Shippensburg University
1871 Old Main Drive
Shippensburg, PA 17257

Ground Source Heat Pump
Feasibility Study

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Entech Project #: 2184.32

June 3, 2010
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Attachment 1 – CMX Engineering Geothermal Feasibility Study
1.0 BACKGROUND
In the April 2008 Campus Master Plan prepared for Shippensburg University, a variety of methods for heating and cooling the campus were explored. One heating/cooling option considered for the new residence halls in the campus master plan was for a ground source heat pump system. Other options, such as replacing the existing coal-fired heating plant with a new, natural gas-fired heating plant and installing a central chilled water system were also explored. However, before proceeding with any of the options recommended in the master plan, Entech Engineering was asked to complete a feasibility study to analyze the options in more detail. This report presents the feasibility study for installing ground source heat pumps for the residence halls.

2.0 PROPOSED RESIDENCE HALL PROJECT
The campus master plan proposes the existing dormitories (2,500 beds) be replaced with new living/learning residence halls. Six new buildings will be constructed, three in the East Quad and three in the West Quad. Air conditioning will be provided in all the buildings. The buildings in the West Quad are expected to be approximately 425,000 square feet, and the East Quad 438,000 square feet. The buildings will be constructed in three phases over three years. The existing residence halls will also be demolished in a phased approach. The drawing on the next page is a campus site plan showing the location of the existing and proposed residence halls.

3.0 GROUND SOURCE HEAT PUMPS
Heat pumps operate using a refrigeration cycle, the same cycle used by household air conditioners. A household window air conditioning unit is a good example of how a heat pump works. During the summer, the air conditioner rejects heat from the inside of the house to the outdoor air. If the air conditioner was turned around, heat would be removed from the exterior air and rejected into a house. Heat pumps accomplish this by using a reversing valve in the refrigeration cycle to allow the cycle to run in reverse during heating mode. Ground source heat pumps operate under the same principal; however, the system uses a well field installed in the earth instead of the air as the heat rejection and absorption medium.

4.0 GEOTECHNICAL AND THERMAL CONDUCTIVITY TESTS
The well field is a critical component of any geothermal heat pump system. In order to have a better understanding of the geotechnical conditions of potential well field sites on campus, Entech subcontracted CMX Engineering to drill two test wells, one at the East Quad and one at the West Quad and perform a subsurface analysis for the wells. CMX Engineering preformed subsurface investigation, thermal conductivity testing, and a geothermal engineering analysis of the test wells. The results are contained within the attached report.
5.0 BUILDING HEATING AND COOLING LOAD
Entech used Carrier’s Hourly Analysis Program (HAP) to calculate preliminary building
HVAC loads and simulate yearly energy use for the proposed dormitories. Since the
buildings are not yet designed, Entech modeled a 97,200 square foot “typical” residence
hall in HAP and used these loads to estimate the heating and cooling requirements for
all six buildings. The HVAC loads for this conceptual building were estimated to be as
follows:

Modeled Heating and Cooling Load
Heating: 2437 MBH or 25 Btu/SF
Cooling: 200 Tons or 486 SF/ton

The loads were entered into a computer modeling program called “GS Heat Pump,”
which was used to size the well field. Using the thermal conductivity test results from the
test wells, the required well field size was calculated as shown below. Because the
geology on campus is so complex (rock, voids, etc) we have added 20% to the required
bore length as a contingency.

West Quad Well Field (Test Well 1)
Number of Buildings 3
Total Building Floor Area 424,700 SF
Total Cooling Load 875 tons
Total Heating Load 10,620 MBH
Thermal Conductivity 1.6 Btu/hr-ft./°F
Thermal Diffusivity 1.07 ft²/day
Well Bore Length Required 181,400 linear feet
Assumed Well Depth 500 ft.
Number of Wells Required 365

East Quad Well Field (Test Well 2)
Number of Buildings 3
Total Building Floor Area 438,400 SF
Total Cooling Load 900 tons
Total Heating Load 10,960 MBH
Thermal Conductivity 1.78 Btu/hr-ft./°F
Thermal Diffusivity 1.19 ft²/day
Well Bore Length Required 177,400 linear feet
Assumed Well Depth 500 ft.
Number of Wells Required 355
6.0 WELL FIELD SIZING AND LOCATION
Assuming the wells are 20 feet apart, the general size of the well field is shown for each quad in the figure shown on the following page. The final arrangement must change in order to avoid existing underground utilities and allow proper phasing of the work. However, this sketch gives the approximate size that will be required for each well field. While the available open land is limited, it appears that it is possible to fit in all the wells that will be required. However, as the well fields move further from the buildings, the pumping costs will increase.

7.0 WELL FIELD COST ESTIMATE
Negley’s Well Drilling provided Entech with a cost estimate to install each well, including piping and grouting. The estimated cost for a well at Site 1 (West Quad) is $8,475 and the cost for a well at Site 2 (East Quad) is $6,405. This cost does not include the cost to relocate existing utilities or patch and repair roads, sidewalks, etc. It should be noted that the estimates are based on only two test bores. Underground conditions can vary considerably, and added contingency should be included to cover unforeseen conditions.

The cost of the well field at Site 1 (West Quad) is approximately $3,100,000. There will be an additional cost of approximately $1.3 million to connect the piping into headers and connect to the buildings. Therefore, the total cost of the West Quad well field is estimated to be $4.4 million.

The cost of the well field at Site 2 (East Quad) is approximately $2,300,000. With the interconnecting piping cost of $900,000, the total cost is estimated to be $3.2 million.

