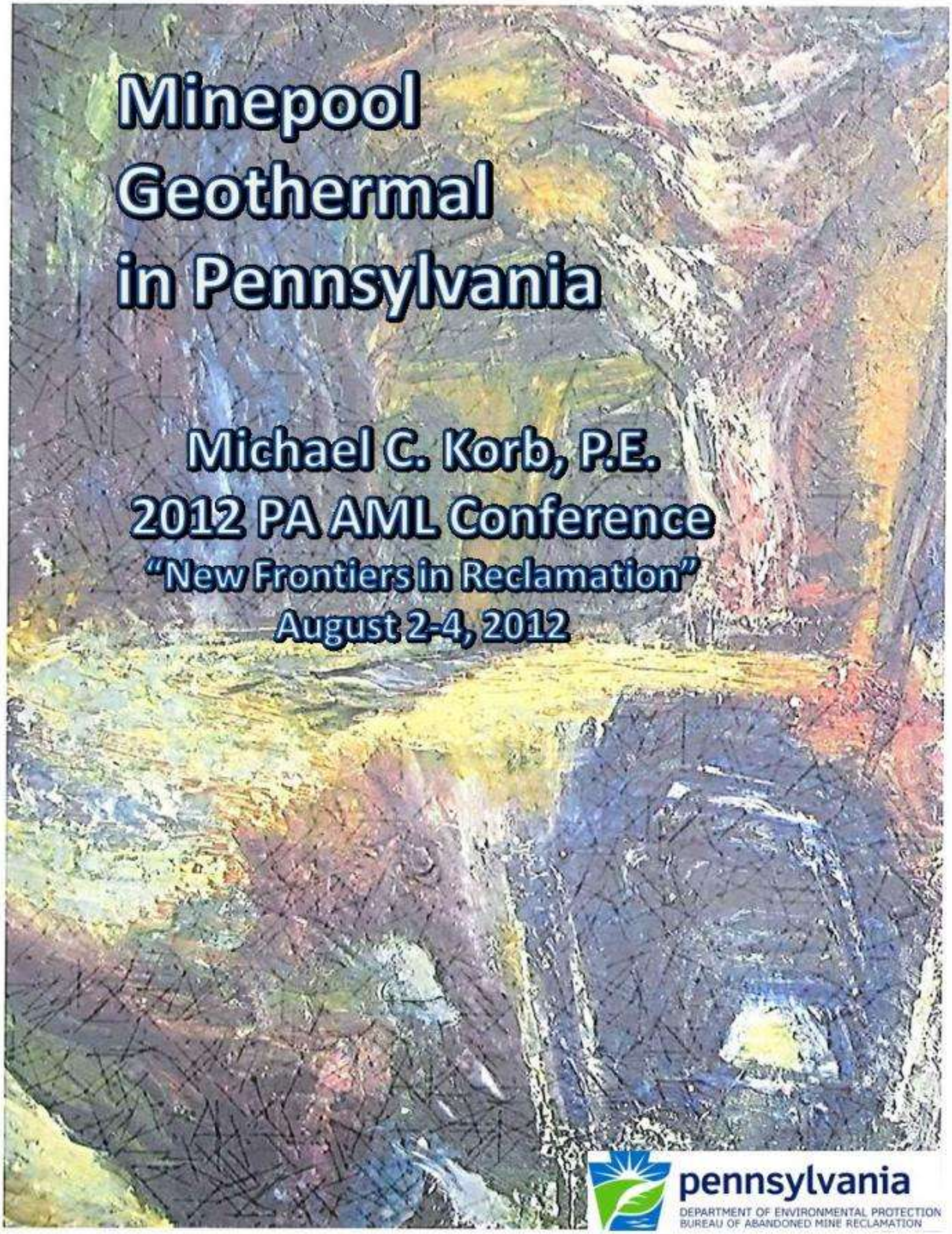

Minepool Geothermal in Pennsylvania

Michael C. Korb, P.E.

