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Report to Accompany the Geothermal Maps of Missouri

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Glossary

Aquifer – A geologic formation, group of formations, or part of a formation that is water-bearing, permeable rock or unconsolidated materials (gravel, sand or silt) from which groundwater can be usefully extracted.

Confining unit – a low permeability unit that separates two aquifers.

GSHP(s) – Ground Source Heat Pump(s)

Hydraulic conductivity – The ease with which water moves through the rock or soil/gravel/sand.

Hydraulic gradient – Change in head per a unit distance

Hydraulic head – The pressure on groundwater at a certain elevation.

Geologic formations – Individual rock layers defined by their physical characteristics including rock type, composition, texture and depositional environment.

Geothermal gradient – Change in temperature of rock with increasing depth, generally becoming warmer; groundwater temperature increases proportionally.

Permeability – Ability of a rock or other aquifer material to transmit water or allow it to flow.

Physiography – The structure, origin and development of topographical features of the earth's surface and their relationship with underlying structures.

Temperature gradient – The change in temperature of the groundwater from one location to another.

Report to Accompany the Geothermal Maps of Missouri

Introduction

Geothermal conditions in Missouri are permissive for residential and commercial use of ground source heat pumps for heating, ventilation and air conditioning (HVAC). Missouri has the potential to reduce dependence on fossil fuels for HVAC uses by increasing the use of ground source heat pumps (GSHPs). Geothermal energy tapped by GSHPs is constant and independent of surface conditions that affect, or are affected by, wind power, solar energy or fossil fuel energy generation. Current GSHP systems in Missouri are used for both heating and cooling, leading to balanced loads and minimal long-term alterations of groundwater temperatures (National Ground Water Association, 2010a). Consequently, use of GSHP systems in Missouri has excellent long-term potential for energy savings. The systems are currently under-utilized in Missouri.

Ground source heat pumps for heating and cooling provide the most economical alternative to electric and fossil fuel powered HVAC systems. GSHP systems are cost-effective to install and have a documented payback rate of four to 12 years, dependent on the type of system replaced and the geologic conditions of the site (Department of Energy, 2010b). The Department of Energy (2010a) states that "Replacing conventional heating and air conditioning systems with GHPs [geothermal heat pumps] typically saves 15–25 percent of total building energy use in nonresidential buildings; in residential buildings savings can be as high as 40 percent....GHPs reduce peak load as well." They also note that GSHP systems generally operate reliably, quietly and provide better humidity control than conventional systems.

According to the National Ground Water Association (2010a), "Groundwater temperature data is necessary for the proper deployment of heat pumps." Groundwater temperature data is used in selection of proper equipment and configuration of the system for efficient operations. More efficient GSHP systems are easier to achieve when groundwater temperature is known (Hanova and Dowlatabadi, 2007). The temperature data presented here is primarily useful for open loop or standing column well systems installed in bedrock.

This report and the geothermal maps provide a source of information for groundwater temperatures. Map data points show the source of the data and the temperature. Contour lines are 10°F. The majority of data is from the primary, uppermost aquifer used in the region. Inset maps are included on each map where temperature data is available from a lower aquifer. Discussion of each map area is included below. A description of the regulatory process involved in installation and operation of GSHP systems is included in Appendix A. The map database contains data used to generate the maps.

The temperatures recorded on the maps and noted in this report are sufficiently high throughout the state for the use of GSHP systems in Missouri. In addition to residential usage, some areas have groundwater temperatures sufficient for industrial and technical uses such as greenhouse and aquaculture facilities. Groundwater for these uses can be as cool as 68°F; higher temperatures are noted on the maps and in this report.

Ground Source Heat Pump Systems Addressed By This Report

There are several types of GSHP systems. Bedrock aquifer temperature data is most useful for open-loop systems and standing columns. Closed loop systems are more dependent upon ground temperature, and are not discussed here.

