GUIDELINES FOR THE CONSTRUCTION OF VERTICAL BOREHOLES FOR CLOSED LOOP HEAT PUMP SYSTEMS

Kevin B. McCray[1]

National Ground Water Association
601 Dempsey Road
Westerville, Ohio 43081
614-898-7791
Fax: 614-898-7786

ABSTRACT

The National Ground Water Association's (NGWA) guidance on appropriate vertical low-temperature geothermal borehole installation practices in varying geological and hydrological regimes identifies the fundamental issues related to the use of this technology: (1) appropriate vertical geothermal borehole installation practices in varying geological and hydrological regimes and (2) the isolation of real environmental concerns from misconceptions.

Borehole completion is a key design factor for low-temperature geothermal heat pump systems. How it is done controls the thermal performance of the borehole, i.e., how much heat transfer the borehole can accomplish.

Through a grant from the Geothermal Heat Pump Consortium, the NGWA: (1) conducted a review of recent research on vertical borehole applications for closed loop heat pump systems; (2) reviewed how geothermal heat exchangers are installed and used – including current published guidelines, regulations and practices; (3) identified possible areas of concern about geothermal heat exchanger installation; and (4) integrated these findings into a document called *Guidelines for the Construction of Vertical Boreholes for Closed Loop Heat Pump Systems*.

The forty-three (43) page document addresses loop field design, test holes and samples, borehole construction, piping, borehole grouting and filling, borehole alignment; loop field identification, heat transfer fluids, and permanent loop piping abandonment.

---

[1] Kevin McCray, a Certified Association Executive, is the Executive Director of the National Ground Water Association and the facilitator of the process that resulted in the NGWA's *Guidelines for the Construction of Vertical Boreholes for Closed Loop Heat Pump Systems*. McCray has been with the Association for 17 years and once served as editor of the *Ground Water Heat Pump Journal* and the *Ground Water Energy Newsletter*. He became Executive Director in September 1995.

Boreholes must be constructed according to local regulations. Borehole diameter is an engineering question determined by heat transfer issues and the construction equipment available for drilling the vertical borehole. The heating and cooling industry and regulators should recognize no single solution is best for all geologic and hydrologic settings. The NGWA does not expect these guidelines to be the final authority on the issues relevant to the construction of vertical boreholes for closed loop heat pumps systems. NGWA believes these guidelines do represent real progress in protecting ground water while allowing the geothermal heat pump industry and borehole drilling industry to grow.

1. INTRODUCTION

Geothermal heat pumps, currently one percent of the national residential heating and cooling market, have been identified as the most efficient and environmentally friendly heating and cooling technology for almost all climates in the United States.

The National Earth Comfort Program seeks to increase geothermal heat pump unit sales from approximately 40,000 to 400,000 and to reduce greenhouse gas emissions by 1.5 million metric tons of carbon equivalents annually by the year 2001 through the replacement of emission-producing heating and cooling systems with renewable energy technology, such as geothermal heat pumps.

Because geothermal heat pumps require the installation of boreholes or trenches with buried piping, concerns have been raised by local and regional code officials and parties interested in ground water protection.

2. MAIN BODY

The work of the National Ground Water Association (NGWA) was to build on recent research by others, review how vertical heat exchangers are installed today; identify possible areas of concern about vertical heat exchanger installation; and seek to isolate real environmental concerns from misconceptions.

To obtain a cross-section of geologic and hydrologic conditions and experiences, four regional work groups were created throughout the United States – the Pacific Northwest; the Midwest; the Northeast; and the South. Included in each regional work group were environmental regulators, borehole construction contractors, ground water scientists, and heat pump engineering experts. Each regional work session group would divide into two teams – one to focus on construction topics, with the second to focus on environmental concerns. After a period of time, each group would switch topics with the other without prior knowledge of the preceding group's thoughts. After each group had reviewed both topics, the efforts were blended together and consolidated. These topics became the outline for drafting the guidelines document. Each regional work session repeated the topics scan as well as reviewed the work of the preceding regional work sessions. In this way, all possible topics that surfaced were thoroughly evaluated and either included or rejected. Each regional work group drafted sections of the guidelines. Each work group that followed critiqued the drafts.

