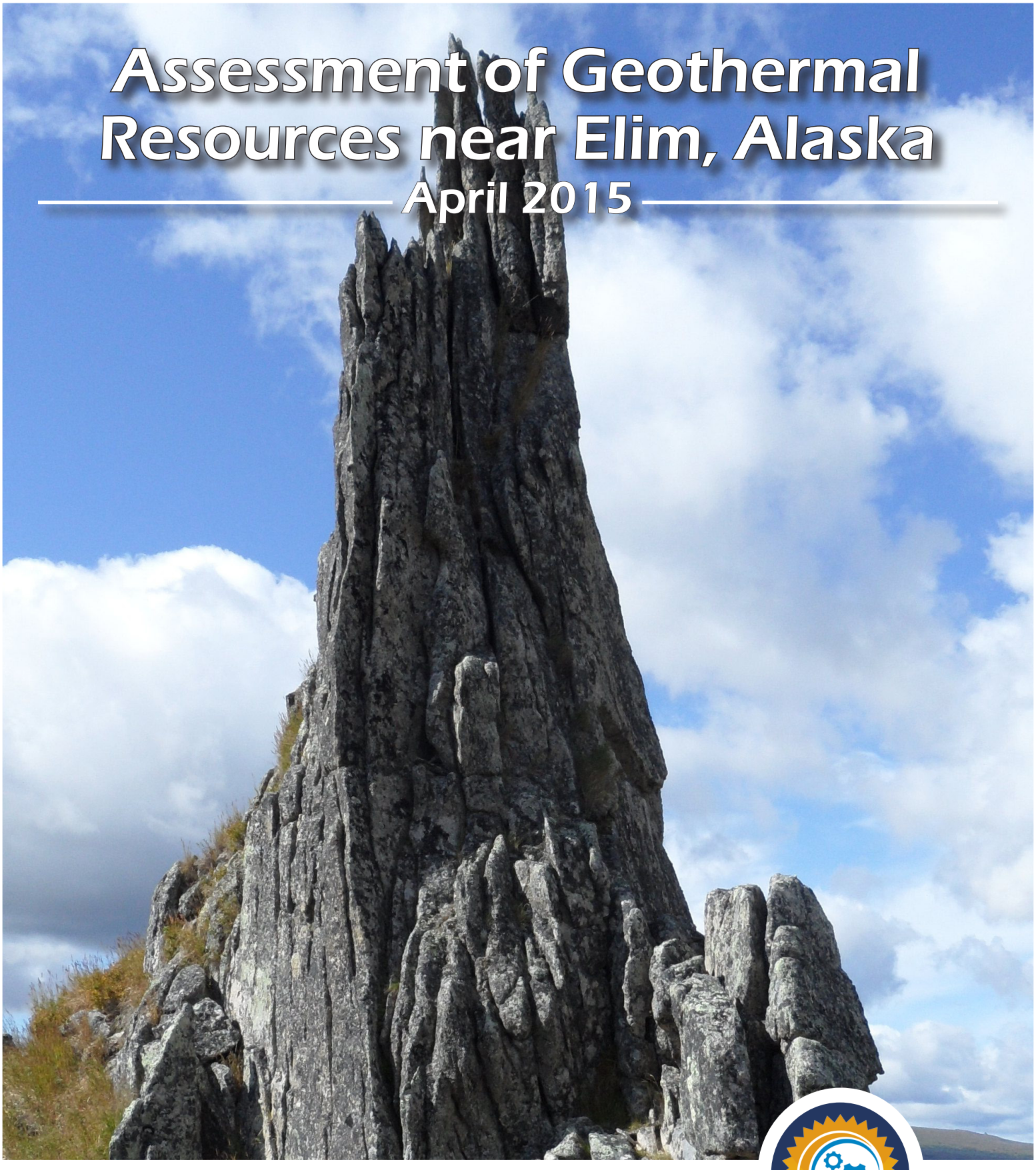
Assessment of Geothermal Resources near Elim, Alaska

April 2015



Prepared by ACEP and the University of Alaska Fairbanks

ACEP
Alaska Center for Energy and Power

UAF UNIVERSITY OF ALASKA FAIRBANKS

An Assessment of Geothermal Resources Near Elim, Alaska
Final Report

Prepared by the Alaska Center for Energy and Power at the University of Alaska Fairbanks

Acknowledgments

Activities described in this report were made possible with funding from the U.S. Department of Energy under DE-EE0000263, "Southwest Alaska Regional Geothermal Energy Project, Pilgrim Hot Springs, Alaska." Residents in the village of Elim were incredibly helpful and welcoming and treated ACEP researchers like family. A special thanks goes to Carol and Paul Nagaruk, Robert and Evelyn Keith, and Sheldon Nagaruk. Bryant Hammond of Kawerak was instrumental in assisting with local management and planning. Dick Benoit was a reliable partner and assisted with an analysis of the local geology and an analysis of geothermal water.