Before selecting a GSHP system, it must be determined that the aquifer has sufficient flow (hydraulic conductivity) and water production capability (hydraulic head) to support the system. In addition, poor

water quality issues, including hardness, acidity and iron content, can cause difficulties. Solid material, such as precipitated iron or manganese can clog wells and the overall system. Poor water quality may require additional equipment and can lead to maintenance issues (Orio et al. 2005).

An open-loop system generally uses two wells. One is the source well; the other is the sink or return well. Water pumped from the source well passes through a heat exchanger and is returned to the aquifer through the second well. For heating, a liquid refrigerant in the heat exchanger absorbs heat from the groundwater and evaporates, forming a cool gas. The refrigerant gas passes through a compressor that raises its temperature and pressure. The compressed gas then transferred heat to air flowing across condenser tubes. The refrigerant gas cools and is reduced in pressure, dropping its temperature and starting the cycle over again. The process is reversed for home cooling. Water remains in the piping system during the process and is unaffected other than a lowering of temperature in the winter and a raise in the summer. In addition, most GSHP systems can also provide hot water or supplement water heaters.

A two well open-loop system is well suited to the geohydrological environment in Missouri. The source and return wells can be switched from summer to winter, allowing use during the winter of warmed water returned to the aquifer during the summer and vice versa. This also limits changes in aquifer temperature, a problem seen in climates where GSHP systems are used only for heating or cooling.

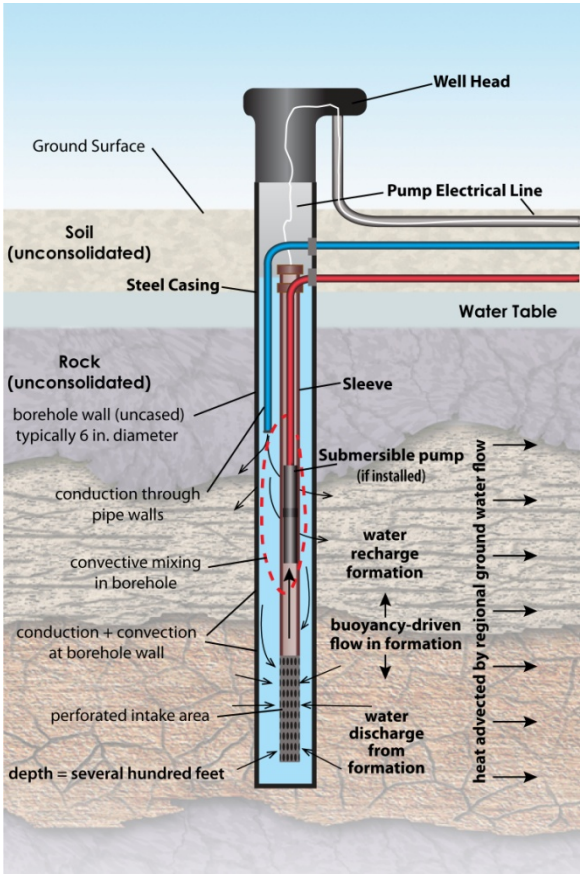

Figure 1. Schematic of a typical standing column well GSHP system (after Deng 2004).

Standing column well systems are a single well open loop (figure 1). Water is drawn from the bottom of the well, passed through the heat exchanger and returned to the top of the well. The returned water exchanges excess heat or cold with the surrounding bedrock as it moves downward. During the winter, the return water will pick up heat lost to the bedrock during the summer and vice versa. Standing column well systems work best where bedrock is less than 200 feet from the surface. They can also be multiple well systems, with each individual well acting as a source and return well.