Following the completion of the four regional work groups, a final national work session was conducted involving participants from each of the regional sessions. The national work session again conducted the topics scan and then conducted a word-by-word, line-by-line review of the drafts prepared in the regional sessions. The final work output from the national work session became the guidelines document.

The result of the four-month work effort was a forty-three-page document called *Guidelines for the Construction of Vertical Boreholes for Closed Loop Heat Pump Systems*. Articles of the guidelines include: loop field design, test holes and samples, borehole construction, piping, borehole grouting and filling, borehole alignment, loop field identification, heat transfer fluids, and permanent loop piping abandonment.

Loop Field Design

Loop field design focuses upon topics such as: loop systems, loop thermal load, loop configuration, depth of borings, number of borings, clusters/circuits, headers and loop piping, borehole spacing, borehole diameter, piping/joints/valves, circulating fluids, site limitations, topography and site access, property lines, underground utilities, above ground utilities, septic fields and other contaminant sources, potable supply wells, surface water or wetlands, buildings/structures, right-of-way, isolation, drilling, the step casing method, and sanitary protection.

Rule-of-thumb calculations for building loads or loop sizing are not appropriate for loop field design. The loop lengths should be determined by means of manual methods or computer software that accounts for the following design parameters: building loads, ground thermal characteristics, heat pump characteristics, loop operating temperature range, field geometry, pipe characteristics, grout or backfill thermal characteristics, local drilling practices and restrictions, and local ground water conditions. The result of the design process should be a complete vertical borehole field specification.

For larger commercial buildings, the design of the ground loop should be based on the greater of the heating or cooling peak building block loads and not the installed capacity of the equipment. Peak block loads incorporate the effects of zone load diversity (variations in load due to scheduling, ventilation, solar exposure, etc.) and are usually less than the installed equipment capacity. In large buildings, the cooling load is normally the dominant load in terms of the ground loop design. In cooling mode, the heat of rejection to the borehole field will include the building cooling load plus the equipment compressor energy. For smaller buildings, the building load shall be calculated in accordance with the Air Conditioning Contractors Association's (ACCA) *Manual J*, or its equivalent. Commercial software for both building loads and loop design is available from several sources. The design of smaller systems (such as residential applications that will be less than five (5) tons in capacity) may be performed by a loop contractor or a heating, ventilating, air-conditioning (HVAC) contractor.

The ground loop should be designed using the appropriate ground thermal characteristics (conductivity and diffusivity) for the site. These parameters may be determined from existing information (local well logs, United States Geological Survey (USGS), state geology department data), a test bore, or an in situ loop test. The thermal characteristics of the native material must be adjusted for the borehole diameter, the type of grout/fill, and the pipe diameter. The required borehole total length and the system thermal performance are influenced by the thermal characteristics of the native materials and the borehole design. Conventional bentonite grouts have poor thermal conductivity relative to most damp native soil and rock materials. As a result, the use of conventional grout tends to reduce loop thermal performance and ultimately increase total borehole length requirements for a given system design load. A thermally enhanced bentonite grout with a thermal conductivity higher than that of conventional bentonite grout should reduce total borehole length relative to using conventional grout. Since both types of grout are likely to have thermal conductivities that are lower than that of the native material, the less grout that can be used (and still provide required environmental protection) the better the system thermal performance should be.

The final step in the design process is to design the loop field. The results of the design process will include total borehole length requirement, loop piping diameter, borehole diameter, grout/fill materials, loop field layout, circuit arrangement, and individual borehole depth. Some of these design parameters may be selected based on good design practice or available drilling equipment, while others must be computed for the specific design conditions.

The presence or absence of ground water also influences total borehole length requirements. Ground water movement assists in heat diffusion and can help overcome an imbalance in the annual thermal loads (cooling dominated loads) to prevent long term temperature buildup in the ground around the loops. The loop designer should account for the presence or absence of ground water in the loop design.

