Report for 2002AR13B: Processes And Controls Affecting Water/Rock Interaction in Abandoned Underground Coal Mines, Including Feasibility and Risk Assessment of Using Mine Water for Public Drinking Water Sources

- Conference Proceedings:
  - Walker, K., C. Varnell, and J.V. Brahana, 2002, Processes and Controls Affecting Water Quality Water Supplies to Meet Our Growing Needs--Scientific, Regulatory, and Public Perspectives, University of Arkansas, Fayetteville, Arkansas.
  - Varnell, C. and J.V. Brahana, 2003, Factors Affecting Water Quality and Surface Water/Ground Water Interaction Associated with Flooded Coal Mines in Greenwood, Arkansas, University of Arkansas, Fayetteville, Arkansas.
- Other Publications:
  - Brahana, J.V., 2003, Hydrogeologic Research Along a Transect from the Ozarks to the Quachitas, Northwest to West-Central Arkansas: Field guide for University of Arkansas' 2003 Field Trip, 66 p.
- Dissertations:
  - Varnell, C.J., 2004, The Environmental Dynamics of Utilizing Water from Flooded Coal Mines in Greenwood, Arkansas, as a Supplemental Public Drinking Supply -- Physical, Chemical,Social, Political, Economic, and Public Perception Considerations: Ph.D. dissertation, Program of Environmental Dynamics, University of Arkansas, Fayetteville, Arkansas, 169 p. [in preparation]
  - Cooper, K.W., 2003, Processes and Controls Affecting Water Quality in Flooded Coal Mines in the Arkansas River Valley: M.S. thesis, Department of Geosciences, University of Arkansas, Fayetteville, Arkansas, 88 p. [in review].

Report Follows:

Problem and Research Objectives

Like many small but growing municipalities in west-central Arkansas and the eastern U.S., the city of Greenwood, Arkansas, draws its water from a surface-water source (Vache Grasse Creek, tributary to the Arkansas River). Small streams such as the Vache Grasse are not adequate to provide for the increasing public water-supply needs of the city during periods of low flow or drought. Underlying Greenwood are abandoned coal mines that have been flooded. The mines include both surface pits and underground workings. Based on estimated volumes of void space computed from old mine maps, the voids represent a huge potential reservoir of water that could be used to augment the water needs of the city if the quality is good. Obvious questions about water chemistry caused by withdrawing water from the mines have thwarted previous efforts to assess the feasibility of developing this resource. Inasmuch as abandoned, flooded mines are widespread throughout west-central Arkansas, the Appalacians, the midcontinent U.S., and other scattered areas throughout the country, with limited water supplies, developing an accurate means to cost-effectively evaluate these mines as potential water supplies would provide a valuable tool to local agencies seeking additional water supplies. This study addresses those questions.

Research objectives include characterization of existing water quality, delineation of the active flow system, development of a conceptual model of flow and transport, and compilation of historical documentation of drinking water use from coal mines elsewhere. The study also addresses flow modeling, and geochemical models of water/rock interaction.

Methodology

The study is based on field data collection, water quality sampling, water-level measurements, precipitation measurements, pumping tests, field reconnaissance, historical data compilation, lab testing, and modeling. Field and lab analyses have assessed major constituents, minor constituents, trace metals, microbial pathogens, nutrients, organics, color, and other relevant EPA drinking water requirements. Water levels at key components of the hydrogeologic system have been monitored continuously using transducers, floats, and analog strip-chart recorders, and a tipping bucket rain gage has provided a continuous record of precipitation recharge. By comparing response to hydrologic events, both magnitudes and lag times, the degree of interaction between the surface and ground water parts of the system have been documented. Field reconnaissance and historical records have been compiled, and a conceptual model serves as the basis of flow models which are presently being tested.