General Geology of Aquifer Regions

The geology of individual formations and aquifers changes across the state, leading to variations in groundwater production and temperature. Geologic conditions leading to warmer groundwater also vary across the state. The state has been separated into six areas marked by physiographic provinces (figure 2) with similar bedrock geology and surface characteristics. Figure 3 is a column illustrating the major Missouri aquifers and the geologic formations that comprise them. The physiographic provinces and their aquifers are as follows:

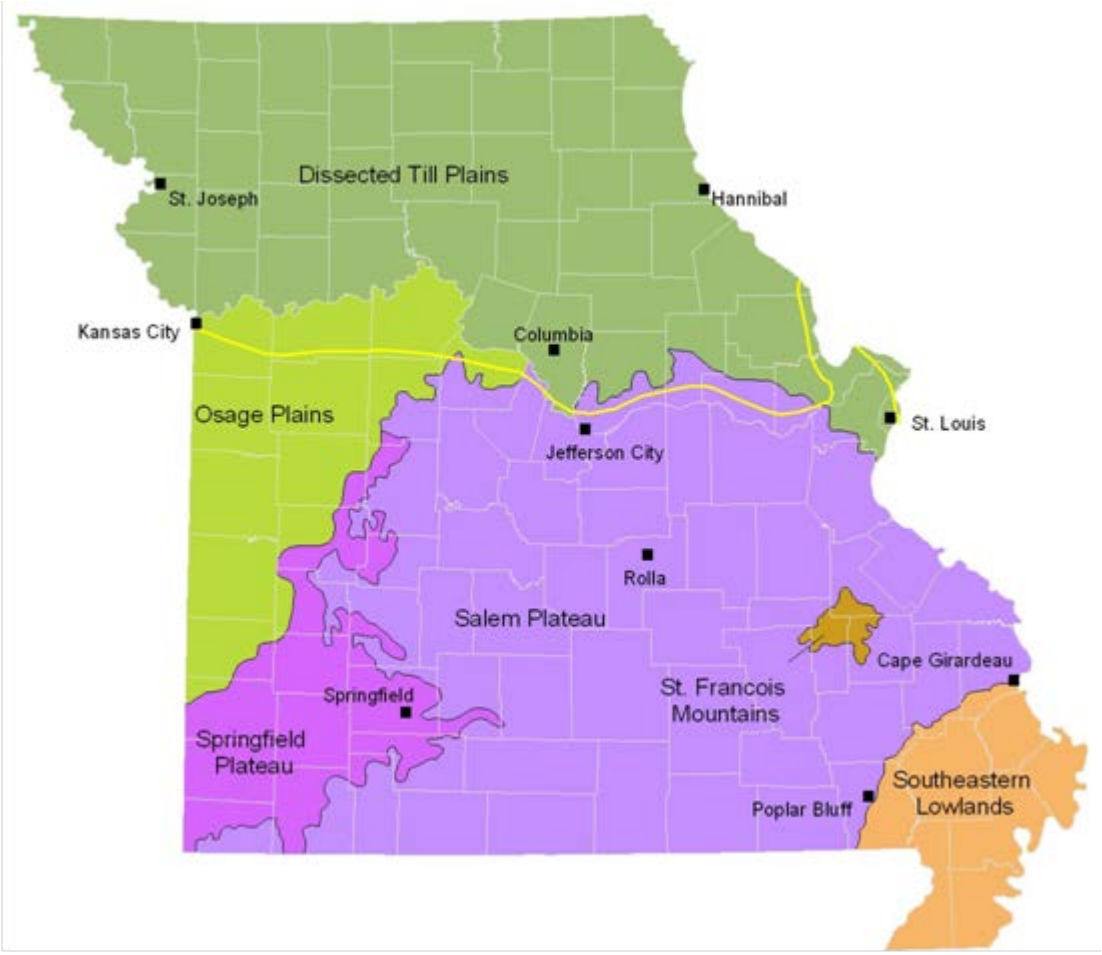

Figure 2. Map of generalized physiographic regions of Missouri as used on the Geothermal Map of Missouri. Yellow line marks southern limit of glaciation.

