Final Report

A Geothermal Heating Assessment for the proposed Grafton County Correctional Facility

20 March 2009

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Executive Summary

Our feasibly study for a geothermal heat pump system for the proposed Grafton County Correctional Facility indicates either an open loop or a closed loop system is feasible and the capital costs are similar to the proposed system of oil boilers and electric chillers.

Based on first order estimates of the space heating, space cooling, and service water heating loads we estimate that an open-loop geothermal heat pump system would require about 200 gpm of groundwater. The geologic setting surrounding the Grafton County Complex appears favorable for extracting water (based on the yield of two wells located in the floodplain on the Vermont side of the Connecticut River) in quantities that could supply a geothermal system by using 4-5 production wells of 40-50 gallons/minute (gpm) to get the required flow.

The proposed geothermal system would achieve cost savings of about $250,000 per year for heating alone based on the estimated fuel consumption of the proposed facility, current fuel costs, and projected near term electric costs. In cooling we predict that savings will be about $22,000 additional. We believe the construction cost of such an open-loop geothermal heat pump system would be roughly the same as the HVAC system currently proposed for the Grafton County Correctional Facility (GCCF).

If the suggested test well shows that an open-loop system is not feasible (i.e. inadequate and/or low quality groundwater) we believe a closed-loop geothermal heat pumps system could be constructed for only slightly more than the HVAC system currently proposed. The operating cost savings from a closed-loop system would be similar to those of an open-loop system, i.e. estimated at about $250,000 per year for heating alone. We estimate that a closed-loop system would require about 29,000 feet of borehole heat exchanger. This could be configured, for example, as a 12 x 12 grid of 200 foot deep borehole heat exchangers thus requiring about 1 acre of surface area under the parking lot and/or in other areas adjacent to the building.

In addition we would expect the maintenance costs for either of the geothermal heat pump options to be about 50% of those for the system currently proposed. Furthermore, roughly half of the current mechanical room space of approximately 2500 square feet would be freed up (or could be deleted from the project) as the geothermal heat pump based systems eliminate the boilers and their associated equipment.

The following recommendations are provided as “Next Steps”:

- A detailed heating and cooling load determination should be undertaken to provide results in a form suitable for geothermal heat pump system design.
- A test well for an open-loop installation should be drilled and evaluated for its yield (gpm) & drawdown (feet).
- If the open-loop system well test does not appear to indicate that such a system is possible, a closed-loop test bore with thermal properties measurements should be commissioned.

Additional recommendations are provided in the Summary section should the County move forward with the geothermal heat pump option.

Study Site

The Grafton County Complex is located on both sides of Route 10 in Haverhill, NH. The geologic setting for a majority of the bottomland at 400 MSL along the Connecticut River is a fluvial-glacial setting of fine sands interspersed with silts and some gravel lenses, and is referred to as "stratified drift material." The buildings at the complex are situated on a kame terrace at an elevation of roughly 500 MSL. Figure 1 shows the setting of the complex in relation to the surrounding topography.

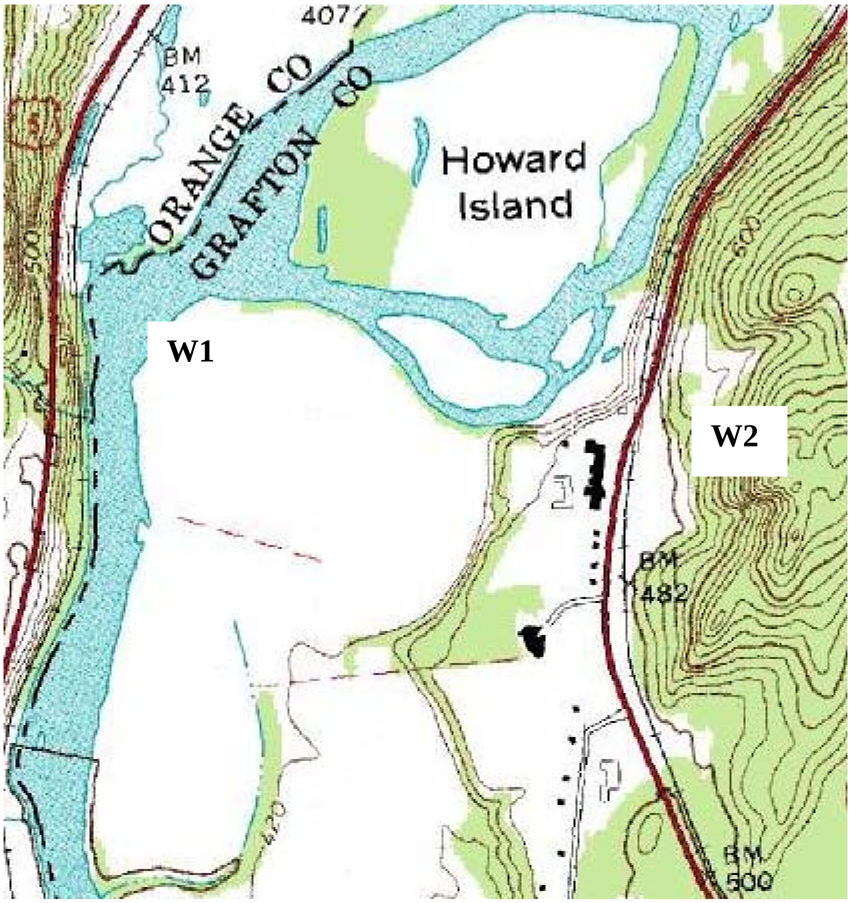

Figure 1: Topographic setting of the site

There have been two wells drilled on the property, one that the maintenance staff identified on the east side of Route 10 and the other well location was found by the USGS in the field near the Connecticut River and these are approximately identified in Figure 1 above as W1 and W2. Unfortunately, no yield data exists on either well.

