the method used does not allow evaluation of the deeper subsurface that would be the target of drilling.

A dipole-dipole resistivity survey or a CSAMT (Controlled Source Audio-Frequency Magneto Tellurics) survey along roads and trails parallel to Karshner Creek is recommended to view the deep structure prior to selecting any production or temperature gradient well sites. A surface SP (self potential) survey may prove very useful. However, its use in permafrost areas needs to be investigated. Also, a microearthquake survey may provide supplemental but useful information to understand the Manley Hot Spring system. This could be accomplished by deploying three portable seismometers at different locations on the Hot Springs Dome. Old mine workings may be available to place the recorders and geophones. A more expensive approach would drill (core) several shallow temperature gradient holes into bedrock to a depth no greater than 200 or 300 ft depth. A study of the core and fractures would allow determination of reservoir characteristics. Detailed temperature logs would allow a 3-D view of the upper part of the reservoir and aid in selecting locations for injection and production.

Additional geochemistry should be collected to sort out whether or not one or more types of geothermal fluids are involved or if there is error in one of the currently available data sets. Analysis of strontium isotopes ($^{187}Sr/^{186}Sr$) in the hottest water may allow evaluation of the subsurface flow path and reservoir host. Granitic rocks (such as the Hot Springs Dome) may have relatively high ratios. If the sources (provenance) for the Mesozoic flysch deposits in the Manley terrane have major fractions of arc-related volcanic clasts, the strontium ratios may be much lower. This may be important to determine if the reservoir is in the Hot Springs Dome granite or if it is in the fractured contact metamorphic areole (hornfels) of the Manley terrane.

The natural discharge rates of the hot springs and geothermometry indicate that important direct-use geothermal potential exists. The geothermometry also predicts temperatures (76 to 93° C) sufficient for small-scale power production similar to the operation at Chena Hot Springs, Alaska.

Minimal additional geophysical or geochemical work is needed. Prior to design of a production well drilling program (and injection well), engineering design temperatures and flow rates will allow proper and appropriate sizing and costing of a well.

3 Site Visit and Scoping Meeting

On August 23, 2006 representatives from the US DOE's GeoPowering the West team conducted a site visit of geothermal springs, existing and potential project sites and electrical utility infrastructure in the Manley Hot Springs area, as well as participated in a community meeting to scope out the geothermal project opportunities to pursue under the Phase II assessment under the NREL TOA. The GPW team members included Joe Bourg and Kevin Rafferty of the Millennium Energy team, David Lockard of the AEA and the Alaska Geothermal State Working Group, and Roger Hill of Sandia National Laboratories. Section 3.1 summarizes the site visit activities conducted, and Section 3.2 details the discussion held at the community scoping meeting.

3.1 Site Visit

The first site visited was the Dart family property which contains a 120' x 30' greenhouse/bathing facility and geothermal surface springs. Upon arriving at the property, the GPW team was met by John Dart, who provided a tour of the greenhouse/bathing facility. Mr. Dart also briefed the team on the history of the property and facility operations, a description of the resource on the property and how it is utilized, as well as his support for the development of additional geothermal projects in the Manley community. He also expressed his family's support for possibly locating geothermal facilities, such as a small-scale power plant, on the family property and/or using the resource the family has rights to if the community would benefit from it.

Figure 8. Greenhouse/Bathing Facility at Dart Property

After touring the Dart's facility, the team was led by Manley resident Bob Zeitler to the area of the property containing the geothermal springs. The springs are located ~1/2 mile north of the road to the property in a narrow, stream cut valley. There are two primary springs. Previous studies have estimated that the larger spring flows about 300 GPM (gallons per minute) at 52°C and the smaller one yields about 25-20 GPM at 56°C. The thermal waters from these springs are used to heat buildings on the property as well as the greenhouse/bathing facility, flowing though 3/4 inch PVC pipe to each site. Previous estimates indicate that only 30-40 percent of the thermal waters are being

beneficially used by buildings and facilities located on the Dart property. It has been reported that in the past, a 6" diameter well was drilled to a depth of ~50 feet at the site, near the smaller spring, which yielded abundant flows of 65°F water. Additional drilling at deeper depths would be required in the future to determine if higher temperature water existed at the site (i.e., over 75° C) with sufficient flow rates that would support a binary power plant.