Age	Major Geologic Formations	Hydrogeologic Unit
Quaternary	Alluvium or Glacial Till	Water from unconsolidated sediment
Cretaceous/ Tertiary	Various formations	No specific unit, water from sand, alluvium
Pennsylvanian	Various formations	No specific unit, minor water from limestones, sandstones
Mississippian	St. Louis Salem Burlington-Keokuk Elsey Reeds Spring Pierson	Springfield Plateau Aquifer
	Northview Sedalia	Ozark Confining Unit
Devonian	Chattanooga	
	Callaway Fortune	Ozark Aquifer
Ordovician	Kimmswick Plattin Joachim St. Peter Everton Smithville/Powell Cotter Jefferson City Roubidoux Gasconade	
Cambrian	Eminence Potosi	
	Derby-Doe Run Davis	St. Francois Confining Unit
	Bonneterre Lamotte	St. Francois Aquifer
Precambrian igneous rocks		

Figure 3. Column with major geologic formations as they relate to aquifers and confining units. Column also shows the major aquifers and confining units in Missouri. After Imes (1990).

Salem Plateau – Has the most extensive groundwater resources in the state. The St. Francois and Ozark aquifers underlie the province and are separated by the St. Francois confining unit. The Ozark aquifer comprises bedrock units from Potosi Dolomite to Kimmswick Limestone in the Salem Plateau.

St. Francois Mountains – Precambrian granites and rhyolites in part overlain by Cambrian-age sandstone, dolomite and limestone. The igneous rocks have low water yields; however, potential exists for higher temperature water due to concentrations of radioactive isotopes in several granite formations. The St. Francois aquifer is also a producer in this region.

Southeastern Lowlands – Contains the greatest volume of groundwater per unit area. Parts of the St. Francois and Ozark aquifers are used in the northwestern part of the province. However, most usable groundwater is in thick deposits of shallow alluvium and deeper Tertiary- and Cretaceous-age unconsolidated sands. The area has higher water temperatures than other parts of the state.

Springfield Plateau – Mississippian-age limestones comprise the Springfield Plateau aquifer and overlie the St. Francois and Ozark aquifers. The Ozark aquifer in this region comprises Derby-Doerun Dolomite through Cotter Dolomite.

Osage Plains – This province is west of the freshwater-saline water transition zone. The region has Pennsylvanian-age strata underlain by Cambrian, Ordovician and Mississippian units. The area has documented groundwater temperatures of 72^0F and 74^0F (Fuller, 1981).

Dissected Till Plains – Cover northern Missouri and characterized by Pennsylvanian-age sandstones, shales and limestones that are overlain by glacial drift. Mississippian- to Ordovician-age strata are exposed along the Missouri and Mississippi rivers and produce some water. Pennsylvanian strata have generally low permeability and yield small quantities of marginal to poor quality water. Usage of water from glacial drift, including pre-glacial stream valleys, increases to the west.

Regulations for Ground Source Heat Pump Systems

GSHP installation and operation procedures and regulations are mandated by the Missouri Department of Natural Resources (2009). Chapter 5 of this document, Heat Pump Construction Code, provides details of requirements for installation and operation of a ground source heat pump. Information from Chapter 5 that relates to open-loop systems is included in Appendix A. These regulations define the terminology and discuss certification standards, well placement standards, general groundwater protection, well construction standards and proper GSHP well plugging. Well construction codes for all wells comprise Chapter 3 of the same document.

Data Collection

Pre-existing data used in this project was collected from multiple sources for greater detail. Groundwater temperature data sources included Missouri Department of Natural Resources Division of Geology and Land Survey (DGLS) written data files, U.S. Geological Survey (USGS) National Water Information System (NWIS) electronic data files, U.S. Environmental Protection Agency (USEPA) STORET electronic data files, Missouri Department of Natural Resources Division of Environmental Quality (DEQ) Public Drinking Water Program electronic data file Internet resource pages, and historic published reports. Plains CO2 Reduction (PCOR) Partnership data was collected in part with funding from the U.S. Department of Energy (DOE) through the PCOR regional partnership. Spring temperatures were obtained from DGLS publications. Oil and gas log temperature data were collected from DGLS files. Remaining pre-existing data was obtained by contacting county, state and city water districts and operators, interaction with the public, the U.S. Army Corp of Engineers and the Missouri Department of

Conservation. Data from landfill monitoring wells was obtained from the Missouri Department of Natural Resources Solid Waste Management Program's records.