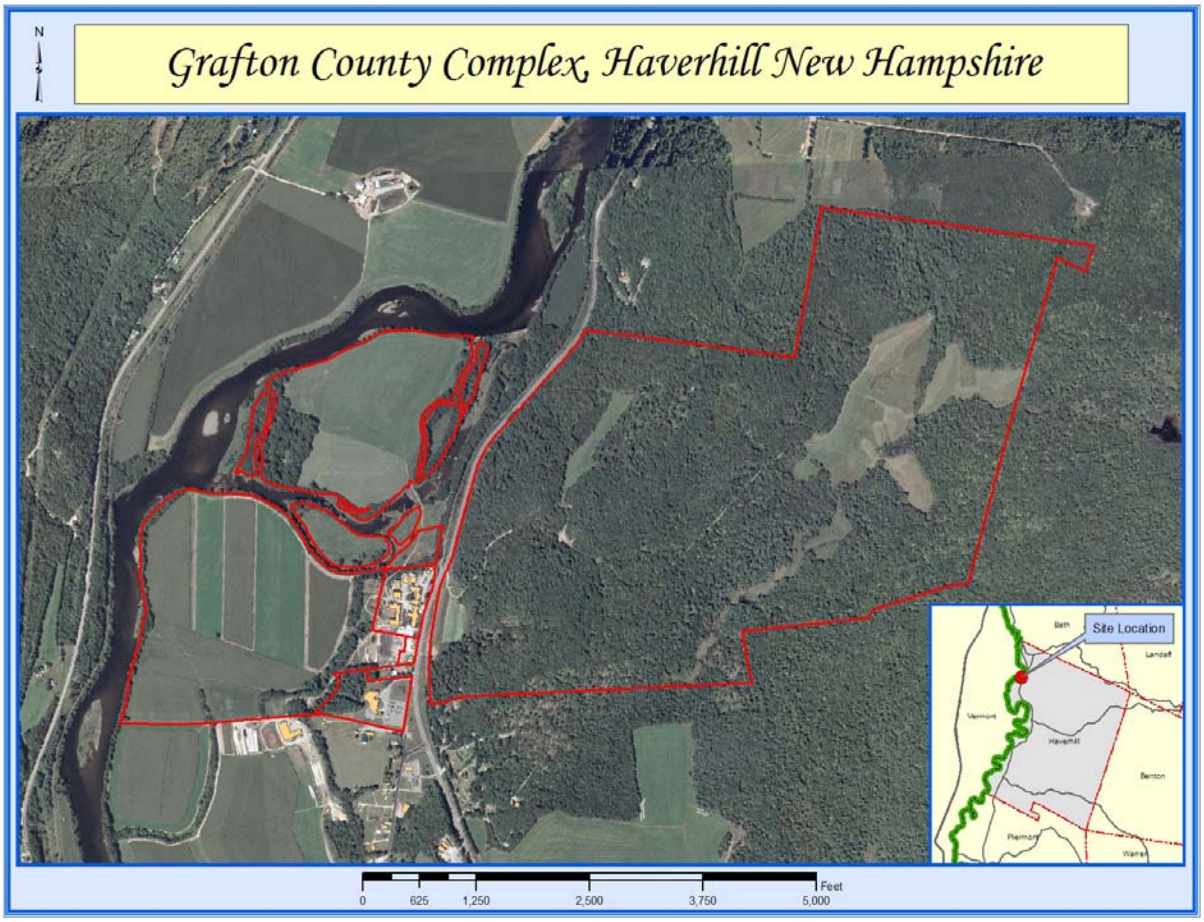

Figure 2: Property Site Plan of the Complex

In Figure 2 above, the Knox farm is upstream of the complex and it is the adjacent property on the Vermont site of the Connecticut River. The well currently used by the farm is a 150 ft deep gravel packed well yielding about 50 gpm according to the owner Paul Knox.

Geothermal Heating Background

The extraction of heat from the ground or the groundwater for use in heating buildings is not new, but with the improvements in the technology to more efficient systems and the cost of fuel oil at record levels, geothermal heating is a very attractive and cost effective means for reducing dependence on fuel oil for building heating. According to a 2004 article in Geo-Heat Center Bulletin, there are over 600,000 installed systems within the United States, but very few installations in VT and Northern NH, likely due to the perceived notion that the area is “too” cold, and until recently the high cost of electricity when compared to heating oil. Schools throughout the country have been using the technology for years as well and a recent 2000 EPA report indicated over 450 schools in 30 states have heat pump systems installed, today there are no doubt many more. The details of the various types of geothermal systems will not be discussed here; the interested reader is referred to Phetteplace (2007) for a recent overview. Groundwater based geothermal heating uses the ground water as a heat source for heat pumps. The heat pumps and the necessary circulating pumps are driven by electricity; no other energy or fuels are needed. Heat pumps can deliver approximately 3 to 4 units of heat or more for every unit of electricity consumed, by "heat pumping" the heat out of the approximately 47 °F ground water up to the temperatures required to heat buildings.

A limited survey of owners, consultants, State Regulators, and mechanical contractors who have knowledge of recently installed commercial geothermal systems was conducted.

1. The Merrimack County Nursing Home in Boscawen, NH recently commissioned a geothermal system for heating their new facility and it has been running since March 2008. Their system consists of 16 standing column wells, 1500 ft deep and placed in the parking lot. The mechanical system has been running with no breakdowns.
2. The Procter Academy in Andover, NH brought a standing column system on-line in the fall of 2008 for two buildings on their campus.
3. The State of Vermont I-89 NB "Rest Area" in Sharon, VT utilizes a geothermal heat pump system with 24-6" diameter borehole heat exchangers, at 430 ft deep each to heat the rest area facility and also "melt" snow/ice on the walkways. This system uses a closed loop of pipes referred to as a closed loop vertical ground-coupled heat pump, as will be described in a bit more detail later. We are in the process of trying to assess the performance of that system as it has been in operation for about 3 years and we have been invited to review the system with their maintenance staff.
4. The Veterans Home in Bennington, VT is in the process of installing a geothermal system for their new facility. We have not been able to assemble the details of their system.

Geohydrologic Setting

The Grafton County Complex properties lie within the Connecticut River Watershed and the lands were formerly underwater during the glacial period; this area along the CT River is known as Glacial Lake Hitchcock. The USGS conducted field studies in the late 80's and early 90's documenting the soils and the aquifers in the Connecticut River through this region; these studies are detailed in Flanagan (1996).

Bedrock underlies the area and consists of metamorphosed layered sedimentary and volcanic rocks. The water bearing capacity of these bedrock formations are dictated by the number and size of the fractures that a well intersects. The USGS report states that of the 2000+ wells they inventoried, the average yield was 6 gal/min, but ranged from 0-425 gpm. The 425 gpm well originally served the Town of Littleton, NH. A quick review of wells from a sampling of the State of NH database in the Haverhill area did not uncover any bedrock wells with yields exceeding 100 gpm.

