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THE DEVELOPING NEED FOR THE REGULATION OF GEOTHERMAL CLOSED LOOP BOREHOLE INSTALLATIONS

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Geothermal, (Ground source heating and cooling - GSHC) technology provides a proven method for saving energy costs for heating, cooling and hot water generation. Thousands of homes, businesses and manufacturing plants across the nation are already taking advantage of these energy-efficient conditioning systems.

Installation of ground source systems involves accessing the sub-surface by excavation or by drilling vertical bores. Because the sub-surface heat-exchange process occurs near or beneath the groundwater table, environmental and water resource regulatory issues make it important to "do the job right." Correct design, materials specification and installation are critically important to maximize efficiency and minimize risk. There is not a one-size-fits-all for geothermal.

Currently, the Commonwealth of Kentucky does not regulate Closed Loop geothermal wells. It does however regulate Open Loop geothermal well installation under Kentucky Administrative Regulations, 401 KAR 6: 310.

A closed loop geothermal heat pump system differs significantly from an open loop system in that no fluids present in the internal processes of the system are in contact with the environment. In a closed loop system, all fluids are pumped through a "closed" circuit of piping, and the fluids never come into contact with the surrounding soil, rock, groundwater, or surface water body.

An open loop system, however, utilizes a pumping well to supply water to the heat exchanger and, most commonly, the spent water is then returned to either another well, an injection well, or to the same well, or to a surface water body.

Recently, the Kentucky Division of Water (KDOW) has responded to numerous questions, complaints and request for technical assistance relating to geothermal borehole installations. KDOW has addressed this need through onsite visits to gain firsthand knowledge of the problems related to vertical borehole installations. However, technical advice and recommendations often go unheeded in regards to KDOW's ability to address the potential to prevent contamination of the groundwater and/or to protect homeowners from a litany of borehole construction and installation problems. This is due mainly to the fact, that KDOW does not have legal authority to enforce construction standards or reporting requirements. Because it is our mandate to protect the Waters of the Commonwealth, KDOW moved to address these issues through the development of a "Guidance Document" to assist geothermal borehole drillers who must develop Groundwater Protection Plans (GPPs) per Kentucky Administrative Regulations 401KAR 5:037.

As the geothermal industry continues to grow, issues associated with geothermal installations are expected to grow and problems will become more prevalent. Recently, members of the Kentucky Ground Water Association (KGWA) voted overwhelmingly to support regulation of the installation of closed loop vertical boreholes. This has led KGWA with the support of Kentucky Water Well Certification Board (an advisory board to the Governor of Kentucky), and KDOW to develop requirements for addressing the need for certification and industry-wide standards. These requirements have been presented as draft legislation to amend KRS 223 in the 2012 legislative session of the General Assembly of the Commonwealth of Kentucky.

STRATEGIES FOR EFFECTIVE MANAGEMENT AND MITIGATION OF NONPOINT SOURCE POLLUTION WITHIN WELLHEAD PROTECTION AREAS

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Wellhead Protection focuses on the prevention of groundwater contamination by managing potential contaminant sources within the recharge area of a well or spring. Once delineated, this recharge area becomes the Wellhead Protection Area (WHPA) for that groundwater source. Solely identifying potential contaminant sources does not mitigate the possibility for contamination. Public Water Systems (PWS) relying on groundwater must be proactive in the development and implementation of management strategies in order to have effective Wellhead Protection Plans (WHPPs).

Potential contaminant sources include both point and nonpoint sources. Point sources are often controlled through the development and implementation of Groundwater Protection Plans (GPPs) or other permitting initiatives. GPPs are required for any activity that has the potential to contaminate groundwater, per 401 KAR 5:037. Nonpoint sources are difficult to identify and manage because they have collective effects over broad areas. Pollution from some nonpoint sources, such as agricultural runoff and onsite septic systems, can be mitigated through alternate land uses, best management practices (BMPs), and installation of municipal sewer systems within the protection area. Land acquisition by groundwater systems is especially effective because the water system can then dictate the land use within their WHPA.

Proposed management strategies for most water systems typically include a combination of public education and regulatory compliance. Regulatory compliance includes state and local regulations, as well as any local or city ordinances passed pertaining to the WHPA. Public education efforts typically include public meetings, brochures, fliers, mailings, Consumer Confidence Reports, and posted notices. Successful implementation of these strategies depends on the resources available to the system and the nature of the contaminants. In order for any management strategy to be effective the utility must have cooperation between the plant operators, the utility water board or commission, businesses and residents within the protection area.