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Executive Summary

The village of Elim, Alaska is 96 miles west of Nome, on the Seward Peninsula. The Darby Mountains north of the village are rich with hydrothermal systems associated with the Darby granitic pluton(s). In addition to the hot springs that have been recorded and studied over the last 100 years, additional hot springs exist. They are known through a rich oral history of the region, though they are not labeled on geothermal maps. This research primarily focused on Kwiniuk Hot Springs, Clear Creek Hot Springs and Molly's Hot Springs. The highest recorded surface temperatures of these resources exist at Clear Creek Hot Springs (67°C). Repeated water sampling of the resources shows that maximum temperatures at all of the systems are below boiling. Clear Creek Hot Springs has the highest geothermometry predicted temperatures, which ranging from 77 to 91°C. The predicted temperatures of the Kwiniuk-Elim Hot Spring system are near 70°C.

Elim is located very close to an expansive low cost beetle-killed wood resource, and villagers estimated that about 80% of home heating comes from wood stoves. Given the nearby topography, the distance to the nearest hot spring, and the availability of alternate sources of space heating, it does not appear that the direct use of the geothermal resource within the village of Elim would be economically viable at this time. In addition, the traditional subsistence lifestyle is very important to residents. Hunting caribou, birds, moose, and marine mammals as well as the gathering of berries, wild greens, and eggs are a major part of their lifestyle. Residents of Elim are not interested in utilizing the geothermal resources to develop tourism infrastructure, though they expressed interest in learning more about using the geothermal resource for electrical production or for a possible fish hatchery near Elim Springs.

Background

The village of Elim, Alaska lies about 460 miles northwest of Anchorage and 96 miles east of Nome on the Bering Sea coast (Figure 1). About 330 people live there, most of whom are Alaska Natives.

Several hot springs exist in the region, the nearest of which is about nine miles northwest of the village on a bank over the Kwiniuk River. It is referred to as Kwiniuk Hot Springs, although many people also refer to it simply as Elim Hot Spring. It was first identified in early USGS surveys (Waring, 1917) but with few details. A number of other hot springs in the region have been described in subsequent publications and can be seen in Figure 1. A rich oral history details other local hot springs, which have not been identified in official publications and are not shown in Figure 1.

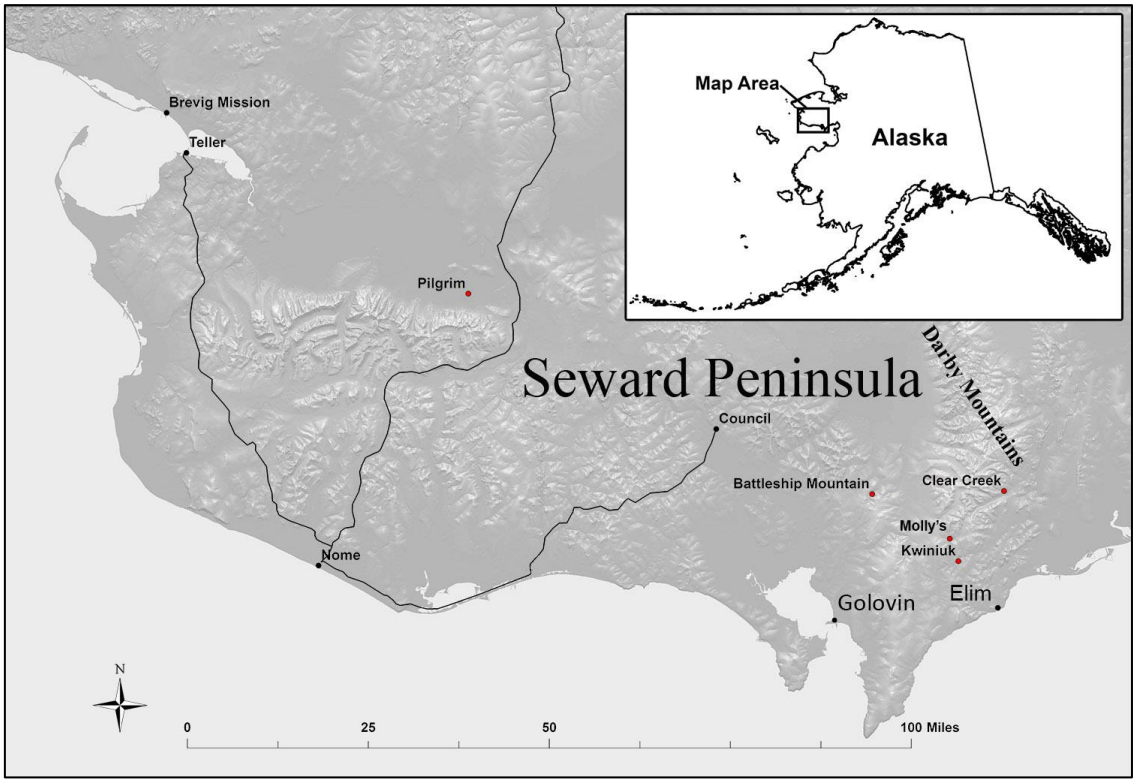

Figure 1. A map of the southern Seward Peninsula. Elim is located on the bottom right. Black dots show locations of towns and villages. Red dots show hot spring locations. The black lines represent roads.

The hot springs near Elim have been used for traditional and therapeutic purposes since before recorded history. When the Alaska Native Claims Settlement Act was passed in 1971, Elim decided not to participate. Instead, they opted for 298,000 acres of land surrounding the village,

Figure 2. View toward the north of the village of Elim, Alaska

which included several hot springs in the area (Ivanoff, 2012). Over the years, residents have repeatedly identified their geothermal resources as a local priority and have consistently identified these resources as a potential source of locally based sustainable economic growth.