There are several communities along the Connecticut and Ammonoosuc Rivers withdrawing in excess of 100 gpm from the stratified drift materials: Lisbon-700 gpm, Littleton-400 gpm, Norwich-975, and Fairlee-900 gpm. The potable water source for North Haverhill is a spring with a source flow of 300 gpm and a couple of dug wells in the area yield as much as 80 gpm. A recent test well (VT Well # 10699) in the village of Newbury, VT and on the floodplain at 400 MSL, had a yield of 87 gpm. This well was only 45 ft deep and the soils were fine sands and gravels. As indicated earlier in the report, stratified drift material lies adjacent to many of the smaller tributaries running through Haverhill toward the Connecticut River. Figure 3 below was taken from the USGS report and it shows the overall boundaries of the stratified drift areas in Haverhill and around the Grafton County Complex. Until test pits are dug or a test well driven, the soils on the floodplain are assumed to be fine grained sands with an estimated hydraulic conductivity (K) of 5 ft/day and the transmissivity (T) is assumed to be less than 1000 ft²/day.

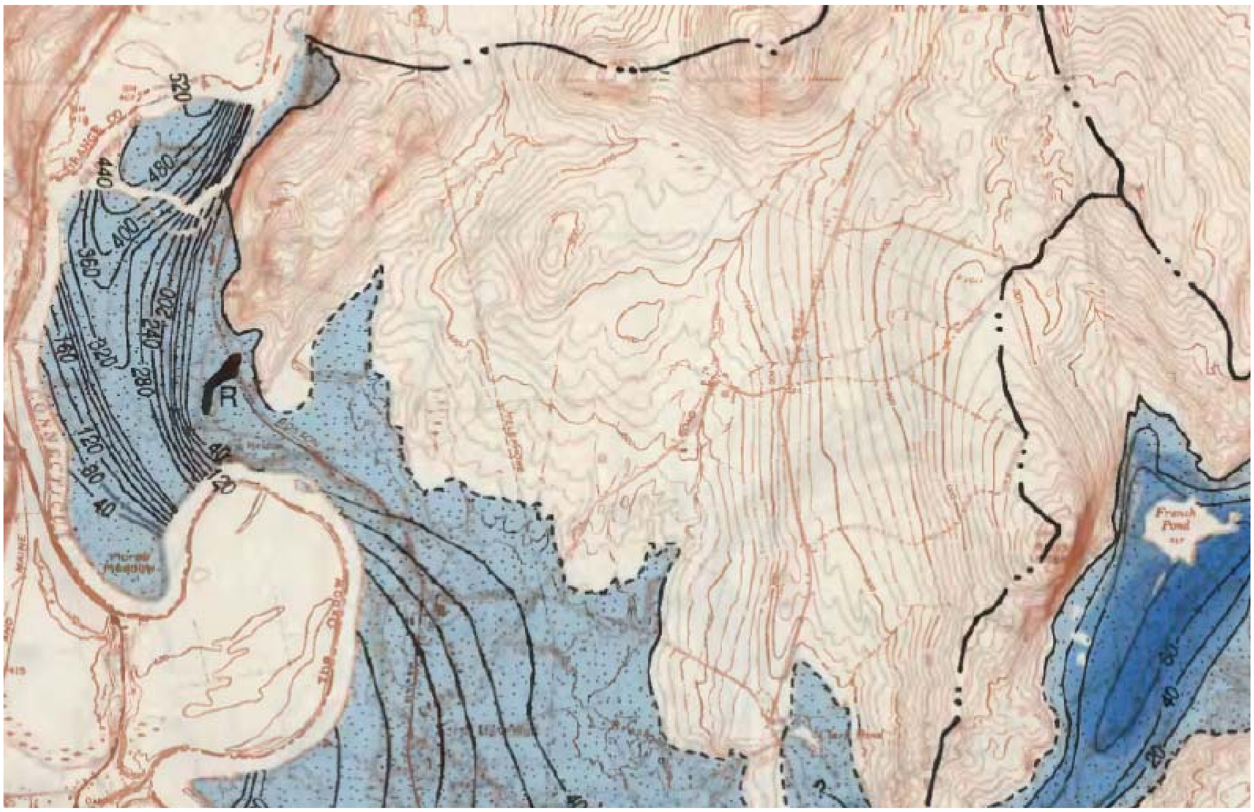

Figure 3: Stratified drift materials in the vicinity of the Grafton County Complex.

In Figure 3 the stratified drift materials are delineated within the blue. The dark blue areas near French Pond have dug well yields approaching almost 100 gpm. The “contour” lines within the blue area represent thickness of the saturated aquifer. The light blue areas have the lowest potential for well yield.

Grafton County Complex Wells.

As mentioned earlier, two wells have been identified on the Grafton County Complex. Well #1 as shown in Figure 1 was drilled on the lower floodplain in 1974 by Maher and penetrated 147 ft with the subsurface characteristics listed in Table 1, but it’s location on the floodplain is not known.   The water level was 23 ft below the ground surface. Well #2 is on the east side of Route 10 along the woods road leading to the upper fields and was abandoned after approximately 20-30 ft of drilling according to information supplied by Jim Oakes in a conversation with Jeff Hoffer, a consulting hydrogeologist working on a potential water source for the Grafton County Complex.

Table 1. Lithology of soils in well #1 on the cropland field (HKA2 in the USGS Report).

Start Depth (ft)	End Depth (ft)	Lithology Code	Description
0.00	21.0	S	Fine sand, some clay
21.0	35.0	CG	Fine sand, some gravel & clay
35.0	147.0	GS	Fine sand and gray clay
147			End of hole

Groundwater Chemistry

The groundwater chemistry of the water in the region is reasonably well known. The water quality data from the Knox Farm well are: a) pH = 7.62, b) Total Alkalinity = 74 mg/l, c) Hardness as $CaCO_3$ = 92 mg/l and d) Total Dissolved Solids = 100 mg/l. These waters are considered “medium hard.” The corrosion potential based on the Longelier Saturation Index and the Ryznar Stability Index implies that the water would show “heavy corrosion,” see Rafferty 1999. The waters for the North Haverhill Water Company also indicate the same heavy corrosiveness. Corrosion of metallic system components and/or pipes is going to be a problem in the long term with constant water flowing for a period of 20 years, although it can be controlled using an isolation heat exchanger of suitable material plus non-metallic piping, the use of an isolation heat exchanger is discussed later in this report.