Principal Findings and Significance

Question	Answer	Basis for Determination	Overview
How much water is stored in the mines?	Our conservative estimate is that in Greenwood #2 alone, more than 20 million cubic feet of water is stored. If no recharge occurs, the City could pump 5 million gallons per day for 30 consecutive days without depleting this single mine of all its water.	We took the lateral dimensions of the mines (length times width), multiplied these times the thickness of the coal seam, which was removed, and reduced this figure by a best estimate of the space occupied by the pillars. The pillars decrease the void space.	This value is considered to be conservative by a safety factor of approximately 2 to 4 times. A more precise estimate of water stored could be computed by digitizing the mine maps, and doing a finite difference approximation.
If we pump Greenwood #2, how will it impact contiguous mines such as Fidelity and Greenwood #1?	Yes, because the mines are hydraulically interconnected to each other, and to most of the strip pits. When we pump any flooded mine, we will lower the water level in the others, and draw water from those sources into our well. This is analogous to a line of bowls filled to overflowing that have tubes connecting one to the other beneath the surface--once we put a straw in one bowl and start sucking out fluid, water levels will be lowered to a nearly level surface in all bowls. When the water level is drawn below the lowest point of connection between different mines, water exchange between mines will cease until the water level rises back above the level of the lowest interconnection.	Water levels in all available wells show a slight gradient from the south to the strip pits in the north. In addition, reported flooding and sediment tracers from Lake Jack Nolan to Alkali Pit have been observed by long-term local residents when Jack Nolan was drained, and other surface water was in low flow. Mine connections between Greenwood #1 and Greenwood #2 are shown on copies of the mine maps as well. Water level perturbations to systematic flood pulses in Vache Grasse Creek also support an open hydraulic connection between different mines.	All data we have collected thus far support the concept that water in the different mines is in hydraulic contact with the other mines. Therefore, any stresses or water removal in one part will affect water-levels in the other mines. Irrefutable evidence will be available during the intense, long-term pumping test if all mines and strip pits are monitored continuously.
What is the source of water in the mines?	We believe Greenwood #2 receives water from several sources. At low flow, we estimate that approximately 0.25 ft^3/sec enters the system from unknown locations along faults. Under flood conditions, recharge occurs rapidly, on the order of hundreds of cubic feet per second, likely into engineered structures breached by flood waters of Vache Grasse Creek and its alluvium.	We estimate the low-flow discharge based on the volume of water exiting from Alkali Pit. Alkali Pit is the lowest water level elevation we observe from the ground-water system. this in turn flows into Vache Grasse Creek, except when flood pulses caused by the bladder dam raise creek stage above the level of Alkali Pit, and for a brief period (tens of minutes), flow is reversed. Under flood stage, huge amounts of water issue from Alkali Pit. These flood "boils", estimated in the hundreds of cubic feet per second range, are chemically similar to surface water that is likely pirated upvalley in the flood plain of Vache Grasse Creek.	The water in the discharge stream from Alkali Pit is chemically similar to water in Vache Grasse Creek. Had it been derived solely from ground water, it would have had significantly more mineralization, such as water we see from some of the side passages in the mine which are not along the main flow path. Supporting evidence will be available during the intense, long-term pumping test when tracer testing is performed. Although this is difficult to measure in a system with such huge storage, we are optimistic we can narrow the location of the inflow.
How good is the water in the mines? Is it safe for drinking and other household uses?	The water in the mines was sampled at available wells, and from where it exits at Alkali Pit. It varies from very fresh, better that the current source of water from Vache Grasse Creek, to highly mineralized. The water appears to be suitable for drinking and other household uses if it is treated. No toxic or harmful substances have been found in any of our analyses of the water. Mine water is highest in dissolved iron, sodium, bicarbonate, and sulfate.The high mineralization is caused by ground water interacting with the wall rock of the mine, and is to be expected. Flow paths are focused along the steepest hydraulic gradients, and water in most dead-end galleries is thought to be essentially stagnant for most conditions.	Sampling of mine water from all available access points, and at different seasons, different flow conditions, and different depths indicates that the flow system is dynamic, but that water quality is variable at different locations and at different depths. Our pumping tests indicate that the water is stratified, with the denser water near the bottom of the void spaces, and less-mineralized fresh water at the top. In general, the longer the residence time of the water in the mine, the more mineralized it becomes. The main pathways along major drifts are generally the loci of most rapid flow, and thus, are the freshest. Storms and other natural conditions change flow boundaries.	Overall, the water is suitable for public use and ingestion after appropriate treatment, which will be similar to existing treatment of the public supply of Lake Greenwood. Highly mineralized water will require more supplies for treatment, and likely will be more expensive to provide.
Question	Answer	Basis for Determination	Overview
What problems are likely to occur from developing the mines as a	1. During periods of intense usage, water levels in the mines will be lowered, and	1. Withdrawal will exceed recharge, based on base flow measurements	1. This occurrence is a virtual certainty. Affected