The total cost for both fields is approximately $5.4 million and with the interconnector to the buildings, the total cost is $7.6 million. The cost estimates for the well fields do not include the cost to relocate existing utilities, which interfere with the well field location, or the cost to patch and repair the roads. Contingency and engineering costs are also not included.
8.0 ENERGY SIMULATION
Entech used Carrier’s HAP program to run a simulation on the sample 97,200 square foot residence hall described earlier in this report. This estimated energy cost per SF of floor area was then used to estimate the energy cost for all six new buildings. The energy model estimated the annual energy cost for the building using ground source heat pumps and then compared it to the cost to operate the buildings if they used fan-coil units. With fan-coil units, the heating would be supplied from the central heating system and chilled water supplied from the proposed central chilled water system. The energy simulations use the following assumptions:

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<td>Average central chilled water system efficiency</td>
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<td>Heat pump efficiency (cooling) kW/ton</td>
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<td>Heat pump (heating) COP</td>
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Using the assumptions described above, the estimated annual energy usage and cost for the new residence halls is shown in the table below. The table compares the ground source heat pump option with the alternative option of installing fan coil units connected to a central heating and chilled water system.

<table>
<thead>
<tr>
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<th>Fan Coil (Gas)</th>
<th>Fan Coil (Coal)</th>
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<td>Electric consumption (kWh/yr)</td>
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<td>Coal consumption (tons/yr)</td>
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<td>112</td>
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<tr>
<td>Annual energy cost ($/yr)</td>
<td>$630,000</td>
<td>$613,000</td>
<td>$520,000</td>
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</table>
9.0 CONCLUSION

Ground source heat pumps are an energy efficient HVAC technology because the well field allows the heat pumps to use the earth to reject and absorb heat. The well field also provides a means to efficiently reject the heat while air conditioning the building without the need for a cooling tower. In general, the economic feasibility for ground source heat pumps will be determined by the ability to pay for the additional cost to install the well field through the anticipated energy cost savings.

With its central heating plant and the possibility of installing a central chilled water plant, the University has other energy cost efficient strategies at its disposal. Since the existing residence halls and the rest of the campus are already connected to the central heating plant, it is rather simple to take advantage of the relatively low cost of coal. If the campus constructs a new, efficient gas-fired heating plant, the fuel cost is generally higher than when using coal. This study evaluates both fuel types.

In the cooling season, the ground source heat pumps are efficient, but not as efficient as what a central chilled water plant can provide. Consequently, during the cooling season, the advantage is with the fan-coil option. When you add the heating and cooling together, the total energy cost for the ground source heat pump option is $630,000 and the annual energy cost for the fan-coil option is $613,000 (Gas) and $520,000 (Coal).

Besides energy consumption, other factors that should be considered are as follows:

- Heat pumps have a normal operating life of approximately 15 to 18 years. Fan coil units and central boilers/chillers have a normal operating life of 25 to 30 years. Therefore, more maintenance will be required for heat pumps.
- A phasing plan will have to be developed to construct the wells around existing and proposed buildings, and existing and proposed utilities. It does not appear that there is sufficient room to install the wells at one time without interference from the construction of the new residence halls.
- A phasing plan for a central heating and cooling system must also be developed. The new central cooling system will not be completed in time for the first commissioning of the first phase of the residence hall project. Temporary chillers will be required for the first year. For heating, valved connections should be installed to accommodate future connection to a possible hot water distribution system replacing the steam distribution system.

After reviewing the factors discussed above, we recommend the University continue with using the central utility systems to serve the new residence halls. There is not an energy cost savings associated with the ground source heat pump option which justifies the expense to install the necessary well field. Because of the challenging geology at the campus, there is also a risk involved with having to bore such large well fields. There is a higher probability of finding geotechnical issues that will increase the cost to install and operate the wells.

With the central utilities, the University will have the following advantages:

- There is an economy of scale with central utilities. Removing a significant portion of the campus from the central heating system does not decrease the number of operators, plant maintenance, etc. and does not significantly decrease the cost to
install and maintain distribution piping throughout the campus. There will be additional cost to maintain a well field with hundreds of wells and miles of piping.

- With central utilities there are technology options that can be implemented now or installed later. For example, cogeneration, thermal storage, bio-mass and technologies not yet invented can be connected to the central utilities.
- The campus presently does not have a central chilled water system. Such systems are energy efficient, more reliable, less equipment noise at the buildings, and as a whole, less costly to install than distributed chillers installed at each building. However, it is difficult to make the initial investment when only a few buildings require new cooling equipment. With the University adding so much cooling at one time (for the residence halls), a great opportunity to install a central chilled water system is presented.

Based upon the above analysis, we recommend the University continue to use the central heating plant for the new residence halls. We also recommend a central chilled water system be installed.
ATTACHMENT 1

CMX Engineering
Geothermal Feasibility Study
GEOTHERMAL FEASIBILITY STUDY

SHIPPENSBURG UNIVERSITY

SHIPPENSBURG TOWNSHIP, CUMBERLAND COUNTY, PENNSYLVANIA

PREPARED FOR:

MR. BRYAN HAAG
ENTECH ENGINEERING
4 SOUTH 4TH STREET
READING, PA 19602

PREPARED BY:

Mr. David J. Buckwalter
PROJECT MANAGER

MR. EDWARD L. BALSAVAGE, P.E.
MANAGING PRINCIPAL

CMX PROJECT NUMBER - 080244901

9/9/08

WORKING TOGETHER FOR A BETTER TOMORROW

910 CENTURY DRIVE | MECHANICSBURG, PA 17055
TEL 717.458.0800 | FAX 717.458.0801 | WWW.CMXENGINEERING.COM
ARIZONA  FLORIDA  MARYLAND  NEVADA  NEW JERSEY  NEW YORK  PENNSYLVANIA  MEXICO
September 9th, 2008

Mr. Tom Wocklish
Entech Engineering
4 South 4th Street
Reading, PA 19602

RE: Geothermal Feasibility Study
Shippensburg University
Shippensburg Township, Cumberland County, Pennsylvania
CMX Project No.: 080244901

Dear Mr. Wocklish:

Submitted herewith is our Geothermal Feasibility Study for the Shippensburg University to be located in Shippensburg Township, Cumberland County, Pennsylvania. Our services were provided in accordance with our Proposal, dated April 24th, 2008 and your Agreement, dated June 24th, 2008.