Figure 9. Larger Spring at Dart Property

Next, the GPW team traveled to the Manley Community Center for a meeting with area residents to discuss the potential applications and priorities for geothermal development (see Section 3.2 for meeting details). Following the community project scoping meeting, Millennium team members Joe Bourg and Kevin Rafferty continued the site visits of potential project sites led by Bob and Kathy Zietler. The first facility visited in the afternoon was the Gladys Dart School where measurements were taken on boiler sizes to support any future analyses of a potential geothermal space heating system. The Millennium team also spent an hour with the students at the school providing a tutorial and discussion on renewable energy and potential geothermal applications in the area.

Next, the team visited the Manley Roadhouse where they examined the heating distribution system for potential geothermal heating retrofit opportunities. The team also learned that the Roadhouse, which is the community gathering place, would be closed for the winter for the first time in recent history primarily due to prohibitively high electricity costs from the local utility.

Figure 10. Manley Road House

The next facility the team visited was the diesel gen set power plant run by United Utilities. The gen set is comprised of one 90 kW and two 125 kW diesel generators. The following bullets detail the characteristics of the power plant operations in FY 2006:

?? 28,000 gallons of diesel fuel used;
?? $61,000 in fuel costs;
?? 8.6 kWh sold per gallon of fuel consumed;
?? 10.5 kWh generated per gallon of fuel consumed; and
?? an average electrical load of 34 kW.

It was determined that this site may not be a good candidate for the location of a binary geothermal power plant since it is believed that higher temperature geothermal resources are available on the other side of the slough from the existing power plant. However, because a binary geothermal power plant is a base load unit, it would likely need to be integrated with diesel generators to provide load following capability. As an alternative, a battery storage system, load bank, or dump load could be utilized to flatten the load curve, although a diesel generator would still be required for backup power purposes. AEA has suggested that if a new geothermal power plant were built, that it would likely recommend construction of a completely new power facility with new switchgear into which a new backup diesel system could be incorporated. In addition, AEA has suggested that it would also investigate a distribution system upgrade to include the Tribal Council building and other residences.

Figure 11. Diesel Generators at Power Plant

After the tour of the power facilities, the team traveled to the Zeitler property to examine the existing geothermal wells owned and operated by the Zeitlers and by Thomas Hetherington on the adjacent property. The Zeitler well is used primarily for supplying hot water to their bathing house, and the Hetherington well feeds into a gravity fed insulated pipeline that provides hot water and heat to the Hetherington residence approximately a 1/4 mile away. Both the Zeitlers and Mr. Hetherington indicated an interest in additional development of their geothermal resources for community or private benefit.

Figure 12. Well, Pump and Pipeline at Hetherington Property

Next, the GPW team visited the tribal community center for a quick tour of the facilities and layout of the site. The tribal community has expressed an interest in geothermal space heating of the facilities and/or greenhouse development.

The final destination of the site visit to Manley was the community water filling station, where residents come to obtain their potable water supplies. This is a 20-acre site that is owned by the community and was mentioned as one of the possible sites for the placement of a binary geothermal power plant.