The first written description of Kwiniuk Springs by Waring (1917) described a "distinctly sulphureted" spring at "two neighboring localities near the Kwiniuk River…The springs are rather inaccessible, having seldom been visited by whites." The 1975 Miller et al. report examines many hot springs on the southern Seward Peninsula and included the chemical analysis of collected water samples (Table 2). The three hot springs closest to Elim are Battleship Mountain, Kwiniuk, and Clear Creek (Table 1). All of these springs issue from granitic rocks (Miller et al., 1975).

Table 1. The three closest hot springs to Elim.

Battleship Mountain Hot Spring	20 miles north of the town of Golovin and on the east side of the east fork of Cliff Creek on a small bedrock terrace about 75 feet above the creek. It has a temperature of 17°C and a hydrogen sulfide odor.
Kwiniuk Hot Spring	9 miles NW of Elim and consists of one principal spring about 100 yards north of the Kwiniuk River. The surface temperature was estimated at 40 – 50°C.
Clear Creek Hot Spring	16 miles north of Elim and are on either side of an east-flowing tributary of Clear Creek. The 63°C springs south of the tributary have an estimated flow of several hundred gpm and are about 400 feet above the Clear Creek valley floor. The 67°C springs north of the tributary are located in an upper and lower area with the lower springs having a lower flow rate than the upper springs.

Elim Region Hot Spring Chemistry and Predicted Temperatures

Many hot springs are located in or near the Darby Mountains near the margins of the large late Cretaceous Darby granitic pluton(s). Water chemistry was used to estimate the maximum resource temperatures of four hot springs in the area. In this report, the predicted temperatures are addressed in a conservative manner and the overall chemistry raises no obvious alarm bells as to the quality of the predictions. Silica and Na/K/Ca geothermometers have been utilized around the world for about four decades. They have been proven to be reliable semi-quantitative indicators of subsurface temperature as confirmed by deep drilling in many dozens to a few hundred drilled geothermal systems. The values presented in this report are probably no better than $\pm$ 5-10°C. There have admittedly been multiple instances where excessive optimism has led to the use of inappropriate geothermometers to predict unrealistically high subsurface temperatures and where later drilling has failed to find the predicted temperatures. In the latter case it is often difficult to tell if the geothermometer was in error or if the drilling was either not deep enough or in the wrong location to encounter the predicted temperatures.

Within Alaska, the hot spring geothermometry has been tested by drilling at only two locations; Chena Hot Springs and Pilgrim Hot Springs. At Chena, the Na/K/Ca and quartz geothermometers both predicted temperatures of 120 - 128°C but extensive and relatively deep drilling failed to encounter temperatures over 80°C. At Pilgrim Hot Springs, the results have been similar to date with quartz and Na/K/Ca geothermometers predicting temperatures of 135-

145°C, though drilling has been unable to verify temperatures over 91°C. Thus, the existing geothermal exploration record on the mainland of Alaska has tended to predict significantly higher temperatures than have been encountered by drilling. With this being said, the predicted temperatures for the three geothermal systems near Elim are low enough that there is much less opportunity for a substantial temperature over-prediction error. Temperatures significantly above the predicted geothermometer temperatures are very rarely encountered.

Several geothermal water samples have been analyzed from the Elim region hot springs since the 1970's. Miller et al. (1975) performed the first chemical analysis of three Elim Area Hot Springs. The analyses show wide differences in chemistry between the three springs (Table 1). In 2012, local residents gathered water samples from Kwiniuk Hot Springs, Clear Creek Hot Springs, and a local spring known as Turner Creek. The 2012 samples were analyzed by the Desert Research Institute in Reno, Nevada. The complete USGS and DRI analyses have charge imbalances of 1% to 8% which indicates these analyses are of reasonable overall quality. Additionally, samples were collected by UAF researcher Gwen Holdmann in March 2014 from a seep known locally as Molly's Hot Spring. Molly's Hot Spring is the former site of roadhouse and reindeer camp during historical times when reindeer herding was common in the region. Molly's Hot Spring is located between Battleship Mountain and Elim Hot Spring and the surface temperature was estimated at about 100°F when visited in March 2014. The residents of Elim emphasized that there were many other unnamed thermal seeps in the area that are rarely visited.

Table 2. Elim area thermal spring chemical analyses. Values are in parts per million.

Spring	**Lab**	**Date**	**Temp °C**	**pH**	**Na**	**K**	**Ca**	**Mg**	**SiO2**	**B**	**Li**	**Cl**	**F**	**SO4**	**HCO3**	**CO3**
Battleship Mountain	USGS	1970	17	8.97	111	1	14	.2		.6		122		16	40	10
Kwiniuk-Elim	USGS	1971	50	7.3	500	9	130	.1	45	1		912	5.8		10	
Kwiniuk-Elim	DRI	2012		8.52	453	9.1	136	.85	46	1.06	2	926	4.84	63.2	10.3	2
Clear Creek	USGS	1970	67	9.43	54	1.4	5.6	.6		.2		4.9		25	34	34
Clear Creek 1	DRI	2012		9.53	52.6	1.43	2.15	<1	80.6	.15	.05	4.1	3.76	25.3	30.3	36.2
Clear Creek2	DRI	2012		9.52	53.1	1.44	2.16	<1	84.3	.15	.05	4.3	3.8	25.9	28.5	35.4
Turner Creek	DRI	2012		8.28	5.1	0.33	46.2	9.4	8	0	.01	4	0	5	224	
Molly's Hot Spring	WET Lab	2014	~37	8.98	120	1.9	4.7	0	47	.6	.43	130	7.3	50	29	9.0