CMX’s program of services included Subsurface Exploration, Coordination and Inspection of the Subsurface Exploration, Thermal Conductivity Testing and Preparation of this Feasibility Study.

CMX appreciates the opportunity to be of service at this phase of the project. If there are any questions pertaining to this matter, or if additional information is required, please contact the undersigned at any time.

Sincerely,

CMX

[Signature]

David Buckwalter
Project Manager

WORKING TOGETHER FOR A BETTER TOMORROW

910 CENTURY DRIVE | MECHANICSBURG, PA 17055
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ARIZONA  FLORIDA  MARYLAND  NEVADA  NEW JERSEY  NEW YORK  PENNSYLVANIA  MEXICO
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## Appendices

- Topographic Map
- Geologic Map
- Geothermal Test Well Location Plan
- Test Well Logs

## Attachments

- Formation Thermal Conductivity Test and Data Analysis (TW-1)
- Formation Thermal Conductivity Test and Data Analysis (TW-2)
1.0 INTRODUCTION

This report was prepared by CMX, on behalf of Entech Engineering of Reading, Pennsylvania, and contains the results of a geothermal feasibility study conducted at Shippensburg University, located in Shippensburg Township, Cumberland County, Pennsylvania. The purpose of this investigation has been to determine the geothermal gradient and thermal conductivity of the subsurface materials for use in design and construction of a heating, ventilating, and air conditioning (HVAC) system.

The scope of work for this project included the completion of a subsurface field investigation, thermal conductivity testing, and geothermal engineering analysis. This report summarizes the results of the work performed and provides conclusions concerning the suitability of the project site for the installation of a geothermal HVAC system.

2.0 SITE AND PROJECT DESCRIPTION

The project site currently consists of the existing Shippensburg University Campus located in Shippensburg Township, Cumberland County, Pennsylvania. Geothermal well location TW-1 was situated in a grass-covered area immediately between Kieffer Hall and Harley Hall, while test well TW-2 was completed immediately north of the existing water tower. Topography across the test well locations varies, with the general location of TW-1 sloping downwards towards the south and the ground surrounding TW-2 sloping downwards towards the east. The location of the site in relation to the surrounding area is presented on the Topographic Map of Site, presented within the Appendix of this report.

The project will consist of constructing two (2) separate housing clusters, replacing the existing dormitories, with the possibility of ground-source, geothermal, heat pump systems. The location of the proposed well field was not known at the time of this report.

3.0 SUBSURFACE INVESTIGATION PROGRAM

In order to evaluate the subsurface soil, bedrock, and groundwater conditions beneath the project site, two (2) geothermal test wells were installed. Drilling and development of the wells occurred from July 8th through July 18th, 2008. Supervision and monitoring of the test wells, designated as TW-1 and TW-2, were provided by a representative of CMX. The approximate locations of the test wells are depicted on the Geothermal Test Well Location Plan (Dwg. No. 080244901-B-100), presented in the Appendix.

Data pertaining to the subsurface investigation was documented in the field and is presented in detail on the Geothermal Test Well Logs, found within the Appendix. The Geothermal Test Well Logs contain general information about the subsurface program and specific data regarding the well installation, including: static groundwater depth, well yield estimates, quantity of casing installed and detailed characterizations of the subsurface materials encountered.
4.0 DESCRIPTION OF SUBSURFACE CONDITIONS

4.1 GEOLOGY

According to the Pennsylvania Geologic Survey's, Geologic Map of the State of Pennsylvania, 1980, the project site is underlain by the Ordovician Rockdale Run Formation (Geologic symbol Orr). The Pennsylvania Geologic Survey publication, The Engineering Characteristics of the Rocks of Pennsylvania, Second Edition, 1982, describes the rock in this formation as consisting of a very light gray, finely laminated, fine-grained limestone. Pink to brown lenses of chert and dolomite beds are interspersed throughout the formation; with white quartz rosettes near the top of the formation.

Bedding in this formation is thick in the upper two-thirds, with medium bedding in the lower one-third of the formation. Fractures are moderately well-developed, moderately abundant, and regularly spaced. The fractures form a blocky pattern and are open and steeply dipping. The rock in this formation is moderately resistant to weathering and is moderately weathered to a deep depth. The soil-to-bedrock interface is typically characterized by pinnacles. The rock of the Rockdale Run Formation is described as difficult to excavate with the bedrock pinnacles creating a special problem. The Rockdale Run Formation is comprised of carbonate rock and is therefore prone to dissolution and the development of karst features (i.e. sinkholes and closed depressions).

4.2 SOIL

The surfaces of the test wells were found to be covered by approximately six (6) inches of topsoil. Beneath the topsoil, subsurface conditions consisted of approximately 20 to 21 feet of residual, overburden soil, derived from the in-place physical and chemical weathering of the parent bedrock. Upon review, the soil was found to consist predominantly of clay with secondary amounts of sand.

4.3 BEDROCK

The bedrock surface was encountered initially at depths of 31 and 20 feet below existing site grades in test wells TW-1 and TW-2, respectively. The underlying bedrock was characterized as light grey to dark grey limestone. The bedrock encountered in test well TW-1 was found to be highly fractured and weathered with soil and mud seams to a depth of approximately 58 feet below the ground surface (bgs). From approximately 58 to 498 feet bgs, the bedrock was found to be competent with few fractures and soft zones encountered. The bedrock encountered in test well TW-2 was found to be slightly fractured and weathered to a depth of approximately 31 feet bgs. From a depth of approximately 31 to 500 bgs the bedrock was found to be competent with few fractures and soft zones.

In general, the bedrock was found to be moderately fractured at variable depths; however, the frequencies of fractures decreased significantly with depth. Please refer to the Geothermal Well Logs, presented within the Appendix, for a detailed description of the subsurface profile and test well construction.