New data collected included existing residential and commercial water wells and springs. Water well temperatures were collected from a running tap using an YSI conductivity/salinity meter. Data from springs was collected using the same meter. A minimum of three readings were taken at each site. GPS locations, date and time were collected for all sampling sites. The Southeastern Lowlands Province and portions of the Dissected Till Plains Province were the most difficult for data collection due to their highly rural nature and sparse population.

Permission was obtained to access the selected wells. When possible, at least two wells at city water or public water supply districts were measured at different depths. For larger cities or districts three to four wells were done. Water was run for two to four minutes depending on the depth and speed of the pump, and was then collected in a bucket where the temperature was measured. Results were recorded in an Access database.

Map and Data Discussion

The geothermal map for Missouri is presented as five separate maps divided by physiographic province. The maps cover the Dissected Till Plains, Osage Plains, Salem Plateau, Southeastern Lowlands and Springfield Plateau. The St. Francois Mountains province is included as an inset map on the Salem Plateau map as the region is small in area.

The map data is coded by point shape for data source and by color for temperature. Map contours are drawn on data points that are less than 1,000 feet in depth, keeping measurements used for contours within the same aquifer. Inset maps on the geothermal maps are shown where significant data are available for wells reaching a lower aquifer or for significant clusters of data. All contours on the maps are approximate and do not indicate a known value at the line location.

Groundwater temperatures throughout the state range from the mid-50°F to the mid-60°F in the uppermost aquifer in each area of the state. The temperatures are permissible for GSHP system use. Areas of higher and lower temperatures are scattered throughout the state and range from upper 40°F values to values higher than 80°F. No values reached 90°F. Discussion of higher temperature data by physiographic province follows.

Dissected Till Plains

Temperatures of 80°F or higher are found at depths of less than 1,000 feet within an area in Caldwell, Clay, Clinton and Ray counties. Similar temperatures are found in individual wells in Boone, Knox and St. Louis counties. Individual occurrences at depths of greater than 1,000 feet were found in Adair, Pike and St. Charles counties. Wells with temperatures of 70°F to 79°F were measured in Adair, Atchison, Clark, Knox and Putnam counties. In addition, oil and gas wells at depths greater than 1,000 feet in the western portion of this area have temperatures in the 80°F and higher range.

Osage Plains

Temperatures of 70°F or higher are found within areas in Cass and Vernon counties, primarily in oil and gas wells deeper than 1,000 feet. Three oil and gas wells in southeastern Bates County are higher than 80°F. An individual higher temperature well (70°F) is in Barton County.

Salem Plateau and St. Francois Mountains

The Salem Plateau and St. Francois Mountains provinces do not have larger areas with higher temperature wells. However, there are single wells and small clusters which suggest potential for higher groundwater

temperature uses. Shannon and Perry counties each have an area with three wells at greater than 70°F and 80°F. Laclede County has a single well over 80°F or higher; Cape Girardeau, Polk and Reynolds counties each have a single well at 70°F or higher.

Southeastern Lowlands

The Southeastern Lowland, including the Bootheel of Missouri, generally has higher groundwater temperatures than does the rest of the state. Few temperatures in the 50°F range were measured in the province. Groundwater temperatures were in the 70°F to 80°F and higher range in southern Pemiscot County, Dunklin County and western New Madrid County.

Springfield Plateau

The Springfield Plateau has several areas with higher temperatures; all higher temperatures are at depths greater than 1,000 feet. The City of Joplin has three wells that have temperatures of 70°F or higher, as are three wells in the western half of Greene County. Individual wells in southeast Jasper County and at Monett in Barry County are also higher than 70°F. In addition, one well southeast of the City of Springfield has a temperature at 80°F or higher at a depth of 2,186 feet.

Project Funding

Funding for this project was provided by the American Recovery and Reinvestment Act (ARRA). The funds were awarded to the DGLS by the Missouri Department of Natural Resources Division of Energy through their Energize Missouri Renewable Energy program, a state energy program for study subgrants and biogas grants.