Oldham County Water District (OCWD) is one example of a PWS that has taken a very proactive approach toward implementing their WHPP. In conjunction with the management strategies listed above, OCWD sponsored an ordinance requiring the use of modified onsite septic systems for all new construction within their WHPA. To reduce the financial impact of the ordinance on developers and home owners, the water system offers grants that can be used to offset the cost of installing the modified septic systems in new and existing residences. This ordinance also aided in preventing the construction of a large-capacity lateral field within the WHPA. Additionally, OCWD has purchased much of the land within its own WHPA. This allows for direct control over what activities can take place, and for the exclusion of potential contaminant sources. OCWD continues to develop and implement management strategies to better protect their groundwater source from existing and future threats.

STATUS AND EARLY FINDINGS AT THE KENTUCKY HORSE PARK MONITORING STATION

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Royal is the largest spring in the Inner Bluegrass, from which Georgetown gets most of its drinking water. The springshed includes a large percentage of urban development in Lexington which makes water-quality monitoring an important tool for identification and mitigation of contaminate sources. The Kentucky Horse Park is a critical site in the springshed because the cave diverges from the Cane Run surface watershed in the park near the Scott county line. Swallow holes are ubiquitous along the surface channel and the middle reaches are dry most of the year. The main conduit was discovered by; 1) observing the slope of the potentiometric surface in the wells, 2) application of a conceptual model of a cave flanked by anastomotic channels and to the results from the drilling, and 3) by reaffirming an anomaly measured on an electrical resistivity profile in 2007 had special significance compared to the later ER profiles. The cave was intercepted at a depth of 18 meters as indicated by a bit drop and loss of return circulation.

Inspection of the cave with a submersible borehole video camera recorded the passage as a meter high but the camera was inadequate to illuminate distant walls. Doppler sonar has also been used to delineate the cave dimensions. The instrument is intended for open water but its' cylindrical shape and the transponder configuration made it possible to lower it into the wells. Stationary hard echoes (amplitude greater than 45, velocity less than 0.01 m/sec) are attributed to walls, fallen rock, and ceiling pendants.

The 20-meter depth and the potentiometric surface rising 6 meters above the cave ceiling made instrumentation a challenge. Well 20 has a 12-volt submersible pump and Well 25 has a Marsh-McBirney 201-D electromagnetic flow velocity meter. Well 23 against the south wall has an YSI 6920v2 water quality logger. Well 24, on the north wall, has a Telog stage recorder (as do five other wells). The pump discharges to a carboy from which water samples are collected. A timer on the pump and an ISCO auto sampler are synchronized. Water quality data are recorded on a Campbell 200s data logger. Well 24, on the north wall of the conduit, and five other wells, have standalone Telog data loggers with Druck pressure transducers. Only a few water samples have been collected to date.

The gauge at Berea Road recorded 12 inches of rain in April 2011 and 7 inches the first three weeks of May. The last week of May and the first week of June had no rain. The water-quality logger was operational May 24, 2011. A sharp rise in water temperature, a rise in conductivity, and a peak in dissolved oxygen were recorded thru June 10th (Fig. 1). Flow velocity and water level remained nearly constant. Water temperature and conductivity returned to groundwater like values abruptly early on the 10$^{th.}$ An afternoon thunderstorm yielded one inch of rainfall late on the 10th. The Cane Run channel was inspected from Berea Road to the Spindletop Country Club on June 16. Inflow to swallow holes was not observed but there were isolated pools. A large pond is located on Cane Run at Spindletop. We hypothesize that water in the pond and/or the discharge from interbasin springs was sustaining the inflow into the Cane Run before the 10th. The water in the pond or flow down the channel became warmed and oxygenated from aquatic plants. When surface water stopped flowing into the swallow holes, the groundwater temperature, conductivity, and dissolved oxygen shifted back to that of groundwater. Alternatively the rapid drop in temperature, etc. could be augmented by the cooler intense rainfall June 10th. If similar conditions occur again we will make observations at the pond and at any interbasin springs that can be found.

An interesting phenomenon is the relatively fast rate of rise of the potentiometric surface in the main conduit resulting from intense rainfall, as opposed to the water level recorded in the lateral wells. There is nearly instantaneous communication of pressure along the length of the conduit, whereas smaller conduits, bedding planes, and joints flanking the conduit have just enough resistance to flow that the volume of water that must be moved to equilibrate the pressure cannot occur fast enough to prevent a lag in the stage in the flanking wells versus those in the main conduit.

Work continues on measuring the cross-section of the conduit wider flow zone. The Doppler sonar and the down-hole video can only "see" the main conduit. The cross-section by video is 5 square meters. Constant-injection-rate groundwater traces are used to determine the total discharge along with a second tracer injected as a slug to measure velocity. A maximum cross-section of 28 m^2 is suggested but more traces are needed to verify the velocity and total discharge under a variety of flow conditions.