The chemistry data shown in Table 2 show a range of chloride values from 4 to about 900 ppm. The Battleship Mountain and Kwiniuk/ Elim Springs have a solid geothermal character with 122 and 900 ppm of chloride. While the Clear Creek and Turner Creek springs both have low chloride contents of 4 ppm, the Clear Creek samples have much higher silica contents of 81 – 84 ppm, and surface temperature demonstrating a definite geothermal nature. The Molly's Hot Spring water appears to be most similar to the Battleship Mountain hot spring chemistry, and has elevated surface temperatures. The Turner Creek sample, with an unknown surface temperature, appears to be from a background cold water source and will not be further discussed.

The wide variation in chloride content demonstrates that the Battleship Mountain, Kwiniuk/ Elim, and Clear Creek thermal springs are from different geothermal systems. The similarity of the two Clear Creek samples show they are from the same geothermal system, which is not surprising, given the close proximity of the Clear Creek Hot Springs to each other. Molly's Hot

Springs is most similar to the water from the 17°C Battleship Mountain. The similarity is most likely due to the two geothermal systems residing in similar rock types.

The calculated geothermometry from the analyses (Table 3) shows chalcedony predicted temperatures of 67 or 68°C for the Kwiniuk/ Elim thermal spring. The higher quartz predicted temperatures of 97 and 98°C for Kwiniuk/ Elim are probably not the appropriate values for a geothermal system with predicted temperatures below 100°C. At Clear Creek, the chalcedony values of 98 and 100°C are probably more realistic than the quartz values of 126 and 128°C. However, due to the pH values near 9.5, a pH correction should be made to correct for the additional solubility of silica at pH values above 9. This reduces the predicted temperatures by about 10°C and is based on a USGS spreadsheet calculation.

Unfortunately, there is no silica analysis from the USGS analysis for the Battleship Mountain Spring. The most credible predicted subsurface temperatures for Molly's Hot Spring are probably the 66°C for the pH corrected Chalcedony and 78°C from the NaK4/3Ca geothermometer. The high pH of the water definitely requires a correction for the silica geothermometer.

Table 3. Geothermometry predicted temperatures for Elim Area hot springs.

Spring	**Lab**	**Surface Temperature °C**	**Chalcedony °C**	**pH Corrected Chalcedony °C**	**Quartz °C**	**pH Corrected Quartz °C**	**Na/K/Ca °C**	**Na/K (Fournier) °C**
Battleship Mountain	USGS	17					40	76
Kwiniuk-Elim	USGS	50	67	67	97	97	72	104
Kwiniuk - Elim	DRI		68	67	98	97	70	110
Clear Creek	USGS	67					57	123
Clear Creek 1	DRI		98	88	126	117	77	126
Clear Creek 2	DRI		100	91	128	119	77	126
Molly's	WET	~37	69	66	99	97	78	

The sole USGS analysis of the Battleship Mountain thermal water gives a Na/K/Ca predicted temperature of 40°C which seems reasonable given the surface temperature of only 17°C. The Na/K/Ca geothermometer values of 72 and 70°C for the Kwiniuk-Elim thermal spring are in good agreement with the chalcedony geothermometer, giving added credibility to these two sets of values. The higher Na/K geothermometer values are widely recognized as providing excessively high predicted temperatures for geothermal fluids throughout the world.

At the Clear Creek thermal springs, the Na/K/Ca geothermometer from the USGS analysis is 57°C, which is less than the measured surface temperature. This is a rare outcome and raises questions about the cation values in the USGS analysis. The Na/K/Ca predicted temperatures

from the two DRI analyses are 77°C, which is modestly lower than the pH corrected chalcedony geothermometer. The Clear Creek samples have the highest predicted subsurface temperatures in the area.

The available data indicate that the Clear Creek geothermal system has the highest subsurface temperatures in the range of 77 to 91°C. The Kwiniuk-Elim has a predicted subsurface temperature near 70°C. The lowest subsurface predicted temperature, 40°C, is from the Battleship Mountain geothermal system. All of the predicted temperature values for Elim area springs are below boiling.

Site Analysis

During discussions with residents of Elim over the last decade, repeated interest has been expressed about learning more about the development options that might exist for the geothermal resources on tribal lands. As part of this analysis, information was gathered through several different means. GIS elevation analysis was conducted to better understand the local topography and determine what logistical challenges would need to be overcome for a direct use project that would deliver hot water to the community of Elim. A site visit was made to explore the nearby geothermal resources and conduct in-person interviews with community members. As discussed, water samples were collected and analyzed to get a better estimate of maximum subsurface temperatures that could be encountered in the case of drilling to access a deeper geothermal resource.