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DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF ABANDONED MINE RECLAMATION

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Michael C. Korb, P.E. | Environmental Program Manager
Pennsylvania Department of Environmental Protection
Bureau of Abandoned Mine Reclamation | Wilkes-Barre
mkorb@pa.gov | www.dep.state.pa.us

Abstract

In 2009 Marywood University, Scranton, Pennsylvania, received a grant from the Pennsylvania Department of Environmental Protection (PADEP) to construct, test, and monitor a geothermal energy system capable of exchanging heat with a minepool that exists beneath the University's campus. Marywood, working with the Scranton office of Greenman-Pedersen, Incorporated, (GPI) and PADEP, installed the geothermal system in 2010 to serve a portion of the cooling needs of Marywood's new Center for Architectural Studies. The system has been expanded to be utilized in Phase II of the Center's construction and is adequately cooling the entire facility.

Coal underlies about one third of Pennsylvania, with anthracite coal in the northeastern and north-central portions of the state and bituminous coal in the central and western portions. There are between 10,000 and 15,000 abandoned underground coal mines and numerous abandoned underground metal and non-metal mines in Pennsylvania, many are flooded. With more than three million people living in and around cities like Pittsburgh, Scranton, Wilkes-Barre, Johnstown, and Hazleton located over known minepools, the possibilities for use of geothermal hear from minepools seem to be unlimited. Yet, only a few facilities are using this apparently great energy source. Pennsylvania and other states are looking for sustainable solutions for minewater treatment, and this may be a potential resource.

This paper discusses the Marywood minepool-geothermal project, other projects and installations in Pennsylvania, the background, benefits, and potential problems with the use of mine water from abandoned mines for geothermal heating and attempts to discover why so few are using the process.

Thanks

"Thanks!" to the people named in the references, especially the papers by Ackman and Watzlaf, and Schubert and McDaniel, and the openness, candor and helpfulness of the people who have been doing this work in past years (Of course, researching is just working with the work that was done by others.); to Eric Conrad, Pat Acker, Austin Burke, and others who encouraged this attempt; and Jon Dietz, Jaci Harner, Wendy Yankelitis, Holly Cairns, Ron Horansky and Jim Sovaiko who provided good help and information; also, to those that read through the drafts and made comments that caused me to focus on parts that were not clear or were left out altogether, where I wrote "beleive" instead of "believe", or where I said something that was "Just stupid!" – my wife Pat, Brandon Diehl of the Foundation for Pennsylvania Watersheds, Terry Ackman, Chuck Cravotta of the USGS, Dr. Brian Redmond of Wilkes University, Steve Daiute of GPI, David Moison; and several of my coworkers at the PADEP Bureau of Abandoned Mines – Larry Dobash, Ron Ryczak, Scott Longstreth (and his mom Debora, the English teacher), Brian Bradley, and Eric Cavazza.

Minepool Geothermal in Pennsylvania

Marvine Colliery

Marvine Colliery of the Delaware and Hudson Coal Company, in Scranton, Pennsylvania, was opened in 1872, and coal was mined underground until 1954. Over those years some 29 million tons of coal were removed, reaching a maximum annual production of 1,124,430 tons in 1931. Some 2070 men were employed at the Marvine Colliery in 1926.[1]

The Marvine Colliery, located at the borders between the city of Scranton and the boroughs of Dunmore and Throop, consisted of two sites located adjacent to one another. They were divided by the Lackawanna River. The Marvine Colliery No. 2 was located to the east of the Lackawanna River, bordered by Olyphant Avenue at the east, East Parker Street at the south, and Interstate 81 at the north. Marywood University is located south and east of Olyphant Avenue.