The water temperatures measured in three wells at two different times from the stratified drift material in Haverhill have been reported by the USGS and they ranged from 44.8 - 48.8°F. This data is consistent with the average annual air temperatures for the region. One well did show extremely high iron content and high dissolved solids.

Potential Water Availability from Drilled Wells on the Grafton County Complex

The nearest source of information for yields of bedrock drilled wells near the Complex come from wells along Briar Hill Road which is on the east side of Route 10 and nearly circumvents the forest property of the Grafton County Complex. The average yield for 15 wells along the road was 8.1 gpm with a range of 0.5 to 20 gpm while the median value was 6 gpm and the static water level ranged between 5-30 ft below the ground surface.

Yield of gravel packed wells that could be potentially sited in the lower fields (cropland) is likely in the 50 gpm range based on the estimated flow of the Knox farm well and the test well in Newbury that we identified in the Vermont well database. To proceed to a level of confidence where a preliminary design could be validated, a pump test with drawdown measurements are needed in the low lying field to verify the yield and the radial extent the drawdown such that we can properly determine production and injection well spacing.

If a 200 gpm flow were required to supply a heat exchanger at the correctional facility at maximum operation, then 4-5 production wells and 4-5 injection wells would be needed to operate an open loop system based on the production of the Knox Farm well and the test well to the south in Newbury. Without actual data on drawdown from a well cited in this stratified drift material, it is hard to configure with a great deal of confidence a well field to insure that there was no flow or thermal interference between wells. However, if we assumed a 200 ft well protection radius, then a well field of roughly 800’ x 1000’ is required and this space is available where the crops are planted, see Figure 4. The economics of drilling 8-10 wells (4-5 with pumps) and constructing a manifold/feed line system to the complex would have to be evaluated as well if the site could sustain the induced groundwater flow vs. a closed-loop geothermal heat pump system as discussed later.

The other means of disposal for the water is an infiltration trench (a large leaching bed) and using the technique developed by Hantush (1967), the mounding of the water in the center of the trench can be calculated. Assuming a K value of 5 ft/day with an infiltration rate of 2.4 ft/day (200 gpm for 10 years) in a 40 ft x 400 ft trench in agricultural field, the mounding of the water in the middle of the trench is projected at roughly 18 ft above the existing water level (the existing levels are approximately 20 ft below the ground). Field pumping tests will confirm both the yield of potential wells as well as the coefficients used in the mounding analysis. The location of a trench could be on floodplain or on possibly on the upper terrace and difference sizes can be evaluated depending on the space available. This 18 ft mounding height is conservative and when the details of the heating load are determined, then the yearly flow requirements can be calculated and then the mounding heights. Another issue to address is the flooding of the fields and the protection of the electrical feed lines to the pumps.

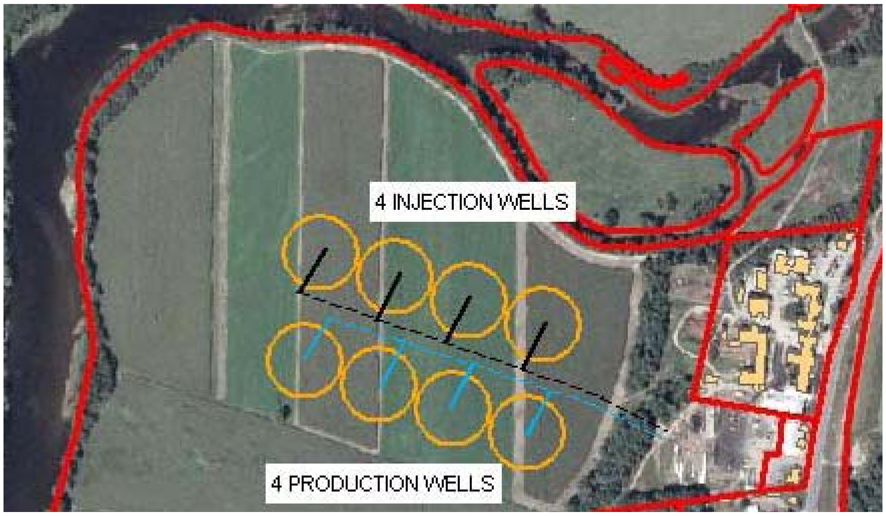

Figure 4: Approximate well layout given assumed loads and well production rates.

Permitting

The permitting of groundwater withdrawal and subsequent disposal of the water falls under the jurisdiction of the State of New Hampshire, Department of Environmental Services (NHDES).

1. A general application permit for Institutions falling under the "Underground Injection Control (UIC) Wells is required and falls within the Water Division of NHDES. The information needed is presented below and some permits/information depends on the type of geothermal system finally selected.

Facility Information - Please provide the following for large Underground Injection Control (UIC) geothermal withdrawal and injection system registration:

- A complete description of the facility and the type of heat exchange system proposed. Include locus map, tax map, and a site plan to identify the site, existing and proposed structures, topography, geothermal well or well field location, the nearest off-site /abutting lot, drinking water sources, and location and/or description of the facility's drinking water source.
- Submit a general description of the site geologic characteristics and geothermal well(s) construction logs that identify which subsurface unit is used as the system's thermal reservoir.
- Submit design plans identifying well and piping configuration including withdrawal and re-injection sampling taps, and flow metering locations.
- Describe the method of reject water (a.k.a. bleed-off water) disposal and identify the location of disposal area(s). Attach plans and supporting hydrogeologic information of any infiltration structures verifying the site is capable of supporting and/or infiltrating the discharge(s) without failure.
- Provide an estimated water balance for the withdrawal, re-injection, and reject water for both average operation and peak operation. *(Note that you may use a readily available temperature record from a nearby source to complete the water balance estimate).*
- Submit groundwater analytical results if available for the proposed geothermal wells.

For additional information or questions concerning this registration please contact Mitchell Locker at (603) 271-2858 or by e-mail at *mlocker@des.state.nh.us*.