Due to the highly fractured and weathered nature of the bedrock encountered in test well TW-1 above a depth of 58 feet bgs, installation of the required casing was very difficult.
4.4 GROUNDWATER

Groundwater was encountered in both of the test wells completed at the project site. The measured static water level measured in Test Well #1 and Test Well #2 was approximately 60.0, and 32.2 feet below the ground surface (bgs), respectively.

Please refer to the Geothermal Well Logs for information regarding groundwater depth and static water levels encountered during completion of the test well. These observations were made at the time of the field operations and groundwater table elevations will vary with daily, seasonal, and climatological variations.

5.0 THERMAL CONDUCTIVITY TESTING

Upon completion of the test wells, 1.25-inch diameter loop-piping was installed to the bottom of the wells and both wells were subsequently grouted to the surface with a 4:1 mixture of NJ#45 sand and Wyo-Ben Thermex Grout. Thermal Conductivity Testing was conducted on test well TW-1 from August 12th through 14th, 2008 and on TW-2 from August 7th through 9th, 2008. Subsequent to the thermal testing, said data was sent to Geothermal Resource Technologies, Inc. (GRTI) for analysis. A copy of the Thermal Conductivity Tests and Data Analyses are attached for review.

The thermal conductivity test showed a thermal conductivity of 1.60 Btu/hr-ft/°F for test well TW-1 and 1.78 Btu/hr-ft/°F for test well TW-2, which provides favorable natural conditions for a closed-looped, geothermal, heat-pump system. It should be noted that the lower thermal conductivity value reported for test well TW-1 is believed to be the result of the voids and mud seams encountered within that test well.

6.0 CONSIDERATIONS OF KARST GEOLOGY

The project site is underlain by a carbonate geologic formation, which is subject to dissolution and the development of sinkholes and other karst-geologic features. As indicated on the Geologic Map presented within the Appendix of the Report, closed depressions can be found surrounding the test well areas and sinkholes are also identified throughout the University campus. In addition, several bedrock outcrops were identified surrounding the location of test well TW-2. The mapped closed depressions and sinkhole is taken from The Sinkholes and Karst-Related Features of Cumberland County, Pennsylvania, William E. Kochanov. Based on our experience on previous projects completed within the Shippensburg University campus, the potential for the development of sinkholes during development of the proposed well field is considered to be high.

Significant amounts of water will be produced during the installation of the proposed well field and maintenance/management of the water discharged to the surface will be an important consideration during installation of the well field. Water should not be allowed to collect or pool in low lying areas of the site and should be directed to appropriate storm water channels. Effective management of discharged water will be important in minimizing the potential for sinkhole development.
Based on our observations of the two (2) test wells, the condition and character of the underlying limestone bedrock appears to be highly variable. The site owner should recognize the risks associated with development in areas underlain by karst geologic features, and contingencies should be made in the construction schedule and budget for the repair of sinkholes and unstable soil conditions encountered during development of the site.

7.0 CONCLUSIONS

The results of the geothermal investigation have shown that the location of the proposed construction area is underlain by the limestone bedrock of the Rockdale Run Formation. As previously mentioned, the outcome of the thermal conductivity testing has shown the site to exhibit favorable conditions for a geothermal HVAC system.

Highly variable subsurface conditions are expected to be encountered within the proposed well field locations. Additional data should be collected regarding the characteristics of the underlying karst geologic formation, including: bedrock elevations, type and nature of bedrock fractures, bedrock discontinuities, and groundwater elevations prior to completing final design of the geothermal well field. This data should be used in establishing the aerial extent of the well field, optimum design depth, and design quantity of well casing required to develop the project.
LIMITATIONS:

The conclusions and recommendations contained in this report are based upon the subsurface data obtained during this investigation and on details stated in this report. The validity of the projections, conclusions and recommendations contained in this report is necessarily limited by the scope of field investigation and by the number of wells that were installed. Should conditions arise which differ from those described in this report, CMX should be notified immediately and provided with all information when available regarding subsurface conditions.

It is emphasized that this geotechnical investigation was made for the site of the proposed well field as shown on the plan enclosed with this report. The validity of the projections and conclusions contained in this report may be affected by the number of borings that form the basis for those conclusions. The recommendations presented herein are based upon the number of borings purchased by the owner and while, depending upon the actual nature of subsurface conditions, those projections and conclusions may accurately set forth the nature of the subsurface conditions at the site where the wells were installed, the conclusions, projections and recommendations presented herein are not to be applied to the remainder of the site.
APPENDIX

TOPOGRAPHIC MAP

GEOLOGIC MAP

GEOTHERMAL TEST WELL LOCATION PLAN

TEST WELL LOGS
# Geothermal Test Well #1

**WELL LOCATION COORDINATES:** 40° 03' 34.892 N, 77° 31' 28.954 W  
**PROJECT NAME:** Shippensburg University Geothermal  
**PROJECT NUMBER:** 080244901  
**LOCATION:** Shippensburg University  
**CLIENT:** Entech Engineering  
**DATE DRILLED:** 7/8 to 7/10/08  
**TOP OF GROUND:** 669.80' AMSL  
**GROUNDWATER:** 60' bgs  
**DEPTH:** 498 feet bgs