Insurance maps of the city of Scranton indicate that the site west of the Lackawanna River was developed first (1872) and the site east of the river (near Marywood) was developed circa 1898-1920. The operation was abandoned in 1963, and its ruins were documented by the Historic American Engineering Record (HAER) around 1990.[2]

In 1915, 940 men working at the Marvine Colliery produced 391,000 tons of anthracite coal. Some 400 feet above them, Marywood College opened on September 8, 1915, with a class of thirty-four women. Four years later, as the first Marywood class of seventeen graduated, a concrete and steel colliery building – Marvine II - was being built at the bottom of the hill from the Marywood Campus.

Marvine II (1955) Source: HAER[2]

Operations ceased at the Marvine Colliery in 1963, and its mine dewatering pumps were shut down. This allowed the mine workings to flood to the elevation of a gravity outlet, in this case, the Old Forge Borehole. This borehole was drilled in 1961 to prevent the rising minepools in the Scranton area from flooding area basements and low-lying neighborhoods.

Marywood University

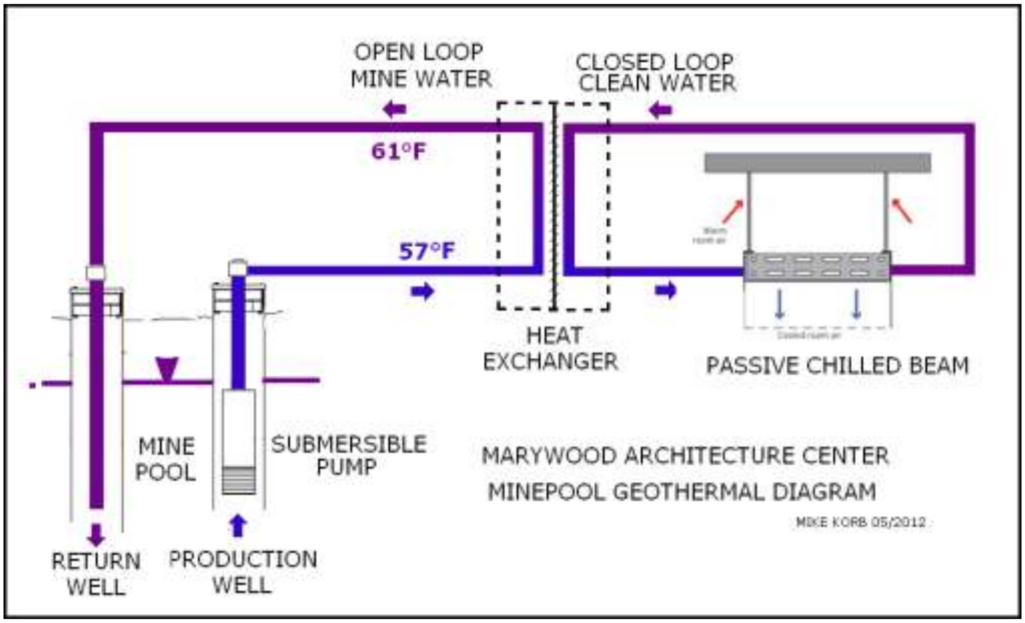
Marywood University is coeducational, comprehensive, residential, and Catholic. Founded in 1915 by the Sisters, Servants of the Immaculate Heart of Mary started Marywood as a college with one building in 1915. Marywood was the first college for women in Northeastern Pennsylvania and the first Catholic college for women in the state.

Marywood University has grown from a liberal arts college for women into a coeducational university (in 1997) consisting of five colleges - Education and Human Development, Creative and Performing Arts, Health and Human Services, Liberal Arts and Sciences, and Architecture. Marywood's scenic 115-acre campus enrolls over 3,400 students in undergraduate and graduate programs.[3]

Marywood Geothermal System

In 2009, Marywood University received a grant from the Pennsylvania Department of Environmental Protection (PADEP) to construct, test, and monitor a geothermal energy system capable of extracting and rejecting heat to the Marvine Mine water pool under the University's campus. The grant from PADEP's Pennsylvania Energy Development Authority Sustainable Business Recovery funds, for the deployment of innovative alternative/ renewable generation, efficiency & demand side reduction projects, was funded by the US Department of Energy (DOE) under the American Recovery and Reinvestment Act of 2009 (ARRA). Marywood, working with Greenman-Pedersen, Inc., Scranton office (GPI) and PADEP, installed the geothermal system in 2010 to serve the cooling needs of Marywood's new Center for Architectural Studies. The system has been expanded and is being utilized to also cool Phase II of the Center.