source of drinking water?	this will dewater the strip pits, and effectively destroy fishing and recreation associated with these surface water bodies "drying up". 2. During periods of intense usage, water levels in the mines will be lowered, and this will induce recharge from Vache Grasse Creek into Alkali Pit, unless engineered structures are built to control this flow. Vache Grasse Creek currently carries the waste water from the water treatment plant. 3. During periods of intense usage and low recharge, water levels in the mines will be lowered, and this will remove the buoyant support of the stored water on mine ceilings where overlying rock is relatively thin. Subsidence is likely to occur, with collapse of the overlying roof material into the mine voids near the strip pits. 4. Geochemical effects of mixing waters from reducing and oxygenated environments, may facilitate additional dissolution and mobilization of undesirable substances that are currently not in the water. 5. Direct recharge in adequate quantities to replenish the reservoir appears to be a function of stage of Vache Grasse Creek. Drought conditions during the winter months when mine recharge is expected may require installation of ancillary structures to facilitate artificial recharge.	from Alkali Pit. The deficit will be made up by removing water from storage, which will lower water levels in the mines. 2. Direct observation of water reversing flow into Alkali Pit and the mines when the stage in Vache Grasse Creek is higher than those two. Use of mine water will create transient lowering of water levels, favoring inflow to the mine. 3. Risk assessment of subsidence is not quantified, but remains a real possibility, based on extrapolation of mining conditions elsewhere (Appalachia), on landforms (internally drained depressions) along the outcrop line, and loss of a bulldozer during construction projects. 4. Empirical evidence indicates that both water types exist in the mines, but under current conditions there are few transient stresses to favor removal of the reduced water. During pumping, the water will be removed from storage, and during recharge from flood events, it will be replaced with oxygenated water. 5. Historically, mine flooding was the result of infrequent high flood stages in Vache Grasse Creek. Annual flow in Vache Grasse is in excess of the anticipated water use from the mines.	landowners will have valid grievances. 2. Hydraulic gradients favoring flow is a virtual certainty, and engineering alternatives will need to be emplaced to prevent unacceptable water from entering the mine reservoir. 3. We have not been able to estimate the probability of subsidence, nor assess the conditions necessary to assign high risk. Historically, collapse has not been a common event elsewhere, but the result of a unique combination of conditions. We strongly encourage ongoing monitoring in response to major withdrawals of water. 4. Water chemistry will change, although we have not seen evidence that it will deteriorate. We strongly encourage ongoing monitoring in response to major pumping tests. It is likely that mine water will initially require more treatment than water from the surface. 5. Engineering alternatives are available to direct recharge to the mines when natural processes fail to do so
What benefits to the City of Greenwood are likely to occur from developing the mines as a source of drinking water?	1. Significant cost savings. 2. Minimal impact on existing land use and infrastructure. 3. Shorter completion date for project. 4. PR benefits as a leader in developing new technology in concert with a broad range of stakeholders.	1. Mines already exist; damming and dredging would require major construction costs. 2. Most land overlying the mines could continue to be used in its present designation; surface impoundment would require abandonment. 3. The storage reservoir is already in place; intake, piping, and engineering structures mentioned earlier are the only new infrastructure required. 4. The methodology has the potential for much wider use; close monitoring assures full support from stakeholders.	1. Savings are estimated to exceed tens of millions of dollars. 2. This option optimizes effective use of space and resources. 3. Physical aspects could potentially be placed in service next year. 4. Resource allocation typically is adversarial; there are numerous benefits from this project.