Acknowledgements

Data collection could not have been possible without the generosity of Public Water Supply Districts and City Water Departments state-wide that provided access and accompaniment to their water wells. Missouri Department of Natural Resources Division of Environmental Quality provided access to data that highlighted areas in the state suitable for data collection and allowed access to their library for collection of landfill monitoring well data. Missouri Department of Conservation and Missouri Division of State Parks allowed access to their private lands. The assistance of Fletcher Bone in data collection and of Karen Loveland in both data collection and database construction was invaluable. Thank you to Nicholas Newport, Missouri Department of Natural Resources Division of Energy, for his overall support of the project. Mark Gordon with DGLS assisted with illustration.

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Appendix A

Ground Source Heat Pump installation and operation procedures and regulations mandated by the Missouri Department of Natural Resources (Missouri Department of Natural Resources, 2009). All "material removed" is related to closed loop systems. The full set of rules should be consulted before construction of a GSHP system, including Chapter 3 – Well Construction Code.

Title 10 - DEPARTMENT OF NATURAL RESOURCES
Division 23 - Geology and Land Survey
Chapter 5 - Heat Pump Construction Code
10 CSR 23-5.010 Definitions

PURPOSE: This rule specifically defines words used in Chapter 5 concerning heat pump wells, otherwise the definitions contained in 10 CSR 23- 1.010 apply.

(material removed)

(2) **Open-loop heat pump water supply well** means a well drilled to supply water for the purpose of heat transfer. This type of well is to be constructed to domestic well standards, 10 CSR 23-3.010-10 CSR 23-3.100 if it produces less than 70 gallons per minute or to public water supply standards if it produces more than 70 gallons of water per minute.

(material removed)

(4) **Water return well** means a well constructed for the purpose of returning water that has passed through the heat pump machine to the same aquifer that it was produced from in the open-loop water supply well.

10 CSR 23-5.020 Certification and Registration of Heat Pump Systems

PURPOSE: This rule sets required standards for certification report form submittal.

(1) A certification report form, supplied by the division, shall be used to report the construction of open-loop and closed-loop heat pump systems which utilize trenches pits and/or wells as loop installation points. One (1) certification report form per heat pump system shall be completed and submitted to the division by the permittee within 60 days after completion of the system. The certification report form shall be accompanied by the certification fee (see 10 CSR 23 – 2 for fees). The permittee shall furnish the well owner one copy, the division one copy and retain one copy in the permittee's files. The report form shall contain all required information. (material removed) Heat pump systems that utilize wells are required to submit one certification report form.

(2) The certification process involves the review of the certification report form to be sure that the heat pump system meets all construction requirements necessary for the specific area the system has been constructed. The minimum construction standards were written to protect Missouri's groundwater and to help ensure that the construction of the system does not constitute a threat to this resource.

(3) Upon successful completion of the review of the certification report forms, a certification number, which indicates that the heat pump system has met the minimum standards set in these rules, will be sent to the landowner.

(4) The registration process involves the documentation of certain types of activities according to the requirements and reported on forms supplied by the division.

(5) A registration report form, supplied by the division, shall be used to report major repairs and alterations of heat pump systems and the plugging of heat pump systems and must be submitted to the division by the permittee within 60 days after completion of the appropriate operations.

The registration report form shall be accompanied by the registration fee. The permittee shall furnish the well owner one copy, the division one copy and retain one copy in the permittees files. The report form shall contain all required information.

10 CSR 23-5.030 General Protection of Groundwater Quality and Resources

PURPOSE: This rule prevents the use of heat pump wells for any other purpose.

(1) Heat pump wells once constructed shall not be converted to any other type of well, except by written approval by the division.

(2) It is the obligation and responsibility of the heat pump installation contractor to ensure that the heat pump system is constructed according to the rules. On systems that utilize wells, the heat pump installation contractor is responsible for the integrity of the annular seal for a period of time from the date of certification to three years after that unless it can be shown that the well seal has been damaged by other persons.