Water Use Registration and Reporting - If the system will withdraw more than 20,000 gallons in any 24 hour period, the system must comply with *Water Use Registration & Reporting Rules*, Env-Wr 700. Please include the following to complete this registration:

- Types of water use at the facility in addition to geothermal heating/cooling.
- The total estimated average, maximum, and annual water use at the facility.
- Permit type and ID for all other water related permits.
- North American Industry (NAIC) or Standard Industrial Classification (SIC) Code.
- Name, location, type, and description of withdrawal or return for ALL sources and destinations.
- Measurement method and location for each source and destination.
- Maximum amount of water that can be withdrawn or returned for each source and destination.
- Topographic map with all sources, destinations, and facility locations identified.

For more information concerning this registration or the water use program please contact Derek Bennett at 271-6685 or dbennett@des.state.nh.us.

Notice for the Potential Need for a National Pollution Discharge Elimination System (NPDES) Permit - If the System Design includes a bleed/reject water discharge to a surface water, a storm sewer discharge with an outflow to a surface water, or a detention / retention pond discharge with an overflow to a surface water; then the project may require a federal NPDES permit.

For more information concerning this program please contact
Jeff Andrews at (603) 271-2984 or by e-mail at *jandrews@des.state.nh.us*.

Notice Regarding Waivers from Other NHDES Programs– If the water balance provided with the facility information indicates that potential reject /bleed water volume may exceed 57,600 gallons in any 24-hour period, then both a large groundwater withdrawal permit and a water conservation program may be required for the project. If, at peak operation, the system bleed/ reject discharge does not exceed 57,600 gallons in a 24-hour period then a written waiver to these programs will be included in the UIC discharge registration issued for the system.

For additional information or questions concerning this waiver approval or conditions please contact Tim Nowack at (603) 271-8866 or by e-mail at tnowack@des.state.nh.us

2. A permit for a large groundwater withdrawal is required if the daily flow extracted from the subsurface and not returned to the aquifer exceeds 57,600 gpd, e.g. bleed water from a standing column well returned to a pond/storm drain/stream/etc or water used for potable purposes are examples. A geothermal system should not be designed that would trigger this permit application and the open loop system proposed here will not have any appreciable consumptive use of water unless it was used to supply potable water as well.

3. All geothermal systems, including vertical closed-loop geothermal wells and horizontal ground coupled systems also require a UIC permit even though no water is being extracted and re-injected into the aquifer. These systems follow the same permitting guidelines as the UIC to insure the construction falls under the Best Management Practices for Groundwater Protection.

4. All drilled wells follow guidelines established by the NH Water Well Board.

In conclusion, it would appear that permitting will not be a major problem for the types of geothermal heat pump systems proposed here for the Grafton County Correctional Facility (GCCF).

Building Heat and Cooling Loads

The first step in assessing the feasibility of a geothermal based heating system is to establish the building heating and cooling loads. Our proposal for this study was based on the assumption that the building loads as calculated by the designer would be available to us as a starting point. However, other than the equipment sizing this information was not provided to us. The equipment sizing, especially fuel fired heating equipment, is usually not a good guide to use in sizing a geothermal heating and cooling system due to the fact that this equipment is typically oversized significantly since there is little cost penalty for doing so. In the case of a geothermal based system, significant cost penalties will result from system over-sizing and these will in turn adversely affect economics.

Making a complete calculation of the heating and cooling load for proposed GCCF is beyond the scope of this feasibility analysis, thus in the absence of the loads calculated by the contracted design team we relied on heating and cooling loads calculated for typical buildings by a DoE sponsored tool called "HVACPowDen08a." This tool and user documentation are available at http://www.geokiss.com/hsoftware.htm. Because this tool does not have a building type for correctional facilities the loads were prorated for various types of buildings that would have uses similar to those of the various areas within the proposed GCCF. All calculations were done for buildings in DoE Climate Zone 6 which is the appropriate climate zone for the GCCF. The HVACPowDen08a tool provides results for three levels of energy conserving design: Base, High Efficiency, and Premier Efficiency. Quoting directly from the user documentation for HVACPowDen08a with regards to the base level of energy efficiency: "Climate corrected envelope specifications and lighting power densities comply with ASHRAE 90.1. Building occupancies and ventilation rates use ASHRAE Standard 62.1-2004 as the primary reference for default values. Base level loads were conducted with 90% ventilation efficiency without the assistance of heat recovery units (HRUs) on the ventilation air." Since the GCCF is being designed to be a LEED compliant facility, we felt that the "High Efficiency" level was the most appropriate assumption for that facility. This basically assumes 25% greater insulation than base, efficient lighting, better insulated ducts than base, and most importantly, heat recovery on the ventilation air, a design feature that is included in the current design for the GCCF. Table 2 provides a summary of the predicted loads for the GCCF using HVACPowDen08a used to prorate the loads for the various areas as discussed above. For each type of building a 100,000 square foot area was assumed as noted in Table 2.

Table 2: Predicted loads from the assumed area types of HVACPowDen08a.

Space type (per HVACPowDen08a)	**Area** (sq.ft.)	**Cooling** (tons/100,000 sq.ft.) Base	**High**	Premier	**Heating** (kBtu/hr-100,000 sq.ft.) Base	**High**	Premier
Cafeteria	4200	609	**448**	415	5930	**1870**	1580
Dormatory	69510	174	**114**	96	1770	**850**	700
Office, medium density	32570	183	**133**	100	2400	**1400**	1100
Fire Station	7900	136	**93**	79	2430	**1410**	1150

We assumed that the food service area would be suitably described by the HVACPowDen08a type "Cafeteria". The intake and multipurpose areas were lumped in with the office areas. For the maintenance, receiving, storage and mechanical areas we lumped them into the HVACPowDen08a type "Fire Station" as that appeared to be the most appropriate building type for these areas of those available in HVACPowDen08a. The inmate housing areas were designated as the HVACPowDen08a type "Dormitory". The total building area was taken as 114,180 square feet from the drawings provided to us, specifically AE001. The areas for each HVACPowDen08a type as described above were then scaled from drawing AE004 with the exception of the dormitory area, which was simply assumed to be the balance of the building after subtracting the areas designated otherwise. With these assumptions taken into account the heating and cooling loads estimated by HVACPowDen08a for the entire building are shown in Table 3 below.

Table 3: Heating and cooling loads for the GCCF as predicted using HVACPowDen08a.