The Marywood Geothermal Energy system design includes two wells - one production well and one recharge well. The production well houses a submersible pump, and the recharge well is simply a cased well that extends to a mine seam that is at the known elevation of the mine pool and serves as a path for the water to be discharged back into the minepool. The campus is located on a hill above the Marvine Mine pool, so that the boreholes are some 400 feet deep. Depth to the minepool is 340 feet.



When the wells were installed, yield tests were performed to verify the desired flow rates could be achieved. Water samples also were extracted to verify that water chemistry results from an exploratory boring were consistent with those extracted from the production well. The design also includes a number of features to monitor the performance of the system. Those features include measuring the amount of energy transferred from the system, supply and return temperatures, electrical metering, and sampling ports to allow samples to be extracted from the production well for analysis to monitor any water chemistry changes that may occur.

(Left) Marywood Center for Architectural Studies (Right) Marywood Production Wellhead
Photos by Michael Korb (MCK) 2012

Water from the production well is pumped to and through a plate heat exchanger in which heat is transferred to a separate fresh water loop that serves the building's cooling needs. The heat exchanger separates the geothermal loop from the building loop and generates water 2°F - 3°F warmer than the water extracted from the mine. This water reports to a passive chilled beam cooling system that utilizes the 55°F-60°F water to cool the architecture studios providing cooling within those spaces without the use of mechanical cooling or forced air. While chilled beams are common in Europe, they are still considered an emerging technology by many in the US. The system developed under the grant has been incorporated into Marywood University's overall campus sustainability effort and the School of Architecture facility has received LEED Gold Certification from the US Green Building Council. 100% of the cooling for both design studio floors of the renovated gymnasium - the School of Architecture - is now being provided by the chilled beams, but this will be the first full cooling season with the completed building.[4]

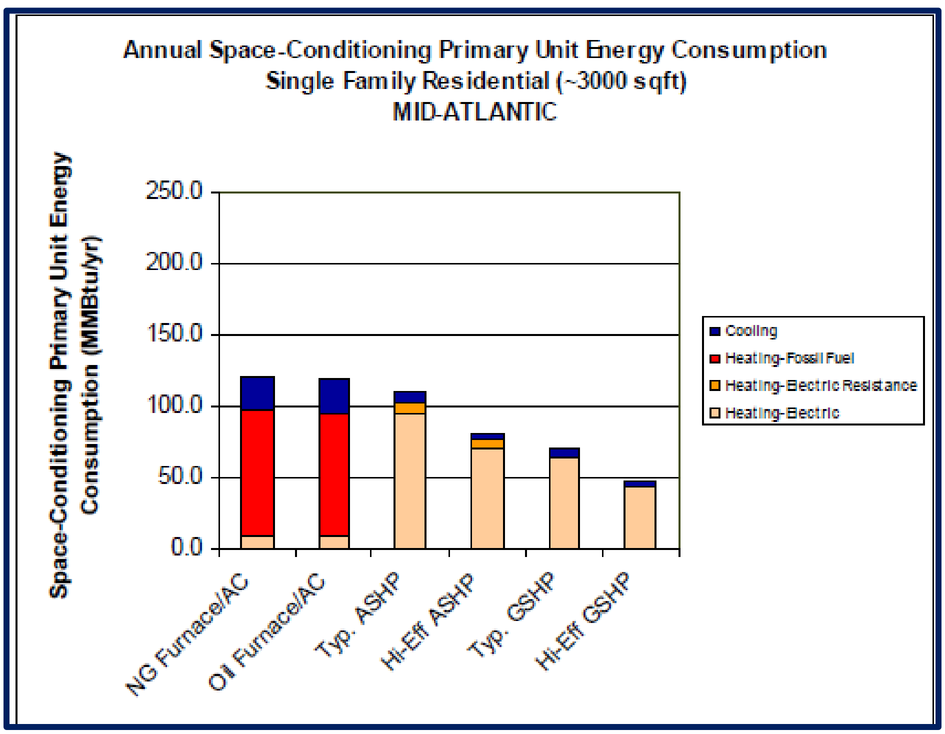
Several potential problems will merit watching at Marywood, besides the economics. Water quality may change because of de-stratification of the minepool caused by pumping. Pumping may draw mineralized water from deeper, poorly circulated strata, causing mixing with the uppermost layers which are generally the water of mine discharges. Iron scaling (fouling) and corrosion may occur over time, causing gradual loss of conductivity in the heat exchanger and increasing pumping pressures.[5]