Other UK researchers are taking advantage of the facility at the Kentucky Horse Park. The site has also been a stop on three field trips during the past six months and by several individuals. We anticipate several papers from the data already on hand and more data are constantly being gathered. Guests are welcome to visit the site. Major support provided from SB-271 funds by the University of Kentucky College of Agriculture.

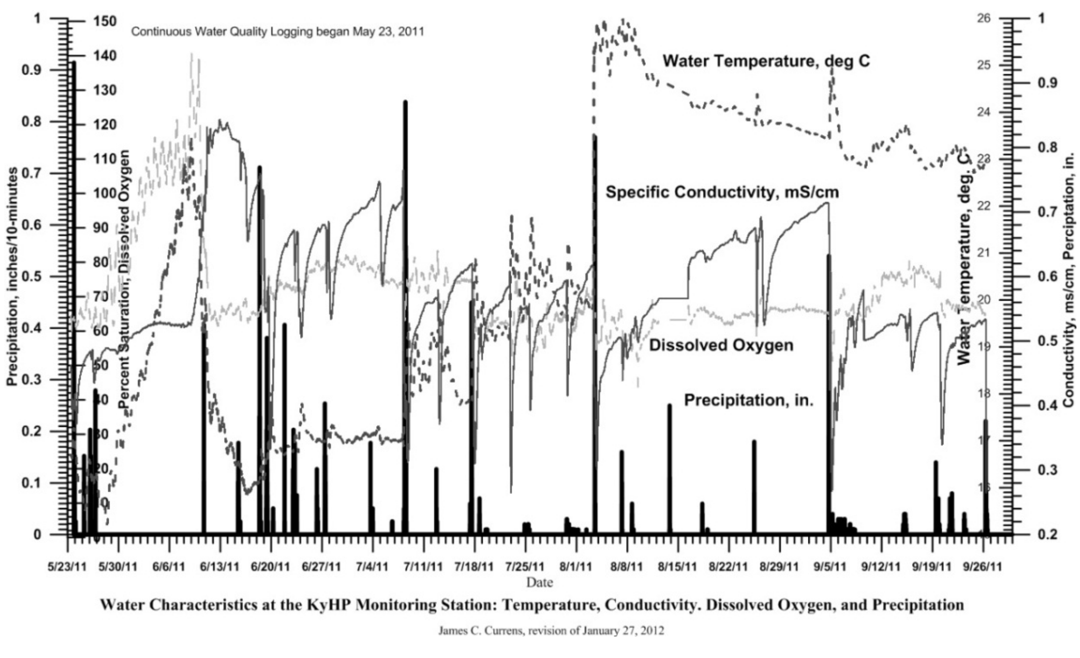

Figure 1. Chemographs from the first data recorded at the Kentucky State Horse Park groundwater monitoring station, Royal Spring aquifer.

FLUID EVOLUTION IN CAMBRIAN-ORDOVICIAN
KNOX GROUP RESERVOIRS

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Carbonate strata in the Cambrian-Ordovician Knox Group, where buried to 2,500 ft. or deeper in the Appalachian and Illinois Basins of Kentucky, are being investigated as a potential reservoir for geologic carbon sequestration. An analysis of archived formation water chemistry data (n~ 930) shows that Lower Ordovician and older reservoirs, including Knox Group reservoirs, are less saline than would be predicted by salinity trends in Silurian and younger reservoirs. The less saline water in the Knox Group suggests the possible influence of meteoric water, but it is not clear whether the meteoric water originated as “old” meteoric water that penetrated exposure surfaces during or shortly after Knox deposition or relatively “young” meteoric water that infiltrated along structural highs, such as the Cincinnati Arch. Distinguishing the causal mechanism is critical as infiltration of “young” meteoric water from the Cincinnati Arch into the deeper basin would imply that injected CO_2 could migrate the opposite direction driven by buoyancy forces.

The role of the Cincinnati Arch in fluid evolution in Knox Group reservoirs was investigated using bulk and isotopic ($d^{18}O$-H_2O, dD-H_2O) chemistry measurements from three geographic areas along the Cincinnati Arch: (1) the Jessamine Dome or Bluegrass region of north-central Kentucky, (2) the south-central Kentucky and north-central Tennessee region where Knox group reservoirs often produce oil and gas, and (3) the Nashville Dome of Tennessee. Most of the water samples came from upper Knox Group carbonates including the Beekmantown Dolomite and Chepultepec Dolomite at depths of less than 100 to approximately 2,500 ft. below ground surface.