	Area	Cooling (tons)			Heating (kBtu/hr)		
	(sq.ft.)	Base	**High**	Premier	Base	**High**	Premier
Building totals	114,180	217	**149**	123	2,453	**1,237**	1,002

Actual load calculations for the GCCF building would provide much more detailed information about the loads than what we have obtained by our estimating methods here. Specifically what is needed for the design of a geothermal heat pump system are the "block loads" on the peak design heating and peak design cooling days. Block loads differ from installed equipment capacity and even the actual peak load. Without delving into a level of detail beyond the scope here, suffice it to say that the block loads are average loads within specific blocks of time during the 24 hour design day and they are aggregated for the entire building taking into account the diversity of demand across all zones; the interested reader is referred to Kavanaugh and Rafferty (1997) for further discussion. These block loads are then used by design tools that account for the heat pump performance, and in the case of a closed-loop geothermal heat pump system, model the response of the ground to the net heat extraction/rejection loads placed on it. For open-loop geothermal heat pump system design the process is a bit simpler as the ground's response need not be modeled, however the flow rates of water required are still based on the aggregated block loads and the performance of the heat pumps. For the calculations performed here we used the design tool GCHPCalc available from Energy Information Services (http://www.geokiss.com/index.htm). Because we lacked the detailed load calculations for the GCCF, diversity was accounted for by assuming a value of 0.8 for the diversity factor across all zones during the time of the peak block heating and cooling loads.

In addition to the space heating and cooling loads of Table 3, there will be service hot water heating loads primarily from showers and meal preparation/cleanup. These loads would also be met by heat pumps, water-to-water heat pumps specifically. We have used the data provided by the facility designer in establishing these loads, their estimates being 250 showers per day and 750 meals per day. The actual hot water requirements for this quantity of daily showers and meals was determined by applying service hot water requirements data from ASHRAE (2007), the resulting values being approximately 4,700 gallons/day for showers and 1,800 gallons/day for meal preparation and cleanup. For design of a geothermal heat pump system these hot water heating loads must also be broken into block loads as discussed above. This was done based on reasonable assumptions about when showers and meals would be taken.

When the maximum block load resulting from hot water generation is added to the maximum block load for space heating the result is a maximum block load of 1,210 kBtu/hr. For cooling the maximum block load is 1,390 kBtu/hr (115 tons). Note that in the cooling case the hot water heating helps offset a portion of the cooling load in determining the block cooling load since the heat pumps that are heating service hot water are removing heat from the system that was input by the heat pumps that are in space cooling mode, the net effect being the block load.

Geothermal System & Costing

System Configuration: The first option which should be explored for the GCCF is an open loop type geothermal heat pump system as shown in Figure 5 (note a closed-loop system is discussed briefly later). Using a conservative design of 40 gpm for each well, a minimum of 12 wells will be required, at least five production wells and a minimum of five reinjection wells, with a backup

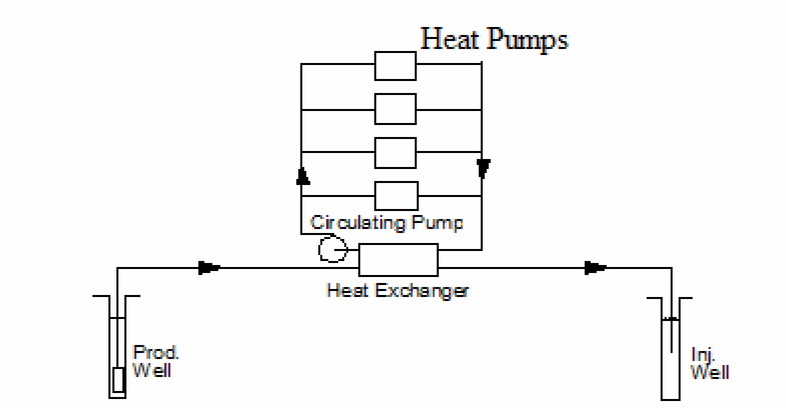

Figure 5: Basic "two well" groundwater geothermal heat pump system with isolating heat exchanger. (Figure courtesy of Kevin Rafferty)

well for both withdrawal and injection. During actual well installation the well yields are determined for each well and if they consistently are above 50 gpm, then one can reduce the number of wells need to four units vs. the five we've assumed, but that is a field determination that can't be made here. For commercial scale groundwater based systems it is standard practice that the heat pumps would be isolated from the groundwater by a heat exchanger and a secondary building circulating loop. This provision ensures that any problems induced by water quality (i.e. scaling or corrosion) will be isolated from the water-to-refrigerant heat exchangers within the heat pumps which in general cannot be mechanically cleaned or easily replaced. The heat exchangers used for isolation are typically of the plate-and-frame type with stainless steel plates which are easily cleaned and are highly resistance to corrosion.

Well Water Requirements: The determination of well water flows in an open-loop geothermal heat pump system is a classic tradeoff between the additional pumping cost of higher flow rates and the improved performance of the heat pumps that results for the more favorable average evaporator temperatures provided by higher flow rates. The groundwater temperature also is a constraint on the design; especially in heating dominated climates such as is the case here where there is only limited heat that may be removed from the water before the freezing temperature is approached. The detailed analysis needed to determine an accurate estimate of the flow rate of ground water is not supported by the level of detail available at this stage and is beyond the scope of this feasibility analysis. Approximate calculations carried out with the loads estimated above suggest that about 200 gallons per minute of well water would be required; this assumes a well water temperature of 47 °F.

Heat Pump Performance: Performance of heat pumps in the heating mode is measured by a parameter called the Coefficient of Performance (COP). The COP, simply put, is the ratio of the heat output to the electrical energy input. Thus if we have a COP of 3, we would be obtaining 3 units of heat for each unit of electricity input, or three times what we would obtain from electric resistance heating. In this example of a COP of 3, the other two units of heat would come from the groundwater. The *system COP* includes the impacts of the well pump and the circulating pump(s) for the building loop, as well as the heat pumps themselves. With a well water temperature of 47 °F we would estimate the system COP to be approximately 4 assuming that high efficiency heat pumps would be used, which we would highly recommend.