10 CSR 23-5.040 Location of Heat Pump Wells

PURPOSE: This rule sets standards for the placement of heat pump wells.

(1) A vertical heat pump well shall be located on a site which has good surface drainage and prevents the accumulation of water within 10 feet of the well and any buried pipes.

(2) Vertical heat pump wells shall not be located within certain distances from pollution or contamination sources. A vertical heat pump well shall be at least

(A) Three hundred feet from a storage area for commercial fertilizers or chemicals, landfill, lagoon, above ground or underground storage tank for petroleum, petroleum products or chemicals.

(B) One hundred feet from a below-grade manure storage area, cesspool, unplugged abandoned well, subsurface disposal field (lateral field), grave, building or yard used for livestock or poultry, privy or other contaminants that may drain into the ground.

(C) Fifty feet from an existing operating well, a septic tank, buried sewer, a pit or unfilled space below ground surface, a sump, except that a well may be drilled closer than 50 feet to a basement or heat pump well.

(material removed)

(4) A variance may be granted if set back distances cannot be met. The variance must be obtained in advance from the division.

(material removed)

10 CSR 23-5.060 Construction Standards for Open-Loop Heat Pump System That Use Groundwater

PURPOSE: This rule sets standards for open-loop heat pump systems that use wells to produce or return groundwater.

(1) Open-loop heat pump systems and their installers that utilize existing surface water supply which is plumbed through the heat pump machine and returned to the same surface water supply are exempt from these rules.

(2) Open-loop Heat Pump Systems and Groundwater Supply Wells. An open-loop heat pump uses groundwater produced from wells which are plumbed through the heat pump machine where the heat transfer of the groundwater is accomplished. The groundwater is then utilized at the surface or returned to the ground via a return well. Any new well utilized to supply water must meet the construction standards set out in 10 CSR 23-3. Any well that was constructed before October 1987, that is utilized as the water supply for an open-loop heat pump system is exempt from these rules, except that the surface disposal of the water may fall under the Division of Environmental Quality rules and the return of the produced water via a well must meet rules set out in this section.

(3) Surface Disposal of Used Water. After the water passes through the heat pump machine, it may be disposed of to the surface only if the water remains on the landowner's property. It may not be run to drainage that leaves the property unless applicable permits are secured through the Water Pollution Control Program, Division of Environmental Quality. If the heat pump utilizes more than 25 gallons of water per minute when it is in operation, surface disposal of the used water is prohibited.

(4) Water Return Wells for Domestic Heat Pump Applications. Water return wells meet the requirements set out in 10 CSR 23 Chapters 1, 2 and 3 concerning casing, casing depth, well seal, borehole, grouting and reporting. The depth of the water return well must not exceed the depth of the water supply well. Water must be returned to the same aquifer it was taken from in the water supply well. A sanitary well seal or a pitless adapter may be used and the water return pipe must extend at least 20 feet below the static water table inside the well casing.

(5) Water Return Wells for Nondomestic Heat Pump Applications. Specifications for water return wells in other than domestic applications will be determined on a case-by-case basis by the division, taking into account the water quality and quantity, geology, hydrology and water usage in the area.

(6) To drill and construct an open-loop heat pump well or a water return well, the driller must have a nonrestricted water well installation permit.

(material removed)

10 CSR 23-5.080 Plugging of Heat Pump Wells

PURPOSE: This rule sets standards on the proper plugging of wells used in heat pump applications.

(material removed)
(2) Open-Loop Heat Pump Wells. Wells used to supply water for the heat pump and water return wells must be plugged as set out in 10 CSR 23-3.110. Plugging of Wells and a registration report form submitted as if it were a water supply well.

(3) Plugging Improperly Constructed Heat Pump Wells. When it is determined by the division that a heat pump well is constructed improperly, it must be brought into compliance with the rules or plugged. To plug an improperly constructed heat pump well, the following specifications must be met:

(A) Remove all pipes from hole;

(B) Clean out well bore of loose material;

(C) Plug well full-length with approved grout; and

(D) Submit registration report form and fee.