Headers should be designed to maintain uniform fluid velocities and to facilitate flushing and purging during construction and balanced flow during normal operation. The use of close-coupled header designs instead of extended or reduced header designs will generally eliminate the need for reverse return piping. Headers may be field fabricated or prefabricated.

In general, the smaller the diameter of the borehole, the greater the thermal exchange efficiency. It is assumed that a smaller borehole diameter is also less likely to permit aquifer contamination by water movement through the borehole. Long-term changes in localized ground or ground water temperatures can occur if the system heating and cooling loads are not balanced.

For borehole-to-borehole spacing, the designer should consider the depth of the borehole, the loop field arrangement, drilling method, drilling and geologic conditions, the annual thermal loading, and land surface restrictions. Large systems with larger load imbalances require more space between boreholes. The annual thermal loading should be considered for large systems for long-term thermal changes in the subsurface. Subsurface thermal changes can negatively impact the efficiency of the system design. Detectable increases of ground water temperatures of neighboring property owners are highly unlikely with a properly operating closed loop heat pump system. A separate ground temperature monitoring system should not be needed.

The drilling contractor may also be concerned about drilling into other boreholes at depth, which is more likely with closer borehole spacing.

Large system loop fields may be divided into separate clusters or circuits to accommodate flushing, purging, and leak detection and repair. The number of boreholes per circuit will depend on borehole depth, spacing, heat extraction or rejection load, and site layout. Circuit isolation valves can be located inside the building or in a vault near the loop field. The use of a vault reduces the number of underground penetrations through the building wall or foundation.

Test Holes & Samples

Large project economics and bid practices often make it advantageous to the owner to install a test borehole as part of the design process. The purpose of drilling a test hole is to obtain information on drilling conditions and native ground heat transfer properties, and to help establish the depth and extent of the water-bearing formation or formations at a specified site. The test borehole installation should duplicate as far as possible the anticipated final design. When a test hole is warranted, it may be converted into a vertical closed loop borehole fully capable of being operated as a permanent vertical closed loop borehole.

When the contractor is to construct a test hole, information should be obtained regarding the depth, thickness and heat transfer potential of the formations encountered. Geographic location shall be stated in terms of coordinates such as quarter section, township, and range, or by other suitable description relative to fixed reference points such as by using global positioning systems (GPS). The contractor shall provide all equipment necessary to assure proper execution of the test drilling and sampling that is required.

It is recommended that samples be collected of all materials penetrated by the drilled vertical closed loop borehole. As many samples should be taken as required and by such means as will assure collection of representative samples of a specific aquifer(s), or formation(s) that will be free of material from intervals above the aquifer or formation of interest. The sample may be obtained with a bailer scow or by coring or other means, such as return flow sampling. Care must be taken to accurately determine the depth interval from which each sample is taken.

Borehole Construction

The contractor/owner or his/her representative, through the use of information gathered by geophysical methods and/or existing local vertical closed loop borehole records and/or the previous drilling of a test hole on the site of the production vertical closed loop borehole, can determine the type of vertical closed loop borehole needed. The construction method best suited to the type of geology can vary from driller to driller and with type of equipment. There are two primary formations that will be encountered: consolidated and unconsolidated. In some instances, both types will be encountered on the same site.

Piping

Piping shall be as specified in International Ground Source Heat Pump Association (IGSHPA) standards for closed loop heat pumps. Current practice is the use of high density polyethylene PE345434C or PE355434C with a UV stabilizer of C, D, or E as specified in American Society for Testing and Materials (ASTM) D-3350 with the following exception: this material shall exhibit zero (0) failures (FO) when tested for one-hundred, ninety-two (192) hours or more under ASTM D-1693, condition C, as required in ASTM D-3350. New piping materials may be developed which meet all IGSHPA and ASTM requirements for these systems. Vertical piping wall thickness in the borehole shall be no less than that of standard dimensions ratio (SDR) eleven (11).[2]

Borehole Grouting or Filling

Completing a closed loop borehole requires placing material -grout or fill -- in the space between the heat exchanger pipe and the borehole wall. Two classes of material are used: grout and fill. Local geologic conditions and regulations will determine which of these two materials is used.