System Operating Temperatures: To aid in understanding how the heat pump system will function, we will provide approximate temperatures within the system. As noted above, because of the limitation that the freezing point of water imposes on an open-loop geothermal heat pump system, the heating mode operation of the system is constrained with respect to how much heat may be removed from each unit of groundwater. The well water temperature we are estimating at 47 °F based on local experience (measurements would be taken as part of the test well recommended later). In the heating mode when we are removing heat from the water with the heat pumps the temperature of the groundwater leaving the heat exchanger would be about 10 °F less than the ground water supplied to the heat exchanger, i.e. approximately 37 °F. On the building loop side of the heat exchanger the water temperature returning from the heat pumps would be lower than this by about 3 °F (the "approach temperature" of the heat exchanger) thus it would be entering the heat exchanger at around 34 °F. The temperature of the building loop water leaving the heat exchanger and being supplied to the heat pumps is determined by the flow rate in the building water loop and is estimated to be around 40 °F. Note that temperature of the water leaving the heat pumps (34 °F) is very close to freezing; to prevent freeze-up in the evaporator of the heat pump a small amount of antifreeze would be added to the building circulating water loop.

In the cooling mode there is much more leeway as we can have leaving water temperatures from the heat exchanger as high as 80 °F or more with diminished heat pump performance being the only penalty for higher operating temperatures. As discussed earlier there is a trade-off between the higher heat pump performance that comes with higher groundwater flow rates and the higher pumping energy that results from those higher groundwater flow rates. Actual temperatures (and pump control strategies) would be worked out in detailed design, but for illustrative purposes assume that the groundwater leaving the heat exchanger might be around 70 °F, thus the temperature increase across the heat exchanger would be 23 °F (70 °F - 47 °F), compared to a temperature drop of only 10 °F in the heating mode. On the building loop side of the heat exchanger the water temperature returning from the heat pumps would be higher than this by about 3 °F (again the "approach temperature" of the heat exchanger) thus it would be entering the heat exchanger at around 73 °F. The temperature of the building loop water leaving the heat exchanger and being supplied to the heat pumps is determined by the flow rate in the building water loop and is estimated to be around 65 °F. This temperature, called the "entering water temperature" or EWT is a primary factor in determining the heat pump performance. A cooling mode EWT of 65 °F is very favorable and thus cooling performance should be expected to be very good. This is in part responsible for the superior cooling performance that can be expected from the proposed open-loop geothermal heat pump system when compared to either air-cooled or water-cooled central chillers that are dealing with the reality of high outdoor air temperatures at the time of peak cooling demand.

The above temperatures are typical of what might be expected at the peak operating conditions. They are provided for illustrative purposes only; they should be considered approximate and not a basis for the design which must be conducted using the methods of Kavanaugh and Rafferty (1997) once building loads are accurately known and actual equipment has been selected.

Operating Costs: The groundwater based geothermal heat pump systems will use electricity as its "fuel" and all fuel oil use will be eliminated. Current cost for electricity is about 0.142 $/kWh, as price increases are known to be forthcoming we'll assume 0.16 $/kWh for the calculations here. The cost of #2 fuel oil under the current contract is $4.00 per gallon. The designer for the jail has estimated annual fuel consumption for the jail as being 90,000 gallons/year. At a seasonal boiler efficiency of 75% this would represent a heat consumption of 9,350 MBtu/yr. At a system COP of 4 (system COP includes power for pumping) this would equate to an electric consumption for the heat pump system of 685,000 kWh/yr. With the assumed electric rate of 0.16 $/kWh the annual electric cost for *heating* with the heat pumps would be approximately $110,000 per year. This should be compared to a cost of $360,000 per year for the estimated fuel oil consumption in the current design, or a saving of about $250,000 per year from the open-loop geothermal heat pump option. This estimated saving is based on the fuel consumption estimated by the facility designer and if that fuel consumption estimate is high, then saving will be overestimated. Of course the converse will of course be true if fuel consumption is higher than estimated, i.e. saving will be even greater.

During the cooling season there would also be savings since as noted above the open-loop geothermal heat pump system would operate at significantly higher efficiencies that a central air-cooled chiller on the variable air volume (VAV) system as proposed by the facility designer. These saving are more difficult to estimate, but we would estimate they would be $22,300 per year or more. This is based on a geothermal heat pump Vs an air-cooled chiller with VAV performance comparison using HVACPowDen08a and estimates of the energy consumption based on a full load cooling hours estimate. Part load efficiencies, particularly of the chiller with VAV system will be lower than full load efficiencies so this estimate of cost savings will likely prove to be very conservative.

Capital Cost: The installation cost of the system is difficult to estimate with a high degree of certainty without more design specifics. According to Kavanaugh and Rafferty (1997) the first cost of a geothermal heat pump system can be equal to or as much as 20% less than the first cost of a 4-pipe VAV system as specified in the original design for the GCCF. Certainly as a conservative first order estimate it seems reasonable to assume that the cost of the heat pumps, heat exchangers, additional electrical service, and the piping they would require within the building would be offset by the boilers, fuel handling and storage, and VAV boxes and piping, all of which would be deleted from the project.

In addition there would be the savings from the cost of the chillers that would also be deleted from the project, we estimate this cost saving would be around $240,000 (based on approximate pricing from chiller vendor). This is a conservative estimate as it only includes the cost of the chillers and does not include the fixtures needed to support the chillers or the specified 30% propylene glycol that will be required for freeze protection since the chillers will be located outdoors. For the open-loop geothermal heat pump system with the well field located down in the flood plain we estimate the cost of the wells, pumps, and piping needed outside of the building to be $280,000. (6-150 ft supply wells and 6-150 ft injection wells @ 30 $/ft, 6 pumps at $6K each, 3000 ft of piping at 50 $/ft, and 2000 feet of electrical @ 20 $/ft). Thus this would indicate that the total open loop geothermal system cost would be about $40,000 more than the system currently proposed. Given the uncertainty in our estimates due to the unknowns, this is essentially equal in cost.