Initial planning efforts focused on the challenges to overcome if hot geothermal fluid were delivered to Elim through pipes for direct use in space heating and agricultural applications. As described in Table 1, the two hot springs nearest to Elim, Kwiniuk and Clear Creek, are still nine and 16 miles from the village respectively. This is a significant amount of infrastructure to deliver geothermal energy, in any form, to the village. Elevation profiles between both of the hot springs and the village were measured and are shown in Figure 3.Site analysis of the topography between Kwiniuk Hot Springs and Elim (top) and Clear Creek Hot Springs and Elim (bottom) is shown in the two diagrams. The top diagram traces the topography of an established trail (shown in brown) while the bottom diagram assumes a straight line since no year-round trail exists between Clear Creek Hot Springs and the Village of Elim. These profiles are not meant to delineate a specific routing of future infrastructure, but rather to give an idea of the elevation differences that exist between the hot springs and Elim. The elevation increases shown between the hot springs and Elim mean that geothermal water would have to be pumped, or at least siphoned, in order to reach the village, adding to the expense of future infrastructure.

Gwen Holdmann of the Alaska Center for Energy and Power visited the community of Elim in March of 2014 to perform geothermal resource assessments and gauge community interest for the development of the local geothermal resources (Appendix A). The primary goal of the visit was to learn from the local community about the nearby geothermal resource, present different potential geothermal development options, and get community input. During the visit, Gwen discussed options including: direct geothermal heat for space heating, a possible district heating loop, agriculture production, using the geothermal resource to generate electricity, and developing tourism infrastructure built around the geothermal resources.

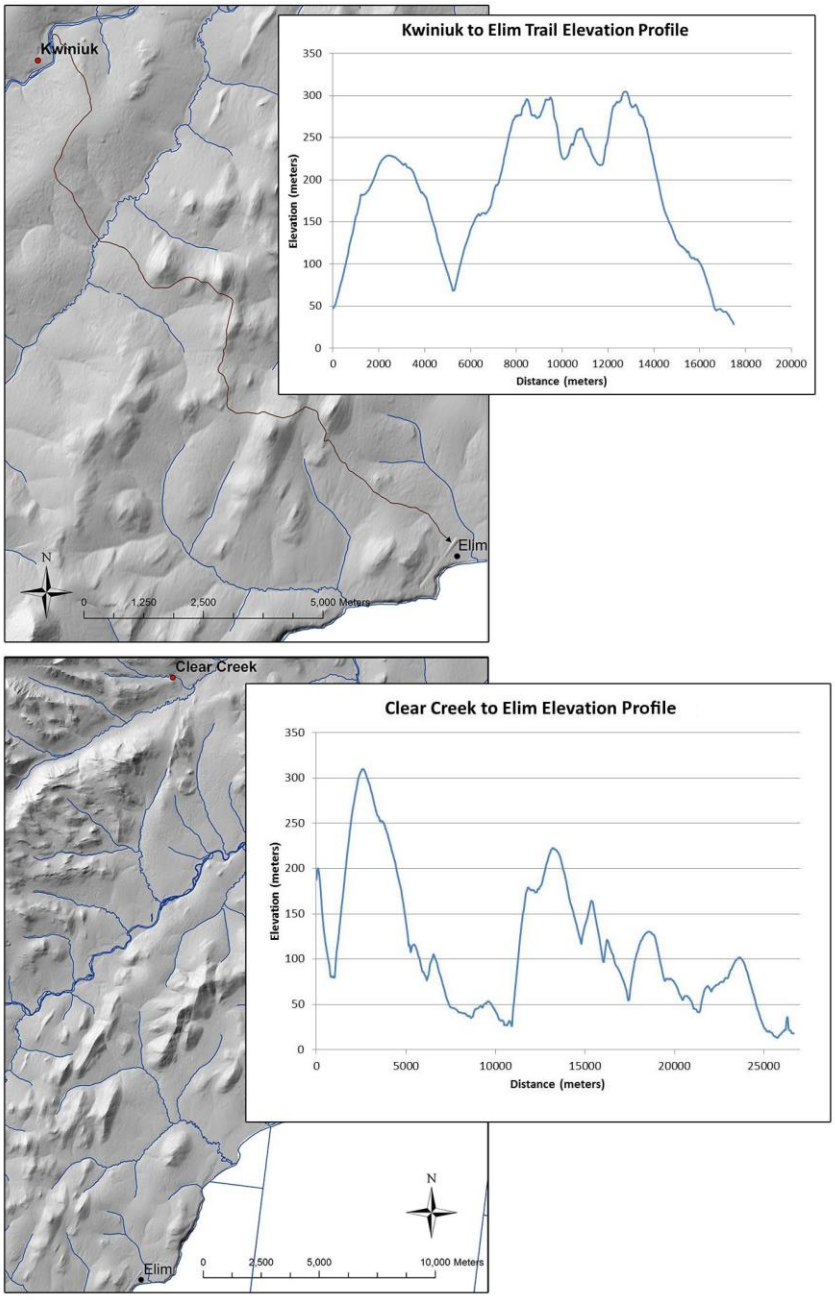

Figure 3.Site analysis of the topography between Kwiniuk Hot Springs and Elim (top) and Clear Creek Hot Springs and Elim (bottom) is shown in the two diagrams. The top diagram traces the topography of an established trail (shown in brown) while the bottom diagram assumes a straight line since no year-round trail exists between Clear Creek Hot Springs and the Village of Elim.