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<tr>
<th>Depth (ft)</th>
<th>Description</th>
<th>Lithologic Log</th>
<th>Well Construction</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0' - 21' - Overburden (Orange brown sandy clay)</td>
<td><img src="image" alt="Lithologic Log" /></td>
<td><img src="image" alt="Well Construction" /></td>
<td>Well Construction Info:</td>
</tr>
</tbody>
</table>
| 20        | 21' - 25' - Boulder  
25' - 31' - Void | ![Lithologic Log](image) | ![Well Construction](image) | CASING: 6-in. ID, 0.188"-wall, black steel casing w/driveshoe, 24 ft to 104 ft. below ground surface (bgs) |
| 40        | 31' - 58' - Weathered Bedrock (Highly weathered dark to light grey limestone with multiple soil seams and voids) | ![Lithologic Log](image) | ![Well Construction](image) | Loop Pipe: 1.25-in. DR-11 loop pipe installed to 498.0 ft.bgs |
| 60        | 52' - 58' - Transitional zone to competent bedrock  
58' - 498' - Bedrock (Dark grey limestone) | ![Lithologic Log](image) | ![Well Construction](image) | GROUTING: 4 to 1 mixture of NJ #45 sand and Therm-ex Grout with a value of 93 BTU/hr-ft°F. tremied from 120 ft bg, 29 batches placed, additionally 16 bags of Enviroplug used |
| 80        | 82' - 84' - Fracture; water bearing zone (WBZ), 12-15 gpm (driller estimate) | ![Lithologic Log](image) | ![Well Construction](image) | Q ~60 gpm |
| 95         | Fracture; WBZ | ![Lithologic Log](image) | ![Well Construction](image) | |
| 100       | Fracture; WBZ | ![Lithologic Log](image) | ![Well Construction](image) | |

**DRILLING METHOD:** Air Rotary  
**DRILLER:** Negley's Well Drilling  
**CMX REPRESENTATIVE:** B. Davidson  
**DRAWN / COMPILED:** B. Davidson  
**DATE COMPiled:** 7/15/2008
## TEST WELL: #1

**PROJECT NAME:** Shippensburg Geothermal

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<tr>
<td>150</td>
<td>154' - Soft Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>167</td>
<td>167' - Soft Zone</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>318</td>
<td>318' - Soft Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>350</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

115' to 498' lost return of cuttings and water
# TEST WELL: # 1

**PROJECT NAME:** Shippensburg Geothermal

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
<th>Lithologic Log</th>
<th>Well Construction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>Total Depth: 498 Feet below grade</td>
<td></td>
<td></td>
<td>Final Q = ~56 gpm</td>
</tr>
</tbody>
</table>

**Comments:** It should be noted that difficult conditions were encountered during the construction of test well #1 due to the presence of highly dissolutioned limestone with pinnacles, voids, and soil seams.

**WBZ** - Water Bearing Zone

**Q** - discharge (blown yield)
# Geothermal Test Well #2

**Well Location Coordinates:** 40° 03' 51.217 N, 77° 31' 09.092 W  
**Project Name:** Shippensburg University Geothermal  
**Project Number:** 080244901  
**Location:** Shippensburg University  
**Field Surveyed:**  
**Topo Estimate:**

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
<th>Lithologic Log</th>
<th>Well Construction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0’ - 20’ - Overburden (Orange brown sandy clay)</td>
<td></td>
<td>6” Black Steel Casing</td>
<td>Well Construction Info:</td>
</tr>
<tr>
<td></td>
<td>10’ - 12’ Boulder</td>
<td></td>
<td></td>
<td>CASING: 6-in. ID, 0.188” wall, black steel casing w/ driveshoe, 4 ft to 64 ft below ground surface (bgs)</td>
</tr>
<tr>
<td></td>
<td>12’ - 20’ Edge of pinnacle</td>
<td></td>
<td></td>
<td>Loop Pipe: 1.25-in. DR-11 loop pipe installed to 500.0 ft bgs</td>
</tr>
<tr>
<td>20</td>
<td>20’ - 31’ - Weathered Bedrock (Dark grey limestone; trace calcite, slightly fractured, slightly weathered)</td>
<td></td>
<td></td>
<td>GROUTING: 4 to 1 mixture of NJ #45 sand and Therm-ex Grout with a value of .93 BTU/hr-ft-°F, tremied from 120 ft bg, 17 batches placed</td>
</tr>
<tr>
<td>31</td>
<td>31’ - 240’ - Bedrock (Dark grey limestone)</td>
<td></td>
<td></td>
<td>Q &lt;1 gpm</td>
</tr>
<tr>
<td>40</td>
<td>24’ - Fracture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>30’ - Fracture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66.5</td>
<td>66.5’ - Fracture; WBZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Drilling Method:** Air Rotary  
**Driller:** Negley’s Well Drilling  
**CMX Representative:** B. Davidson  
**Drawn/Compiled:** B. Davidson  
**Date Compiled:** 7/15/2008
**TEST WELL: #2**

**PROJECT NAME:** Shippensburg Geothermal

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
<th>Lithologic Log</th>
<th>Well Construction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>105' - Fracture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>212' - Soft Zone; WBZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td><strong>240' - 500' - Bedrock</strong> (Light grey limestone with trace amounts of calcite)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>307' - Soft Zone; WBZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>350</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>373' - Soft Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>395' - Soft Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q ~10 gpm

6" borehole
## TEST WELL: #2

**PROJECT NAME:** Shippensburg Geothermal

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
<th>Lithologic Log</th>
<th>Well Construction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td>449' - Soft Zone</td>
<td></td>
<td></td>
<td>449' to 500' lost return of cuttings and water</td>
</tr>
<tr>
<td>462'</td>
<td>475' - 479' - Soft Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>Total Depth: 500 Feet below grade</td>
<td></td>
<td></td>
<td>Final Q = Not obtainable due to return loss</td>
</tr>
</tbody>
</table>

**Comments:**

WBZ - Water Bearing Zone

Q - discharge (blown yield)

CMX Project No. 080244901
ATTACHMENTS

FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS (TW-1)

FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS (TW-2)
FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for: Negley’s Well Drilling, Inc.
16199 Cumberland Highway
Newburg, PA 17240
Phone: (717) 532-9190
Fax: (717) 532-2073

Test location: Shippensburg University, Bore #1
Shippensburg, PA

Report Date: September 2, 2008

Test Performed by: Negley’s Well Drilling, Inc.
Executive Summary

A formation thermal conductivity test was performed on Bore #1 at the Shippensburg University site in Shippensburg, Pennsylvania, at a GPS location of N 40° 03' 34.892" (latitude), W 77° 31' 28.954" (longitude). The vertical bore was completed on July 10, 2008 by Negley’s Well Drilling, Inc. GRTI’s test unit was attached to the vertical bore on the morning of August 12, 2008. Geothermal Resource Technologies, Inc. analyzed the collected data using the “line source” method.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data in real time and in a form used to calculate the formation thermal conductivity. The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = 1.60 Btu/hr-ft-°F

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity = 1.07 ft²/day

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature = 54.5-58.5°F

A copy of the original collected data is available either in a hard copy or an electronic format upon request.
Test Procedures

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has published a set of recommended procedures for performing formation thermal conductivity tests for geothermal applications. GRTI is committed to adhering to ASHRAE recommendations. Some of these recommended procedures are listed below:

(1) Required Test Duration – A minimum test duration of 36 hours is recommended, with a preference toward 48 hours.