3.2 Community Scoping Meeting Summary

At 10 AM on August 23, the GPW team participated in a community geothermal project scoping meeting with residents of the Manley area. Twenty-three people were in attendance at the meeting, which was designed to garner community input into the Phase II study elements under the NREL TOA. David Lockard kicked off the meeting with roundtable introductions of the GPW team and resident participants. Mr. Lockard then provided some introductory remarks to the group stating that with fuel prices changing, that there is increased interest in alternative energy in the state. He then highlighted the recent success that Chena Hot Springs has had with the development of its 2 X 200 kW binary geothermal power plant units, noting that Chena was a turning point for Alaska, the nation, and possibly beyond. It is the first geothermal power plant in Alaska, as well as the lowest temperature geothermal plant in the world. He then stated that based on previous studies that the resource at Manley is likely to be similar to that at Chena, and that we are here today to scope out future technical assistance support and develop a focus for follow-on efforts for geothermal development in the area. Mr. Lockard then discussed the local electric utility situation noting that a major focus of the study could be to look at alternatives to diesel fuel generation with geothermal power generation -- but that we are here to listen to the community to guide these future efforts. One participant asked, "How will it change the cost of electricity with a geothermal power plant?" Mr. Lockard responded that currently, United Utilities charges 68 cents per kWh, and that ~25 cents per kWh is attributed to diesel costs. Therefore, a geothermal power plant would reduce the fuel cost portion of the electricity rates significantly. However, we don't know the exact answer right now, but that answer would be included as a part of the feasibility study. A similar question was asked regarding the payback period of a new geothermal power plant, and members of the GPW team agreed that it could be as low as 6-7 years, but that these numbers would be verified by the feasibility study.

After these introductory remarks, the meeting was opened up into a Q&A type format. The questions and answers are summarized below:

Q. Where would you drill to get to the geothermal resource?
A. While we have some ideas, based on local knowledge, this would have to be determined through additional investigations, testing, and exploratory drilling activities.

Q. What is the downside to geothermal?
A. There are not many negatives. The main concern with geothermal is that you don't deplete the resource by taking too much out, although with re-injection and proper design this is typically not a major concern. Managing the resource is key.

Q. How do you get the heat out to generate electricity?
A. The short answer is with a heat exchanger. Then, the GPW team provided a detailed description of the heat exchange process as well as a description of the binary power plant technology.

Q. What are the environmental concerns?
A. The environmental concerns are limited since the geothermal water is recycled through re-injection, and while the old geothermal plants did have hydrogen sulfide in the emissions, this has been eliminated with the closed loop system design. The other concern is that there is fluoride in the water, and the design of the system needs to ensure that the equipment is tailored to avoid corrosion from the fluoride. Also, in a binary system a working fluid is used. In the case of the Chena plant, a benign refrigerant (R134) is used, and an MSDS (Material Safety Data Sheet) is available for it - other low-temperature plant designs use pentane as the working fluid.

Q. Is AEA and DOE asking for permission today to proceed with the development of the project?
A. No, we are at a very preliminary stage. There is a long ways to go before we get to that point. Today, we are here to obtain community input into the scoping of a feasibility study only, and there is no obligation to the community to proceed any further than that. If, after the feasibility study is complete the community decides to move forward, then we will work cooperatively with the community in identifying local champions and proceeding in a coordinated fashion. It should also be noted that geothermal development could change your community with the addition of a geothermal power plant, greenhouses, and other development.

Q. The utility does not serve the tribal complex, and tribe operates its own generation. 90 kW is the direct load at the powerhouse. The tribe did apply for service and the fee would have been $72,000. The tribe thought it could double, and there is a political issue with the cost of companion services so we did not proceed. Will the tribe be included in this feasibility study?
A. We would likely limit the study at this time to existing customers of the utility. We could, however, explore opportunities for other funding sources to study the tribal complex separately.

Q. Are there risks to the resource from drilling?
A. There are always risks with drilling. For example, drilling though a fissure could allow cold water in and cool the geothermal water, but cementing the well can mitigate this problem.

Q. What about private property rights and geothermal resource rights?
A. Every intention is to respect private property and geothermal resource rights; this must be done legally.

Q. Manley also has good wind and hydro resources. There may be potential for a wind farm at the top of Bean Ridge (about five miles from town) and the Tanana River is right here. Is there any way to reshuffle some of the dollars for the geothermal assessment to look at wind and/or hydro?
A. The money from GPW can only be used for geothermal technical assistance. However, AEA has a MET tower program, and is also involved in hydroelectric development. Therefore, AEA may be able to assist Manley directly in wind and hydro assessments separate from the geothermal assessment.