Geothermal Heating and Cooling

People have used geothermal energy in North America for at least 10,000 years. Native Americans used hot springs for cooking, warmth and cleansing, and have a history with every major hot spring in the United States, located mainly in the West. Hot springs are rare in Pennsylvania – apparently only in the area near Warm Springs Lodge in Perry County, where Sherman's Creek has six warm (about 69°F) springs that gave the inn its name.

Homes have often been built near hot springs to take advantage of natural heat, but the construction of the Hot Lake Springs Hotel in Oregon in 1864 was the first time that the energy from hot springs was used on a large scale. In 1892 Boise, Idaho became the world's first district geothermal heating system with water is piped from hot springs to town buildings. Today, there are four district heating systems in Boise that provide heat to more than five-million square feet (sq.ft.) of residential, business, and governmental space. Although no one imitated this system for some 70 years, there are now 120 district heating systems in the United States and dozens more around the world. Geothermal technology moved east when Professor Carl Nielsen of Ohio State University developed the first ground-source heat pump for use at his residence in 1948.[6]

Geothermal heat pumps (GHPs) have been in normal use since then. GHPs use the constant temperature of the earth as an exchange medium. A few feet below the earth's surface, the ground remains at a relatively constant temperature — ground temperatures range from 45° to 75°F. The GHP takes advantage of this by exchanging heat with the earth through a ground loop system.[7] GHPs use the least energy to cool and heat space and are the most economical HVAC system for residential as well as commercial usage.



Source: Navigant Consulting, submitted to US DOE Office of Energy Efficiency and Renewable Energy (EERE) Geothermal Technologies Program[8]

(From looking at this chart, it appears that Marywood should be looking into installing a high efficiency heat pump to get the most bang for their buck and not just use their system for cooling.)

A number of universities have undertaken installation of ground-source geothermal systems for their heating and cooling in the past several years – notably Ball State, Ohio State, Missouri University of Science and Technology, and Cornell, as well as Juniata College in Pennsylvania and Allegheny College of Maryland. At Ball State, Indiana in March, the University dedicated the first phase of the nation's largest ground-source, closed-loop district geothermal energy system which will replace coal-fired boilers to heat and cool 47 buildings using 3600 4"-5"Φ boreholes 400 to 500 feet deep, and burial of some 10 miles of pipe.[9]

Photo shows drill rigs at Ball State boring a portion of what will be some 3600 wells buried under an old soccer field, parking lots and 25-40 acres of green fields.

Source: Ball State University[10]

(Apparently a lot of surface is being torn up to put in these wells.)

Marywood's system installation required only two boreholes and 2000 feet of pipe. Imagine the savings in drilling cost and land disturbance to other schools if they could have used just a few holes into a minepool!