During Gwen's visit, village leaders often referenced Molly's Hot Spring. ACEP has heard rumors of the existence of this hot spring for years but has never visited it nor seen it on any published maps. In addition, the most recent visit by any member of the village to the hot spring was 25 years ago. Gwen and several people from Elim were able to travel by snow mobile and

Figure 4. Village members participate in a community meeting about geothermal resources in March 2014 (top left). Wood is widely available and accounts for about 80% of the home heating needs (top right). Gwen Holdmann and Elim residents enjoy lunch under Molly's Hot Spring which has not been listed in published literature (middle left). Village residents walk towards an unnamed seep. The rolling topography shown in the picture is typical of the region (middle right). Elim Hot Spring is shown with residents in the background. The hot spring has been bermed up to allow for soaking and enjoyment (bottom left).

visit Molly's Hot Spring and obtain a water sample for analysis. The Molly's Hot Spring chemistry and geothermometry are presented in the previous section and shown in Figure 1.

During discussions with village leaders, it became clear that Elim was located very close to an expansive low cost beetle-killed wood resource, and villagers estimated that about 80% of home heating came from wood stoves. Given the nearby topography, the distance to the nearest hot spring, and the availability of alternate sources of space heating, it does not appear that the direct use of the geothermal resource within the village of Elim would be economically viable at this time.

The traditional subsistence lifestyle is very important to residents. Hunting caribou, birds, moose, and marine mammals as well as the gathering of berries, wild greens, and eggs are a major part of the lifestyle in Elim. Residents indicated that they were not interested in using the hot springs as a draw for tourists.

The two uses that residents were interested in were electrical production as well as an investigation into a possible fish hatchery near Elim Springs. Obviously, significant hurdles exist for both development options however as of the publication of this report, discussions between village and local development entities is ongoing. A geothermal power plant would likely need to utilize the Clear Creek Spring resource since it is the hottest spring in the area. Clear Creek is 16 miles north of Elim.

Conclusions

Using an in-person site assessment, community meeting, and chemical analysis has enabled a high level analysis of the geothermal resources in the vicinity of Elim. All of the hot springs that were examined as part of this analysis are low temperature in nature and, based on the geothermometry results, it is likely that maximum temperatures do not exceed boiling. Given the accessibility of inexpensive beetle-kill spruce that provides an estimated 80% of the village's space heating needs and the challenging nearby topography, supplying geothermal fluid to the village for space heating and other direct use applications is not economically practical at this time. Other possible ways to exploit the geothermal resources for local benefit would be through a geothermal power plant at Clear Creek Hot Springs or a fish hatchery facility near Elim Hot Springs. Both application have significant hurdles to overcome and would require careful business planning and enthusiastic project champions.

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Appendix A:
March 2014 Elim Trip Report

Kids fishing for tomcod just outside village

Subsistence lifestyles appeared very intact. While I was in Elim (2 days), I ate: smoked salmon, dried quail, beluga, raw herring eggs, wild potato, pine pitch (chewing gum, it is still stuck to my teeth), blueberries, cranberries, caribou. They showed me pictures off all kinds of other subsistence activities from collecting greens to various eggs and hunting. They are very busy all the time!

Carol Nagaruk shows off a wide range of home-made handicrafts, artwork, and subsistence foods her family has produced/collected. Her mother (seated on couch) Alice Charles, is an expert ‘parky’ maker.

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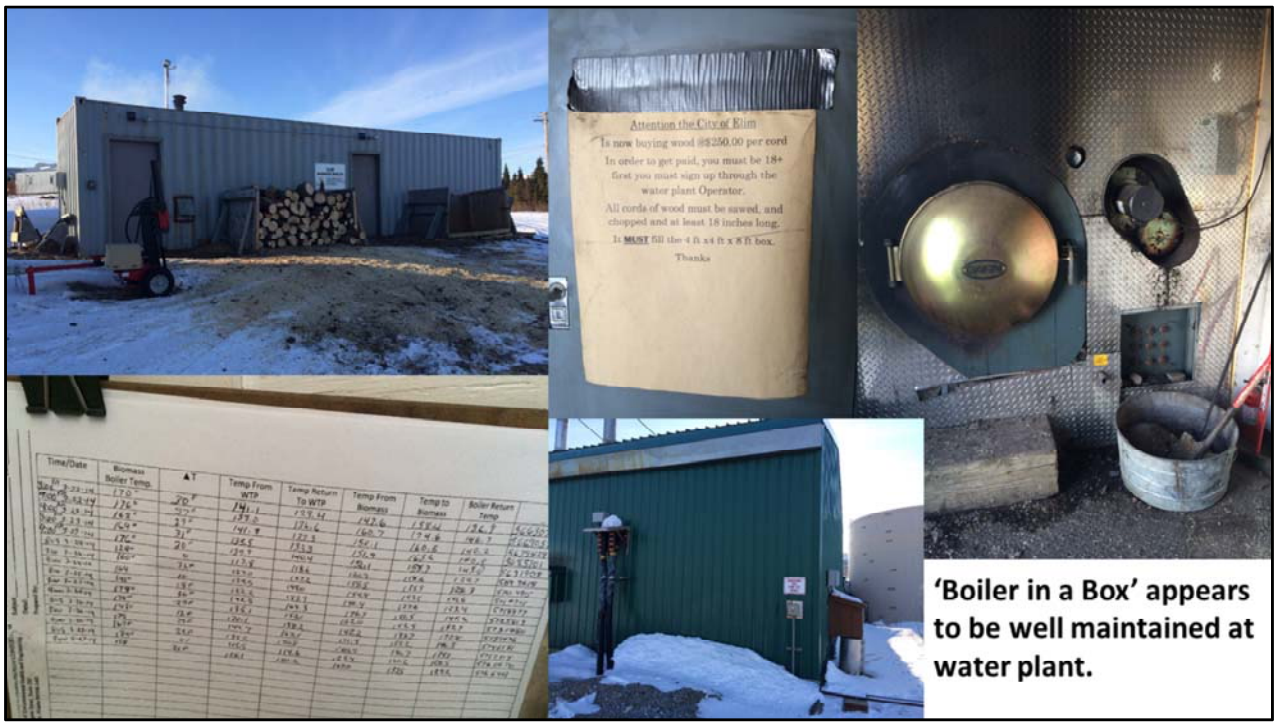
Paul with caribou, from 'Koyuk side'