Q. What if United Utilities doesn't want to do anything with the geothermal project?
A. United Utilities may not be involved in the geothermal power production project, or may not want to do it. However, Manley is on the list for powerhouse refurbishment (not soon though), and there may be opportunities for a partnership to do the geothermal, as well as an opportunity to look at outside partnership opportunities to own, operate, and maintain a geothermal power plant. In addition, AEA will be looking at distribution system upgrades for Manley as part of the powerhouse refurbishment project. We are not seeking to be hostile to local utility. The Powerhouse Operator from United Technologies in attendance stated that they would not want to run the geothermal plant, but that it could be transferred to AVEC or another interested party.

Comment: This project fits into Manley's informal community plan for economic development to support keeping the school open, the roads open and paychecks coming. We are looking at tourism.

Comment: The key is economic development. Lower power costs will put more money in our pockets, and people will develop their own businesses and economic development opportunities.

Comment: The Tribal Council is working on goals and a community plan. We want to look at greenhouses and other economic development opportunities. David Lockard responded that state provides help (via grants) with community plan development.

Next, the discussion focused on direct use opportunities. David Lockard posed the question, "What would you like to look at with respect to direct use geothermal applications? The responses included:

?? *A community swimming pool and gym*, which could be used to teach kids from other villages how to swim, since drowning, is a leading cause of death in children in rural Alaska.
?? *District heating for the community*. Kevin Rafferty commented that he would advise against spending much time on district heating applications since it is typically a cost prohibitive proposition, although there may some opportunities in the heart of the Manley community where buildings are closer together, but that direct space heating of buildings would likely be more applicable. However, if a geothermal powerhouse is built, there may be sufficient electric power generated to provide electrical space heating at a different lower rate that would similar to the cost of heating with fuel oil.
?? *Snow melting*. Kevin Rafferty commented that again, this would be a cost prohibitive proposition.
?? *Greenhouses*. Growing Vegetables such as lettuce and tomatoes could also be an opportunity to explore.
?? *Community Cold Storage*. Cold storage could be provided with geothermal via absorption chilling technology, such as that being used to refrigerate the Ice Museum at Chena Hot Springs.

After a discussion on the above options, it was decided that the priorities for geothermal direct use applications were space heating of buildings, greenhouses, fish farming, and a community swimming pool. In addition, while not a direct use, it was also mentioned that hydrogen production could be an option to consider via an electrolysis process that uses electricity from the geothermal power plant; since the load at the powerhouse is only 90 kW, and a 200 kW binary geothermal power plant is currently the smallest unit available, there may be a opportunity to produce hydrogen from the excess power. However, the sizing of a hydrogen production facility would likely need to

wait until after the geothermal power plant is on line for awhile since it is likely that electric loads in Manley will increase as power costs come down.

Q. What types of geothermal resource prospecting needs to be done?
A. Thermography, resistivity, and satellite imaging would be used to narrow down the sites before exploratory drilling is done.

Q. What is the lowest temperature you can generate power at using geothermal?
A. 200°F was the lowest temperature prior to the Chena project, which is generating at 165 ^{o}F. However, the key is the difference in the temperature (delta T) between the geothermal water and the cooling water. Given the right conditions, temperatures as low as 140 ^{o}F could be used. David Lockard then referred to the Alaska Renewable Energy Atlas and highlighted that the Manley resource is probably similar to that of Chena Hot Springs.

At the conclusion of the meeting, David Lockard asked the participants for their consensus agreement on a proposed statement of work for the Phase II study under the NREL TOA. Based on this request, the following statement of work was developed:

?? Priority I: Develop an investment-grade feasibility study to determine possible locations and the technical and economic potential of a low-temperature geothermal binary power plant at Manley.
?? Priority II: Conduct a qualitative assessment of cascaded direct use opportunities near the power plant location including: a community swimming pool/hot tub, greenhouses, and space heating of major buildings (school and Manley Roadhouse).
?? Priority III: Conduct a qualitative assessment of distributed direct use applications beyond the power plant site focused on greenhouses and space heating at the tribal community complex.