Waters in south-central Kentucky were NaCl-rich and salinity ranged from 12,400 to 108,000 mg/L, TDS. Waters from the Bluegrass and Nashville Dome areas, in contrast, were less saline (467- 8,189 mg/L, TDS) and compositionally more variable (NaCl-, $NaHCO_3$-, and $CaHCO_3$-rich waters). Chloride:bromide ratios for south-central Kentucky waters were similar to seawater (Cl:Br= 290), and, along with the higher salinities, support the hypothesis that little, if any, meteoric water infiltrated the Knox in this area. Chloride:bromide ratios in the Bluegrass area are mostly lower (39 to 292), and $d^{18}O$ and dD data for the Bluegrass ($d^{18}O$= -7.3 to -8.1 per mil, dD= -41 to -57 per mil) and Nashville Dome ($d^{18}O$= -5.9 to -6.4 per mil, dD= -34 to -36 per mil) areas fall on or close to the meteoric water line. Collectively, the data support dilution of Knox waters by meteoric water in the Bluegrass and Nashville Dome areas.

Chloride concentrations are similar between the Bluegrass (11- 1,300 mg/L) and Nashville Dome 15- 1,500 mg/L) areas, which suggests that they were similarly influenced by meteoric flushing. The similarity diverges, however, when the ratio of chlorine-36 to total chlorine is measured. Chlorine-36, produced largely in the atmosphere by cosmic ray interactions with argon-40, has a half-life of 301,000 years. Upon entering the groundwater system as precipitation, the ratio of chlorine-36 to total chlorine in meteoric water declines with time. Chlorine-36:total chlorine values for the Nashville Dome area range from 160 to 709 (n= 7) with most ratios being slightly less than the value for meteoric water before nuclear testing (400). This suggests that dilute Knox groundwater in the Nashville Dome area is relatively young meteoric water. Bluegrass chlorine-36:total chlorine values, in contrast, are markedly lower and range from 1 to 176 (n= 6) with five ratios being less than 6. The low chorine-36:total chlorine values suggest that Knox waters in the Bluegrass region have attained secular equilibrium. If correct, this would suggest that, although dilute, Knox groundwater in the Bluegrass region is possibly older than 1.5 million years old.

SIMULATING LONG-TERM FATE OF CO_2 FOR A WESTERN KENTUCKY DEEP SALINE RESERVOIR CO_2 STORAGE TEST

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Geologic sequestration is the process of injecting carbon dioxide (CO_2) into deep subsurface rock formations for long-term storage, as a means to reduce CO_2 emissions to the atmosphere. Research is under way across the nation to determine where and to what degree this technology can be used. The Cambrian-Ordovician Knox Group, a 4000-foot-thick sequence of dolostone and minor dolomitic sandstone, is a prospective sequestration target in the southern Illinois Basin. Thorough evaluation of the Knox Group is critical because the main sequestration target elsewhere in the Illinois Basin, the Cambrian Mount Simon Sandstone, is thin or absent throughout most of western Kentucky. The Kentucky Geological Survey, as part of the Kentucky Consortium for Carbon Storage, drilled an 8,126-foot-deep test well (KGS #1 Blan well) in Hancock County, Kentucky, and injected 690 tons of CO_2 into the Knox Group dolostone and sandstone reservoirs.

Evaluation of well and core data indicate that the Knox Group has reservoir properties suitable for CO_2 storage and that the overlying Maquoketa Shale has sealing capacity sufficient for long-term confinement. Injection testing with brine and CO_2 was completed in two phases. The first phase tested the entire Knox in the open borehole at 3,780–7,397 feet below casing cemented at 3,660 feet, and the second phase tested a mechanically-isolated dolomitic-sandstone interval at 5,038–5,268 feet.

To understand the long-term fate of CO_2 injected into the Knox reservoirs, geochemical reactions among CO_2, brine, and rock-forming minerals were modeled using TOUGHREACT. The model benefited from a robust data set collected from the KGS #1 Blan well, including core porosity and permeability, petrographic and XRD mineralogy, brine chemistry, and temperature and pressure measurements. Kinetic batch models and 1-D radial reactive transport models were used to evaluate the migration of the injected CO_2, mineral dissolution and precipitation.

Results from these models suggest (1) mineral trapping capacity of dolomite rocks for CO_2 is small and the majority of CO_2 will remain in aqueous or supercritical/gas phases for a long time, (2) injected CO_2 causes dissolution of dolomite and precipitation of dawsonite and quartz, (3) presence of siliciclastic minerals, such as k-feldspar, facilitates mineral trapping, and (4) the radius of influence of the injected CO_2 from the tests is about 30 feet from the well.

NOTES