Grout is a high solids fluid mixture of cement or bentonite of a consistency that can be forced through a pipe and placed as required. Various additives, such as sand or hydrated lime, may be included in the mixture to meet certain requirements. For example, sand is added when a considerable volume of grout is needed.

The reason fill is used is to achieve greater heat transfer than grout can provide. Fill is the use of cuttings or other materials that can be placed in the borehole under site specific conditions, such as void zones or dry boreholes (when at least twenty-five (25) feet above the water table), or single, non-flowing aquifer.

The reasons for grouting are: (1) protection of the aquifer, or aquifers, including limiting the potential for water movement between aquifers, for purposes of maintaining quality or preserving the hydraulic response of the producing zone(s), (2) provide thermal contact between the loop piping and the formation (borehole) wall, and (3) accomplishing one & two in an efficient and economical manner.

Contractors shall comply with state and local completion requirements. In determining the specific grouting requirements of a borehole at a designated site, consideration must be given to existing surface conditions, especially the location of sources of pollution, and to subsurface geologic and hydrologic conditions. In general, the entire length of each individual loop borehole will be grouted and/or filled. In all cases, formations which yield water must be adequately sealed off to prevent cross-contamination of the overlying or underlying water bearing zones. To accomplish this, the annular space shall be grouted to seal off the water bearing zones.

High solids bentonite grouts, the most common grout material, are extremely beneficial as a closed loop borehole sealant, except where drying out and washing away can not be prevented.

---

[2]This is outside diameter and not inside diameter.

Bentonite drilling fluids are not an acceptable grout. As engineered products, bentonite grouts must be carefully mixed and installed according to the manufacturer's specifications.

Borehole Alignment

Alignment of a borehole is never perfect. Under most conditions, the contractor can keep alignment within practical limits by exercising reasonable care. Alignment becomes critical on deep holes. Conditions that cause wells to become out of alignment include the nature of the material penetrated while drilling, trueness of surface or bridge casing, tension of cable tool drilling line, and pull-down force on drill pipe in rotary drilling. Solutions for the problems vary as widely as do the conditions which cause the problems. The borehole shall be in alignment to such an extent that the closed-loop piping can be placed to the entire borehole depth and such that the borehole does not intersect another nearby borehole.

Loop Field Identification

Because the loop field will be buried and out of sight, it is important to identify the location of the boreholes in case header repairs are needed or excavation work needs to be performed for other utilities.

Heat Transfer Fluids

A heat transfer fluid is needed to transfer heat between the loop field and the heat pump system. Potable water has excellent pumping and heat transfer properties for this application. Any water used as a heat transfer fluid shall be from a potable source. Depending on the local ground temperature and the heating design conditions for the loop field, antifreeze may be required to provide freeze protection of the circulating fluid. The antifreeze should exhibit acceptable heat transfer and pumping characteristics, be safe to install, reasonable in cost, provide corrosion protection to system materials, and not produce an unacceptable risk to the environment in the event of a system leak. The anti-freeze is normally placed in the system from inside the building after the entire loop field is completed, pressure tested, flushed, and purged. The concentration of the anti-freeze solution should be checked to assure proper freeze protection. The volume of the loopfield and the volume of the building piping will determine the amount of anti-freeze needed for the desired protection. If concentrate is added, time for proper mixing will need to be considered. At the anti-freeze add point there should be identification posted of the anti-freeze material, manufacturer, and other identifying information.

Permanent Loop Piping Decommissioning

Unsealed abandoned loop piping may constitute a hazard to public health, safety, welfare, and to the preservation of the ground water resource. To seal an abandoned vertical loop piping properly, several things must be accomplished: (1) removal of heat transfer fluids, (2) prevention of ground water contamination, (3) conservation of yield and maintenance of hydrostatic head of aquifers, and (4) prevention of the intermingling of desirable and undesirable waters.