After consensus was achieved on the scope of work, David Lockard asked the participants if they had any additional comments or concerns related to the proposed Phase Ii study efforts. One participant stated that location of the power plant is critical, and that they need to know where it would be and where the wells would be sited. Another participant questioned how the development of geothermal projects would impact existing resources, and that he would hate to see electrical generation from geothermal compromise the existing resource flows. The GPW team responded that it would include a risk assessment in the write-up of the Phase II study report, as well as include information on the ownership structure of geothermal rights (i.e., who owns the resources). Mr. Lockard also suggested that the community should think about potential sites for power generation and community direct use projects. One participant suggested that the community owns 20 acres that is a publicly funded water well, and that this could be a potential site.

At the conclusion of the meeting, local contacts were designated for follow-up activities as the Phase II project proceeds. Pam Redington was designated as the contact for Manley as she is the Secretary of the Manley Hot Springs Community Association, Elizabeth Woods (Tribal Administrator) is the contact for tribal related activities, and Elaine Gray of Manley Land Surveyors is the contact for local maps.

4 Conclusions and Recommendations

Based upon previous studies of the geothermal resource in the Manley area, as well as the resource characterization provided in this Phase I study, it is apparent that significant opportunities exist for geothermal project development in the community. Coupled with the fact that Manley is in a rural, and economically depressed region of Alaska, with electricity rates of 68 cents per kilowatt-hour, we believe that with the recent advances and lower costs of binary power plant technology that there is an excellent opportunity to explore the potential for geothermal power generation at Manley. In fact, Manley may be one of the better economic applications of small scale, low temperature geothermal binary power generation technology in the State of Alaska. In addition, through the use of cascading the geothermal resource after it is used for power generation, that economic development opportunities also exist through direct use applications such as space heating, a community swimming pool, space heating, greenhouses, and/or aquaculture. Distributed direct use applications also may provide for private or tribal business ventures. Therefore, based on the site visits and the community scoping meeting, the following consensus based statement of work is proposed for a Phase II feasibility study of power generation and direct use projects at Manley:

?? Priority I: Develop an investment-grade feasibility study to determine possible locations and the technical and economic potential of a low-temperature geothermal binary power plant at Manley. Specific tasks shall include:
   - Assessment of potential sites;
   - Description of low-temperature binary power plant technology;
   - Estimate of annual energy output;
   - Assessment of economic potential, including determination of estimated project costs and benefits and calculation of benefit-to-cost ratios, payback periods, busbar energy costs and value of energy generation, net present value, and return on investment;
   - Further exploration and geologic assessment of the geothermal energy resource; and
   - Recommendations for next steps in the project development process

?? Priority II: Conduct a qualitative assessment of cascaded direct use opportunities using waste heat downstream of the binary power plant including: a community swimming pool/hot tub, community greenhouse, and space heating of major buildings (school and Manley Roadhouse). Specific tasks shall include:
   - Estimates of unit piping costs ($/LF) for piping to the existing school building;
   - Evaluation of each application to include mechanical equipment capital costs, operating costs, and potential heating savings as appropriate (i.e., Manley Road House); and
   - Conceptual designs of individual applications, as appropriate.

?? Priority III: Conduct a qualitative assessment of distributed direct use applications beyond the power plant site focused on greenhouses and space heating at the tribal community complex. Specific tasks shall include:
   - Evaluation of each application to include mechanical equipment capital costs, operating costs, and potential heating savings as appropriate; and
   - Conceptual designs of individual applications, as appropriate.

It is recommended that NREL proceed with the development of a Phase II task order under the TOA technical assistance mechanism to fund the consensus-based statement of work detailed above. It should be noted, however, that the final scope of work will be dependent upon the availability of funds, and that tasks should be funded based upon the priority order identified.

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