(2) Power Quality – The standard deviation of the power should be less than or equal to 1.5% of the average power, with maximum power variation of less than or equal to 10% of the average power. The heat flux rate should be 51 Btu/hr (15 W) to 85 Btu/hr (25 W) per foot of borehole depth to best simulate the expected peak loads on the u-bend.

(3) Undisturbed Formation Temperature Measurement – The undisturbed formation temperature should be determined by recording the minimum loop temperature as the water returns from the u-bend at test startup.

(4) Installation Procedures for Test Loops – The bore diameter is to be no larger than 6 inches, with 4.5 inches being the target diameter. To ensure against bridging and voids, the bore annulus is to be uniformly grouted from the bottom to the top using a tremie pipe.

(5) Time Between Loop Installation and Testing – A minimum delay of five days between loop installation and test startup is recommended if the formation is expected to have a low thermal conductivity or if low conductivity grouts (< 0.75 Btu/hr-ft-°F) are used. A minimum delay of three days is recommended for all other conditions.

GRTI's testing procedures deviate slightly from those above with regard to item (5). While item (5) bases the delay between installation and testing on the expected formation conductivity, GRTI bases its delay on the type of drilling used in the installation. When air drilling is required, a five-day delay is recommended to allow the bore to return to its undisturbed temperature. For mud rotary drilling, a minimum waiting period of two days is sufficient.

For a complete list of recommended procedures, refer to the ASHRAE 2007 HVAC Applications handbook, pages 32.12-32.13.
Data Analysis

Geothermal Resource Technologies, Inc. uses the “line source” method of data analysis. The line source equation used is not valid for early test times. Also, the line source method assumes an infinitely thin line source of heat in a continuous medium. If a u-bend grouted in a borehole is used to inject heat into the ground at a constant rate in order to determine the average formation thermal conductivity, the test must be run long enough to allow the finite dimensions of the u-bend pipes and the grout to become insignificant. Experience has shown that the amount of time required to allow early test time error and finite borehole dimension effects to become insignificant is approximately ten hours.

In order to analyze real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time. Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data. This procedure is normally repeated for various time intervals to ensure that variations in the power or other effects are not producing erroneous results.

Through the analysis process, the collected raw data is converted to spreadsheet format (Microsoft Excel®) for final analysis. A copy of this data can be obtained either in a hard copy or electronic copy format at any time. If desired, please contact Geothermal Resource Technologies, Inc. and provide a ship-to address or e-mail address at one of the following:

Phone: (828) 225-9166
Fax: (828) 281-4139
E-mail: grticam@aol.com
Formation Thermal Conductivity Test Report

Date .................................................. August 12-14, 2008
Location ................................................ Shippensburg, PA
Undisturbed Formation Temperature .................. Approx. 54.5-58.5°F

Borehole Data – As Provided by Negley’s Well Drilling, Inc.

<table>
<thead>
<tr>
<th>Drill Log</th>
<th>Overburden (clay)</th>
<th>0'-22'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fractured limestone (boulder)</td>
<td>22'-25'</td>
</tr>
<tr>
<td></td>
<td>Fractured weathered limestone, void</td>
<td>25'-31'</td>
</tr>
<tr>
<td></td>
<td>Weathered limestone/mud seams/voids</td>
<td>31'-52'</td>
</tr>
<tr>
<td></td>
<td>Semi competent limestone</td>
<td>52'-58'</td>
</tr>
<tr>
<td></td>
<td>Competent limestone</td>
<td>58'-82'</td>
</tr>
<tr>
<td></td>
<td>Fractured limestone</td>
<td>82'-84'</td>
</tr>
<tr>
<td></td>
<td>Dark grey limestone w/trace amounts of calcite w/some mixed soft layers of limestone</td>
<td>84'-500'</td>
</tr>
</tbody>
</table>

U-bend Size ................................................ 1 1/4 inch
U-Bend Length ............................................. 498 ft
Grout Type .................................................. Wyo-Ben Therm-Ex
Grout Solids .................................................. 64%
Grouted Portion ............................................. 35-498 ft
Note: Due to voids, Enviroplug/cuttings were used from 0-35 ft.

Test Data

Test Duration .............................................. 45.9 hrs.
Average Voltage .......................................... 232.2 V
Average Power ............................................. 7,498 W
Total Heat Input Rate ................................... 25,590 Btu/hr
Calculated Circulator Flow Rate ....................... 8.3 gpm
Shippensburg University, Bore #1
August 12-14, 2008

Figure 1: Temperature versus Time Data
The temperature versus time data was analyzed using the line source analysis for the time period shown above. An average linear curve fit was applied to the data between 10 and 45.9 hours. The slope of the curve ($a_1$) was found to be 2.55. The resulting thermal conductivity was found to be 1.60 Btu/hr-ft-$\cdot$°F.
Estimated Thermal Diffusivity

The reported drilling log for this test borehole indicated that the formation consisted of clay and limestone. A heat capacity value for limestone was calculated from specific heat and density values listed by Kavanaugh and Rafferty (Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, 1997). A weighted average of heat capacity values based on the indicated formation was used to develop an average heat capacity for the formation. An estimated diffusivity value was then found using the calculated formation thermal conductivity and the estimated heat capacity. The thermal diffusivity for this formation was estimated to be 1.07 ft\(^2\)/day.