The basic concept governing the proper sealing of the loop piping is the restoration, as far as feasible, of the hydrogeologic conditions that existed before the vertical loop borehole was drilled and constructed. Improperly decommissioned vertical loop piping might serve as an uncontrolled invasion point for contaminated and polluted water. Any vertical loop piping that is to be permanently abandoned should be completely filled in such a manner that vertical movement of water within the vertical loop piping, is effectively and permanently prevented. Any unsealed portion of the borehole surrounding the vertical loop piping shall be sealed, so that ground water is permanently confined to the specific zone in which it originally occurred. If all these objectives can be accomplished, all the rules for sealing loops heretofore presented will be fulfilled.

To seal abandoned vertical loop piping properly, the character of the ground water must be considered. If the ground water occurs under unconfined, or water-table conditions, the chief problem is that of sealing the loop piping with impermeable material so as to prevent the percolation of surface water through the original vertical loop, or where visually obvious, within the borehole, to the water table. If the ground water occurs under confined or artesian conditions, the sealing operation must confine the water to the aquifer in which it occurs thereby preventing loss of artesian pressure by circulation of water to the surface, to a formation containing no water, or to one containing water under a lower head than that in the aquifer which is to be sealed.

3. DISCUSSION

The National Ground Water Association does not anticipate these guidelines will satisfy every regulatory body involved with the construction of vertical boreholes for closed loop heat pumps systems, nor did we set out to achieve such a document. Our effort was intended to create an exposure to the current issues related to such construction and to offer insights as to the practical resolution of these issues. However, of paramount concern at all times was that we develop guidelines consistent with the protection of the subsurface environment.

The Association does not expect these guidelines to be the final authority on the issues relevant to the construction of vertical boreholes for closed loop heat pumps systems. NGWA believes these guidelines do represent real progress in protecting ground water while allowing the geothermal heat pump industry and borehole drilling industry to grow.

4. CONCLUSIONS

Boreholes must be constructed according to local regulations. Borehole diameter is an engineering question determined by heat transfer issues and the construction equipment available for drilling the vertical borehole. The heating and cooling industry and regulators should recognize no single solution is best for all geologic and hydrologic settings. The NGWA does not expect these guidelines to be the final authority on the issues relevant to the construction of vertical boreholes for closed loop heat pumps systems. NGWA believes these guidelines do represent real progress in protecting ground water while allowing the geothermal heat pump industry and borehole drilling industry to grow.

ACKNOWLEDGEMENTS

These guidelines were prepared under the auspices of the National Ground Water Association (NGWA) work group for drafting guidelines for the construction of vertical boreholes for closed loop heat pump systems, with oversight from the National Ground Water Association's Special Committee on Research and Technology Transfer. The group responsible for drafting the NGWA *Guidelines* was comprised of prominent technical professionals and closed loop vertical borehole contractors, as well as representatives from state regulatory agencies. Specifically, these individuals were: Larry Burd, Larry Marchiniak, Ralph Cadwallader, Arnold Ward, Dr. Dennis Goldman, Pat Kelly, Dr. William Murphy, Dr. Karen DenBraven, Kevin Rafferty, John Henrich, Ron Holben, Tom Riewe, Carl Mason, Ron W. Hohlfeld, Tim Parks, Charles Eichelberger, Norm Primost, Stuart Reese, John Berry, Dr. Chuck Remund, Howard Cutter, James Harrell, Mark Lassiter, Marcus Geist, David Dinse, Mike Turner, Martha Horvitz, Tim Yoder, and Christine Reimer.

The National Ground Water Association also acknowledges the assistance of Dr. Carl Hiller of the Electric Power Research Institute, as well as of Dr. Harvey Sachs of the Geothermal Heat Pump Consortium.

Financial support for development of these guidelines was provided by a grant from the Geothermal Heat Pump Consortium, Inc., under U.S. Department of Energy grant DEFG07-95ID13347. Under the terms of the grant to the NGWA, the NGWA had full control of the developmental process and of the content of this document. The participation of Dr. William Murphy, professor, University of Kentucky, as an independent authority on heat flow in geothermal boreholes, was made possible by funding from the Electric Power Research Institute.

REFERENCES

McCray, K. B., Editor, (1997). *Guidelines for the Construction of Vertical Boreholes for Closed Loop Heat Pump Systems*. National Ground Water Association, Westerville, Ohio.