Closed-loop geothermal heat pump option: The discussion so far has focused primarily on an open-loop geothermal heat pump system. In the event that adequate groundwater is not available or its quality is deemed unacceptable, a closed-loop system would be an option. The concept of a closed-loop geothermal heat pumps system is shown in Figure 6 for a residential scale system. In an application for the GCCF there would be multiple heat pumps within the building (as shown in Figure 5) and many more borehole heat exchangers than the three shown in Figure 6, however the basic concept is the same. Rather than using groundwater as is done with the open-loop system, the closed-loop system exchanges heat with the ground via high density polyethylene (HDPE) piping that is buried in the ground. Within this piping is water or a water-based solution (i.e. may contain antifreeze) that is used to convey heat from the ground to the heat pumps when they are in the heating mode or convey heat from the heat pumps to the ground

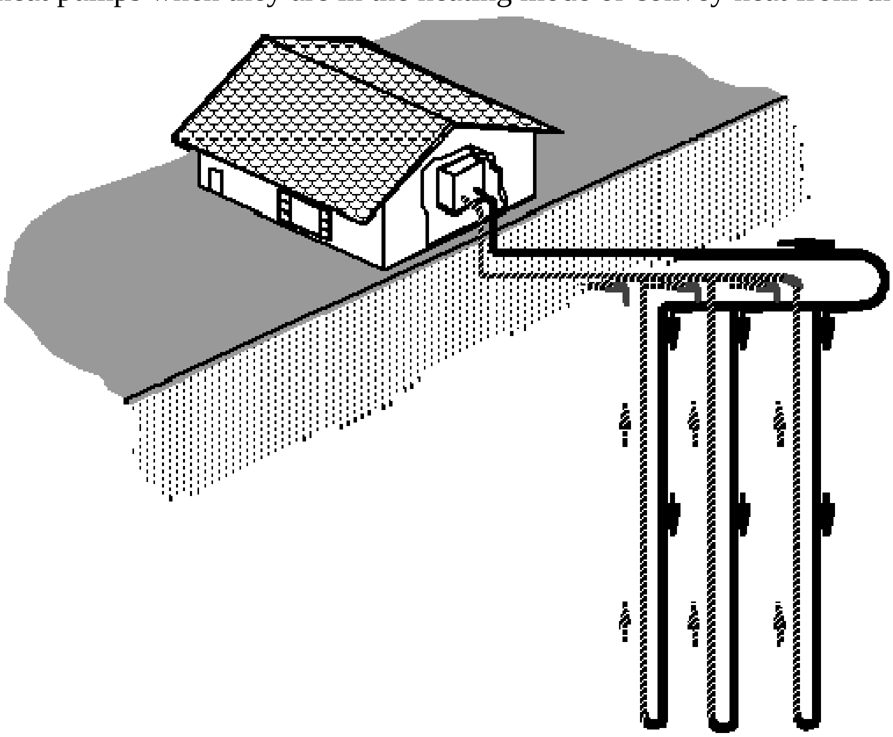

Figure 6: Residential scale closed-loop geothermal heat pump system.

when they are in the cooling mode. For more information on these systems the reader is referred to Phetteplace (2007). Using the block loads estimated earlier for the GCCF a borehole heat exchanger was designed using the GCHPCalc design tool. GCHPCalc is a well verified and widely used design tool in the geothermal heat pump industry and is available from Energy Information Services (http://www.geokiss.com/index.htm). Using a 12 by 12 grid of borehole heat exchangers spaced at 20 feet apart GCHPCalc predicts that the GCCF would require the borehole heat exchangers to be 200 feet deep each. Note that the basic choice of well field arrangement and thus the resulting borehole heat exchanger depth is somewhat arbitrary; half as many borehole heat exchangers at twice the depth would also work. The actual choice of depth would be determined after a test bore has been drilled and the geological conditions are better known. It is quite likely given what is known about the geology at the GCCF site that bore would be deeper than 200 feet since no bedrock is expected until much greater depths are reached and drilling conditions would likely be quite uniform up until bedrock is reached. The borehole heat exchanger field could be located under the parking lot for the GCCF and/or other areas adjacent to the building. With a total footprint of about an acre finding sufficient area should not present a problem. At an estimated cost of $15-20 per lineal foot (all inclusive) for the borehole heat exchanger field that would mean its estimated cost would be approximately $432,000 to $576,000. Thus for the closed loop option the cost saving from deleting the chillers will not offset the cost of the borehole exchanger field. It does appear that the additional cost would be paid for in about one year by the operating cost savings as estimated above. Note that the in-building portion of the costs for a closed-loop system would likely be slightly lower than for the open-loop option as the heat exchangers would be eliminated.

It should be noted that for both the closed-loop and open-loop options a significant amount, perhaps 50% or more of the space consumed by the current 2500 sq. ft. mechanical room would be freed up since the boilers would be eliminated and only pumps and heat exchangers (open-loop option) would remain. In addition, it would also be expected that maintenance costs would be reduced by approximately 50% by either geothermal heat pump option.

The estimates we have prepared here are based on the GCCF proceeding as currently configured. If the facility is scaled back any additional capital cost for the geothermal options will decrease relative to the conventional equipment options. This comes about due to the fact that the geothermal options decrease in cost essentially in proportion to the capacity of the system, where as for conventional systems the cost reduction will not be as great.

Recommendations

We would recommend that the following steps be taken and we stand ready to help the County do so:

- A detailed heating and cooling load determination should be undertaken to provide results in a form suitable for geothermal heat pump system design.
- A gravel packed test well for an open-loop installation should be drilled on the agricultural field and evaluated for its yield (gpm) & drawdown (feet) including measuring the radial extent of the drawdown in a couple of observation wells.

- If the open-loop system well test does not appear to indicate that such a system is possible, a closed-loop test bore with thermal properties measurements should be commissioned.

If the Grafton County Commissioners decide to pursue the geothermal heat pump option further, as we hope they do, we would recommend that they look into the availability of rebates or other financial incentives from state and federal sources. Third party financing of that portion of the system might be an option that would allow rebates normally not available to the County government to be utilized. We would be glad to help the County pursue these opportunities if engaged to do so.

Finally, while geothermal heat pump systems are not complicated, they are not common place either, especially in the Northeastern United States. Certain aspects of their design and installation are foreign to designers and installers of "conventional" HVAC systems. Experience has shown that when approached like a conventional system by designers and installers of conventional systems the result usually suffers both with respect to functionality and efficiency. For these reasons we would recommend that if the County decides to undertake a geothermal heat pump project for the proposed GCCF that they retain the services of individuals/organizations that are experienced in the field to review/oversee both the design and construction. Of course, we would be glad to function in that capacity for the County, but foremost we want to stress that someone qualified be retained; it does not need be us.

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