<table>
<thead>
<tr>
<th>Est. Average Heat Capacity (Btu/ft(^2) °F)</th>
<th>Thermal Conductivity (Btu/hr-ft-°F)</th>
<th>Est. Thermal Diffusivity (ft(^2)/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.9</td>
<td>1.60</td>
<td>1.07</td>
</tr>
</tbody>
</table>
Frequently Asked Questions (FAQ’s) Regarding FTC Testing

Q: Thermally-enhanced grout is specified for the final loop field design. The test bore was grouted with a low conductivity, 20% solids, bentonite grout. How do I adjust the thermal conductivity value to account for this?

A: While the conductivity of the grout is important for the loop field design, it is not important for determining formation thermal conductivity. We use the “line source” method to analyze data, which assumes an infinitely thin line rejecting heat at a constant rate into an infinite medium. The initial ten hours, which is influenced by the bore dimensions and grout conductivity, is ignored in the analysis. However, once the heat has penetrated into the formation, the temperature rise of the formation approaches steady-state. It is the slope of the temperature rise that is used in the analysis. Hence, no adjustment to the reported formation thermal conductivity is required.

Q: The software I use to design the loop field requires that I input a value for “soil conductivity”. Is this the same as formation thermal conductivity?

A: Absolutely. Formation, soil, and ground are all used interchangeably to describe the conditions in which the u-bends will be installed. The use of the word “formation” simply implies that the installation conditions may be soil, rock, or some combination of the two.

Q: I’ve just received your report. I have a formation conductivity of 1.54 Btu/hr.ft.°F. How do I translate that into a loop length requirement, in terms of bore depth (in feet) per ton?

A: The formation thermal conductivity test provides values for three key parameters required for the ground loop design. These are the “Undisturbed Formation Temperature, Formation Thermal Conductivity, and Formation Thermal Diffusivity.” These parameters, along with many others, are inputs to commercially available loop design software (e.g. GchpCalc, available at GeoKiss.com/software). The software uses all of the inputs to determine the required loop length in bore depth per ton.

Q: Is the “Undisturbed Formation Temperature” listed in the report the temperature that I enter into my loop design software where it calls for the “Deep-Earth Temperature”?

A: Generally, yes. The “Undisturbed Formation Temperature” is the constant temperature of the formation. We attempt to determine this value by measuring the temperature of the water entering the test unit at the beginning of the test. However, the value we measure and report may be inaccurate if the test is initiated too quickly after the installation of the test bore, or if the testing operator failed to activate the data acquisition unit prior to energizing the heating elements. If you suspect the temperature we are reporting to be too high or too low, we recommend that you investigate further through other sources.
FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for: Negley’s Well Drilling, Inc.
16199 Cumberland Highway
Newburg, PA 17240
Phone: (717) 532-9190
Fax: (717) 532-2073

Test location: Shippensburg University, Bore #2
Shippensburg, PA

Report Date: September 2, 2008

Test Performed by: Negley’s Well Drilling, Inc.
Executive Summary

A formation thermal conductivity test was performed on Bore #2 at the Shippensburg University site in Shippensburg, Pennsylvania, at a GPS location of N 40° 03' 51.217" (latitude), W 77° 31' 09.092" (longitude). The vertical bore was completed on July 14, 2008 by Negley’s Well Drilling, Inc. GRTI’s test unit was attached to the vertical bore on the morning of August 7, 2008. Geothermal Resource Technologies, Inc. analyzed the collected data using the “line source” method.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data in real time and in a form used to calculate the formation thermal conductivity. The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = 1.78 Btu/ hr-ft-°F

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity = 1.19 ft²/day

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature = 53.5-55.5°F

A copy of the original collected data is available either in a hard copy or an electronic format upon request.
Test Procedures

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has published a set of recommended procedures for performing formation thermal conductivity tests for geothermal applications. GRTI is committed to adhering to ASHRAE recommendations. Some of these recommended procedures are listed below:

(1) Required Test Duration – A minimum test duration of 36 hours is recommended, with a preference toward 48 hours.

(2) Power Quality – The standard deviation of the power should be less than or equal to 1.5% of the average power, with maximum power variation of less than or equal to 10% of the average power. The heat flux rate should be 51 Btu/hr (15 W) to 85 Btu/hr (25 W) per foot of borehole depth to best simulate the expected peak loads on the u-bend.

(3) Undisturbed Formation Temperature Measurement – The undisturbed formation temperature should be determined by recording the minimum loop temperature as the water returns from the u-bend at test startup.

(4) Installation Procedures for Test Loops – The bore diameter is to be no larger than 6 inches, with 4.5 inches being the target diameter. To ensure against bridging and voids, the bore annulus is to be uniformly grouted from the bottom to the top using a tremie pipe.

(5) Time Between Loop Installation and Testing – A minimum delay of five days between loop installation and test startup is recommended if the formation is expected to have a low thermal conductivity or if low conductivity grouts (< 0.75 Btu/hr-ft·°F) are used. A minimum delay of three days is recommended for all other conditions.

GRTI’s testing procedures deviate slightly from those above with regard to item (5). While item (5) bases the delay between installation and testing on the expected formation conductivity, GRTI bases its delay on the type of drilling used in the installation. When air drilling is required, a five-day delay is recommended to allow the bore to return to its undisturbed temperature. For mud rotary drilling, a minimum waiting period of two days is sufficient.

For a complete list of recommended procedures, refer to the ASHRAE 2007 HVAC Applications handbook, pages 32.12-32.13.
Data Analysis

Geothermal Resource Technologies, Inc. uses the "line source" method of data analysis. The line source equation used is not valid for early test times. Also, the line source method assumes an infinitely thin line source of heat in a continuous medium. If a u-bend grouted in a borehole is used to inject heat into the ground at a constant rate in order to determine the average formation thermal conductivity, the test must be run long enough to allow the finite dimensions of the u-bend pipes and the grout to become insignificant. Experience has shown that the amount of time required to allow early test time error and finite borehole dimension effects to become insignificant is approximately ten hours.