Photo showing land disturbed at Marywood production well

Source: Marywood University[3]

There are four basic types of ground loop systems. Three of these—horizontal, vertical, and pond/lake—are closed-loop systems. The fourth type of system is the open-loop option. Which one of these is best depends on the climate, soil conditions, available land, and local installation costs at the site. All of these approaches can be used for residential and commercial building applications. The open-loop system uses well or surface body water, or the minepool, as the heat exchange fluid that circulates directly through the GHP system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This option is obviously practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met.[11] The Marywood system utilizes an open-loop system and a heat exchanger but does not have a heat pump.

The open system utilizing a minepool such as Marywood has a huge volume of water for heat exchange, not just a finite amount of recirculating fluid as may be used in a closed loop, or in open loops utilizing wells. In the closed loop, the limitation is the contact area between the loop and mine pool. However, for an open system, the limitation would be the pumping rate, interconnection of the mine pool, and the size of the heat exchange units. Closed-loop systems which circulate a heat exchange fluid could have application in minepool geothermal where the potential for scaling or corrosion is high.[5]

The Marywood project utilizes a large existing underground pool of water that has resulted from the abandoned anthracite mines in Northeastern Pennsylvania. "The goal of the project was to install a working system that can be replicated for building cooling, as well as process cooling. This concept can be used to cost effectively cool buildings utilizing the vast underground minepool. It will provide an opportunity for computer installations and manufacturers to operate cooling processes without using mechanical cooling or domestic cold water to reject process heat. In the end, manufacturers will be able to achieve the same amount of process cooling with less energy, minimize domestic water consumption, and provide a product at a lower cost."[4]

Minepools

Coal underlies about one third of Pennsylvania with anthracite coal in the northeastern and north-central portions of the state and bituminous coal in the central and western portions. It is estimated that between 10,000 and 15,000 abandoned underground coal mines and numerous abandoned underground metal and non-metal mines exist in Pennsylvania. Many of the mines below drainage are flooded. Information on the full extent of the minepool water resources in Pennsylvania and comprehensive inventories of minepools or minepool complexes do not exist.[12]

Some data has been generated on the anthracite region, and additional work has been done on the Pittsburgh coal seam, which has some 1.36 trillion gallons of stored water under 1,912 square miles (sq.mi.) of western Pennsylvania and northern West Virginia.[13] The Pittsburgh seam's 1,912 sq.mi. of underground voids was what was flooded at the time the report was prepared (ca. 2003) and it continues grow as additional mining occurs. The Pittsburgh seam lies below about 5,000 sq.mi. and of course there are seams that also have been commercially mined that lie above and below the Pittsburgh that also are storing water.[14]

A reconnaissance of mine drainage in the Pennsylvania anthracite coal by the United States Department of the Interior Geological Survey (USGS) in 1983 identified 251 sites that had an average total discharge of 918 cubic feet per second (412,000 gallons per minute (GPM)). Most of the anthracite fields are found in the five Pennsylvania counties of Schuylkill, Carbon, Northumberland, Lackawanna and Luzerne, extending 50 miles east and west and 100 miles north and south covering approximately 484 sq.mi.[15] Anthracite has been mined in eastern Pennsylvania for more than 200 years with production of some eight billion tons. Most mining (about 90 percent) was done by deep mining methods creating vast underground voids. Precipitation percolates from the surface into these voids. During active underground mining, water was removed by pumping. Pumping increased production costs and forced the closing of many deep mines as the demand for anthracite declined after 1930. As more underground mines closed, pumping costs of the remaining mines increased and today there is no underground anthracite mining below drainage. Today nearly all 484 sq.mi. of the anthracite fields are underlain by large abandoned mine pools with overflows and discharges in drainage tunnels, boreholes, pits, and various openings.

No survey of the minepools or the volume of water impounded in the anthracite fields has been completed since the 1950s when many mines were still operating. The US Bureau of Mines (USBM) estimated 106 billion gallons was impounded at the end of 1952.[16] The US Geological Survey (USGS), in cooperation with PADEP, the Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR), and the Dauphin County Conservation District, estimated the water volume in storage in the mines of the Western Middle Anthracite Coalfield to range from 60 to 220 billion gallons.[17] All anthracite mines below drainage are flooded and it is my opinion that the water impounded in the Pennsylvania anthracite fields amounts to one trillion gallons, based on the volume of coal mined underground since 1800.