There are no caribou right around Elim in recent years. They mainly go closer to Koyuk to get their deer. Their appears to be many hybrid between caribou and reindeer, as their used to be a lot of reindeer herding in the region. In fact, their used to be a roadhouse at Molly's which was actually a reindeer camp. Elim 'lost' their reindeer herd many decades ago.

Grocery store – slim pickings in the produce aisle, but hey – you can buy caribou meat, which is packaged as 'exotic game'!

Caribou hides drying outside a home (maybe not so exotic)

The community estimates about 80% of heating is from wood. There are piles of wood in front of most homes that represent a few days of wood storage – they seem to collect on as-needed basis. There is a substantial amount of beetle killed trees, which serve as the wood supply. Apparently, trees 50 years of age and older are dead or dying; the community understands this (from foresters) to be part of a 400 year cycle. This seems to be corroborated by local knowledge, though the villagers are concerned about climate change and how this might effect the beetle cycle. They feel the tundra is shrink as their tree line expands; they are also loosing ground to erosion. It might be interesting to look at indoor air quality and wood stove efficiency. I only went in 2 private homes, Carol and Paul Nagaruk and Sheldon and Emily. Most of our time was spent in the IRA building.



The project is apparently managed by the staff at the water plant (see large water tank behind green treatment plant building in lower RH pic). There was no long-term storage, only one cord outside building in wood box, and some stored inside the conex. Everything was clean, neat, and on-line. The city is purchasing wood for $250/cord.

Images from around town. Clockwise from top left – 1) typical street in Elim; 2) new school; 3) fuel header to the tank farm (>2000 ft); emergency transport vehicle.

There are 90 students at the Elim Aniguin school. Lots of young children all over town, but they were all friendly, respectful, and inquisitive. We ran into a few teenagers after dinner who stopped us and inquired nicely about why we were in town, and welcomed us to Elim (nearly everyone we met would say 'welcome to Elim'). They were headed to the school for tutoring.

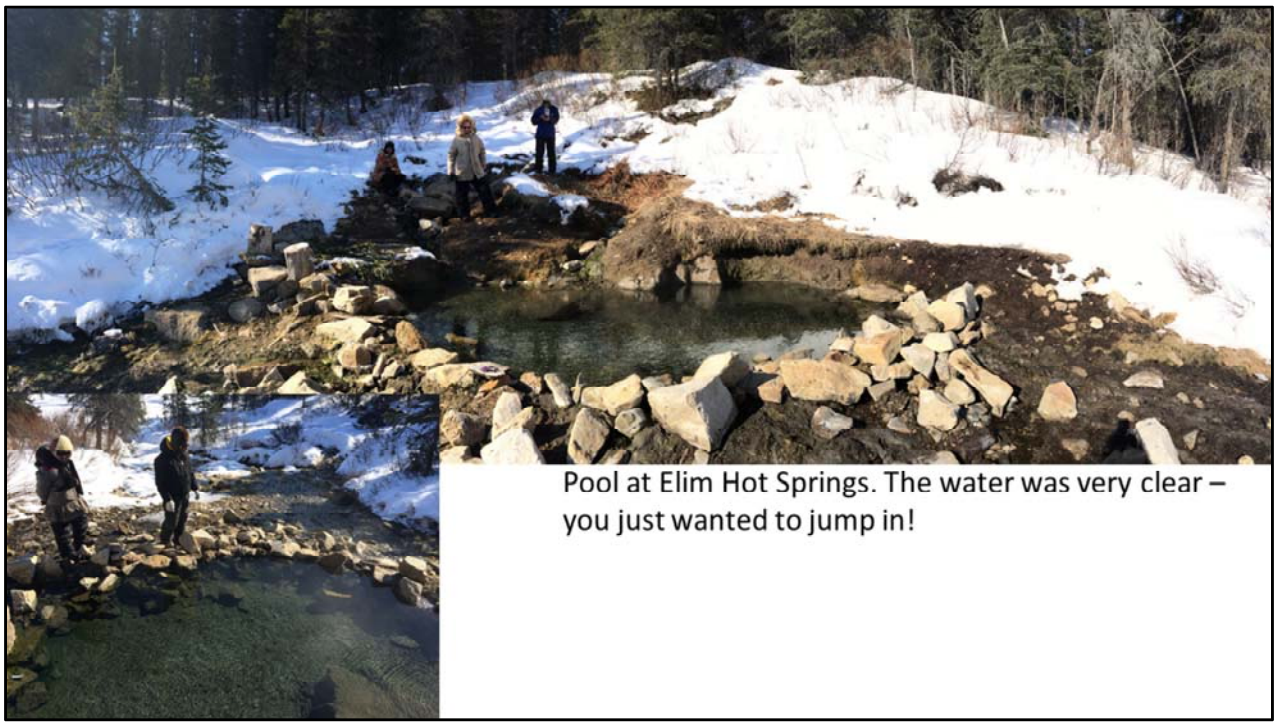
People have a generally favorable opinion of AVEC, although they are frustrated AVEC just installed a met tower and are 'a decade behind schedule' in assessing the wind resource. (Incidentally, people generally said the wind doesn't blow that much there, which would be consistent with all the trees in the area).