In order to analyze real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time. Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data. This procedure is normally repeated for various time intervals to ensure that variations in the power or other effects are not producing erroneous results.

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Phone: (828) 225-9166
Fax: (828) 281-4139
E-mail: grticam@aol.com
Formation Thermal Conductivity Test Report

Date ............................................................... August 7-9, 2008
Location ........................................................... Shippensburg, PA
Undisturbed Formation Temperature ......................... Approx. 53.5-55.5°F

Borehole Data – As Provided by Negley’s Well Drilling, Inc.

Borehole Diameter ................................................. 6 inches

Drill Log ..............................................................

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0'-25'</td>
<td>Overburden (clay)</td>
</tr>
<tr>
<td>25'-29'</td>
<td>Broken weathered limestone, trace calcite</td>
</tr>
<tr>
<td>29'-38'</td>
<td>Broken limestone w/clay layers</td>
</tr>
<tr>
<td>38'-500'</td>
<td>Dark and light gray solid limestone w/trace calcite</td>
</tr>
</tbody>
</table>

Note: Bore produced <1 gpm water at 68 ft; <2 gpm at 210 ft; =10 gpm at 310 ft.

U-bend Size ...................................................... 1 1/4 inch
U-Bend Length .................................................... 499 ft
Grout Type ....................................................... Wyo-Ben Therm-Ex
Grout Solids ..................................................... 64%
Grouted Portion .................................................. Entire bore

Test Data

Test Duration ..................................................... 54.3 hrs.
Average Voltage .................................................. 232.2 V
Average Power ..................................................... 7,505 W
Total Heat Input Rate ......................................... 25,614 Btu/hr
Calculated Circulator Flow Rate .............................. 8.4 gpm
Shippensburg University, Bore #2  
August 7-9, 2008

Figure 1: Temperature versus Time Data
Line Source Data Analysis

Shippensburg University, Bore #2
August 7-9, 2008

Figure 2: Temperature versus Natural Log of Time

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Slope: $a_1$</th>
<th>Average Heat Input (Btu/hr-ft)</th>
<th>Thermal Conductivity (Btu/hr-ft-°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – 46 hrs</td>
<td>2.29</td>
<td>51.3</td>
<td>15.0</td>
</tr>
</tbody>
</table>

The temperature versus time data was analyzed using the line source analysis for the time period shown above. An average linear curve fit was applied to the data between 10 and 46 hours. The slope of the curve ($a_1$) was found to be 2.29. The resulting thermal conductivity was found to be 1.78 Btu/hr-ft-°F.
Estimated Thermal Diffusivity

The reported drilling log for this test borehole indicated that the formation consisted of clay and limestone. A heat capacity value for limestone was calculated from specific heat and density values listed by Kavanaugh and Rafferty (Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, 1997). A weighted average of heat capacity values based on the indicated formation was used to develop an average heat capacity for the formation. An estimated diffusivity value was then found using the calculated formation thermal conductivity and the estimated heat capacity. The thermal diffusivity for this formation was estimated to be 1.19 ft²/day.

<table>
<thead>
<tr>
<th>Est. Average Heat Capacity (Btu/ft² ºF)</th>
<th>Thermal Conductivity (Btu/hr-ft-ºF)</th>
<th>Est. Thermal Diffusivity (ft²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.9</td>
<td>1.78</td>
<td>1.19</td>
</tr>
</tbody>
</table>
Frequently Asked Questions (FAQ’s) Regarding FTC Testing

Q: Thermally-enhanced grout is specified for the final loop field design. The test bore was grouted with a low conductivity, 20% solids, bentonite grout. How do I adjust the thermal conductivity value to account for this?

A: While the conductivity of the grout is important for the loop field design, it is not important for determining formation thermal conductivity. We use the “line source” method to analyze data, which assumes an infinitely thin line rejecting heat at a constant rate into an infinite medium. The initial ten hours, which is influenced by the bore dimensions and grout conductivity, is ignored in the analysis. However, once the heat has penetrated into the formation, the temperature rise of the formation approaches steady-state. It is the slope of the temperature rise that is used in the analysis. Hence, no adjustment to the reported formation thermal conductivity is required.

Q: The software I use to design the loop field requires that I input a value for “soil conductivity”. Is this the same as formation thermal conductivity?

A: Absolutely. Formation, soil, and ground are all used interchangeably to describe the conditions in which the u-bends will be installed. The use of the word “formation” simply implies that the installation conditions may be soil, rock, or some combination of the two.

Q: I’ve just received your report. I have a formation conductivity of 1.54 Btu/hr.ft.“F. How do I translate that into a loop length requirement, in terms of bore depth (in feet) per ton?

A: The formation thermal conductivity test provides values for three key parameters required for the ground loop design. These are the “Undisturbed Formation Temperature, Formation Thermal Conductivity, and Formation Thermal Diffusivity.” These parameters, along with many others, are inputs to commercially available loop design software (e.g. GchpCalc, available at GeoKiss.com/software). The software uses all of the inputs to determine the required loop length in bore depth per ton.

Q: Is the “Undisturbed Formation Temperature” listed in the report the temperature that I enter into my loop design software where it calls for the “Deep-Earth Temperature”?

A: Generally, yes. The “Undisturbed Formation Temperature” is the constant temperature of the formation. We attempt to determine this value by measuring the temperature of the water entering the test unit at the beginning of the test. However, the value we measure and report may be inaccurate if the test is initiated too quickly after the installation of the test bore, or if the testing operator failed to activate the data acquisition unit prior to energizing the heating elements. If you suspect the temperature we are reporting to be too high or too low, we recommend that you investigate further through other sources.