The minepool reservoir water temperatures in the anthracite region vary between 41°F and 65°F with temperatures of discharges in the Eastern Middle Field (Hazleton area) averaging 47°F, in the Southern Field (Tremont to Nesquehoning) 52°F, the Northern Field (Shickshinny to Forest City) 54°F and the Western Middle (Shamokin area) 55°F.

Measured temperatures of the Old Forge borehole, where the water from the Marvine minepool discharges, vary from 58°F to 61°F.[18]

Old Forge Borehole – Discharge of Scranton Area Minepools

Photo by MCK 2011

The water chemistry at Marywood hardly resembles mine drainage:

MARYWOOD BOREHOLE 2010	
pH	6.6
conductivity	1160 UMOHS/CM
alkalinity	158 MG/L
sulfate	320 MG/L
Fe	0.4 MG/L
Mn	0.2 MG/L

Source: B.F. Environmental Consultants Inc.[19]

OLD FORGE BOREHOLE 2012	
pH	6.4
conductivity	1090 UMOHS/CM
alkalinity	99 MG/L
sulfate	317MG/L
Fe	16.2 MG/L
Mn	1.9 MG/L

Source: LRCA[20]

The public often perceives mine water quality as "acid mine drainage" - uniformly contaminated and very acid. Most deep mining in the anthracite region stopped decades ago and the mines flooded and remained flooded, greatly reducing the oxidation of pyrite in the mines and the production of sulfuric acid. If you add to that infiltration of surface water, years of flushing of contamination, and stratification of more acid water in lower layers, some areas of the top layer have pretty good water. Most of the mine outfalls in the anthracite region are not particularly acid, typically more than pH 6, whereas Wilkes-Barre rain sometimes approaches pH 4. People tend to be reluctant to use mine water for anything if they think the water is bad. [21]

Six power stations in the anthracite region have used AMD as make-up cooling water. They include the Panther Creek Generating Station in Nesquehoning, Carbon County, which uses water from the Lausanne mine tunnel (Lansford Minepool); the Gilberton Power Company in Frackville, Schuylkill County, uses water from the Gilberton Minepool; Wheelabrator Frackville Energy uses water from the Morea Mine; Northeastern Power Company at McAdoo uses AMD from the Silverbrook mine, the WPS Westwood Generation Plant in Tremont has used AMD from the Lykens mine; and Schuylkill Energy Resources, Shenandoah, also Schuylkill County uses AMD from the Maple Hill Mine. These independent power producers all treat the mine water on-site before using it.[12] Depending on the water quality and the application, minepool geothermal may or may not require treatment. Long-term pumping tests may be appropriate to evaluate potential changes in water quality for design of treatment strategy or pumping strategy to avoid treatment. Groundwater modeling may be useful to evaluate the area of influence of pumping.[5]