Robert, Sheldon, Carol and Paul showing us the location of unmapped thermal anomalies

We never held a real community meeting. We had lots of discussions at the IRA with community members, but never gave a formal presentation. This was mainly because we went out of town to visit the thermal springs, and it was not certain when we would return. Up until 7:30pm the day the meeting was scheduled, Sheldon and Robert were still 'not sure' if they would call a meeting for that night. Instead, we stayed up talking about their history and lives until 1am.

On the way to Elim Hot Springs. The image above is taken at Rosemary's peak. The hot springs is in the valley immediately below this rock, with the rock roughly in line with the springs.

We decided instead of looking at a map, we should go and look for some of these sites. We organized a spur-of-the-moment expedition, Including Robert and Evelyn Keith, Paul and Carolyn Nagaruk, Bryant Hammond from Kawerak, and myself. First stop: the well mapped Elim Hot Springs.



Pool at Elim Hot Springs. The water was very clear – you just wanted to jump in!

The hot springs were up on a hillside a bit, and I believe the 25GPM flow rate documented previously. There are a few seeps, and the bank has been dug out a bit to enhance flow. There is a fairly steep bank behind the springs, and the whole setting is in a bit of a dead-end down-dropped area like a mini circ. The flow discharged several dozen feet along a gradual slope to a small creek below. The rock in the area was very broken up. It was granite, but much was finer grained and lighter in color.

Next stop: Molly Hot Spring. We broke out the trail; it was challenging going until we got 'up high'. Carol (pointing) was the one leading the way.

Molly Hot Spring is not on the official map, but we've heard about its existence for years. So we decided to try and find it, 'just on the other side of this hill'. There were a few interesting things about this. Firstly, no one had a map or GPS. Secondly, their was no trail. Thirdly, Carol had been their most recently – about 25 years ago. This meant everything was based on dead reckoning and a very ingrained map of the area (while they hadn't actually gone to Molly's, they had been in the vicinity many time on hunting trips). Paul and Robert went ahead to break out the first part of the trail while we waited at the springs. It was quite a effort to make it through the first stretch, as the snow was not packed and quite fluffy.

Hill above Molly Hot Springs. There is a visible line of cottonwood trees along the creek below (unusual for the area).

I was impressed at their ability to head cross country to find these unmapped hot springs. We stopped to get a bearing above the valley where Molly hot springs was located. Paul is pointing in the direction of Clear Creek Hot Springs here.

Unnamed thermal seep near Molly's Hot Springs

We paralleled the creek and first found this seep, which we crossed the creek to investigate and sample. The flow rate is exceedingly low – we needed to dig a hole to collect a sample. Maybe 2-3GPM. The temperatures were cool to the touch, but definitely above ambient. Our guess was around 50F. This seep turned out to be about a ¼ mile from Molly's.

We had a much harder time finding Molly Hot Spring itself. It took Carol crashing around in the Cottonwood trees for awhile. I've included a picture of a picture they showed me from an old photo album of the site, but their must have been a lot more snow that year. You can see the creek bottom appears filled in with snow where we picnicked.

Molly's Hot Springs is located just above the creek bank. There are a few small seeps, probably totaling about 25GPM (seemed very similar in many ways to Elim HS, including the temperature). This hot springs is located very roughly halfway between Battleship Mountain and Elim HS. Interestingly, none of the locals were aware of a hot springs at Battleship Mountain, though they were aware of others in the region (including some still un-named).

Picnic at Molly's

Picnic at Molly's

On the menu: beluga, dried quail, dried samon, coffee, pilot bread, pastries, freshly baked bread (still warm), homemade fish spread.

Possible scarp across creek from Molly's and secondary seep. Parallels most of the valley floor.

Clear Creek Hot Springs – image above is looking directly at the springs, which is located on the hillside in roughly the middle of the image. In the foreground is a steep 'cliff' that is difficult to descend.

Images from a school field trip led to the sight to conduct a scientific investigation.

This expedition was led by teacher Rick Holt, who is now based in Colorado. No data or information from the study exists.

Carol Nagaruk checking out the scenery atop one of the many granite tors in the region. Carol was able to locate Molly's HS after last being there over 20 years ago.