Geothermal Use of Minepool Water in Pennsylvania

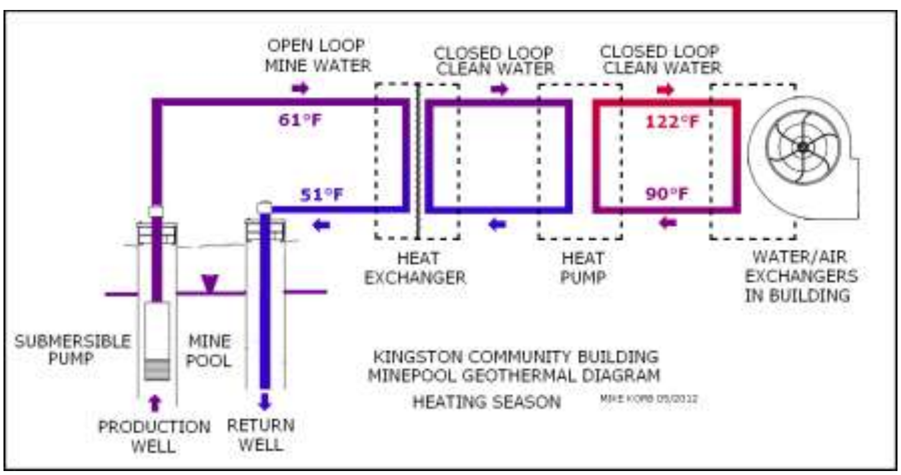
In spite of a number of successful published examples of utilization of minepool water for geothermal uses in Springhill, Nova Scotia, Canada[22], Monktonhall, Midlothian, Scotland and Heerlen, Netherlands[23], Park Hills, Missouri[24], and others; excellent presentations and academic papers notably those by George R. Watzlaf and Terry E. Ackman (retired from the US DOE Pittsburgh)[25]; support of the US DOE, PA DEP, and West Virginia Water Research Institute; recent research grants for projects in Scranton, Johnstown and Pittsburgh; there are less than a handful of projects actually operating in Pennsylvania.

I have been able to find only **two** – Marywood in Scranton and the Kingston Recreation Center near Wilkes-Barre, Luzerne County.

In 1979, Kingston Borough, Luzerne County Pennsylvania, worked with Pyros and Sanderson Architects, and Utility Engineers (who later combined to form QUAD3 Group, Inc., a full service architectural, engineering and environmental firm located in Wilkes-Barre, Pittsburgh and Scranton) to obtain a grant to build a 17,000 sq.ft. community recreation center from the United States Department of Interior (DOI) Heritage Conservation and Recreation Service, an agency created by the Carter administration in 1977, and absorbed by the National Park Service in 1981.

In the early 1980s, the DOE was active in northeast PA promoting the potential of utilizing minepools as heat sinks for minepool geothermal heating and cooling systems[26] and provided a grant to install a system in the center. The engineers worked with the Bureau of Mines and Dr. Brian Redmond of Wilkes University to drill boreholes to the mine for production and return wells. Jim Palumbo, one of the founding partners and current President of QUAD3 Group, recounts that "It just seemed natural to use the resources (the minepool) at hand to save money for the Recreation Center, and the grant sure helped to make the decision."[27] The top of the Dorrance minepool in Kingston varies between 6 and 14 feet below the Center, and a pump some 30 feet below the surface in a borehole would always have water to supply the system. The Kingston installation has been the site to visit for engineers working on minepool systems around the world.[28] The Center opened in 1981, and the heat pump system has been working successfully, albeit with some repairs, for more than 30 years.

The 8"ф production and return wells have 102' casings through the alluvium and extend another 90' through rock into the Abbot seam, the first mined out seam. Because of the lack of construction standards for these types of wells, the production well was constructed as a sanitary well. It was constructed to seal off zones that could result in the formation of poor water quality, such as coal seams and bedrock units high in iron and manganese. The cased well had a drive-shoe and the annular space was grouted to prevent short circuiting of water along the casing. The water is returned to the well to minimize aeration and subsequent oxidation of the iron in the water. Static water levels after drilling were 7' with no pumping drawdown.[29]



A submersible pump in the production well pumps 90 GPM to the heat exchanger. Mine water flows along one side of the flat plate exchanger with clean water flowing on the other side. The clean water loop transmits cooling to the water/air heat exchangers during the cooling season, and heat to a closed loop that passes through a heat pump during the heating season.[26] Around 2000, the original pipes deteriorated, the wells collapsed and the heat exchanger had to be replaced. Plastic piping was installed, and the system now undergoes maintenance every three months.[30] The production well has been replaced once and the pumps three or four times in thirty years.[28]

The annual cost of heating and hot water, and a comparison with other heating systems that might have been installed, estimated using February 2012 Northeast Pennsylvania fuel costs, are as follows:

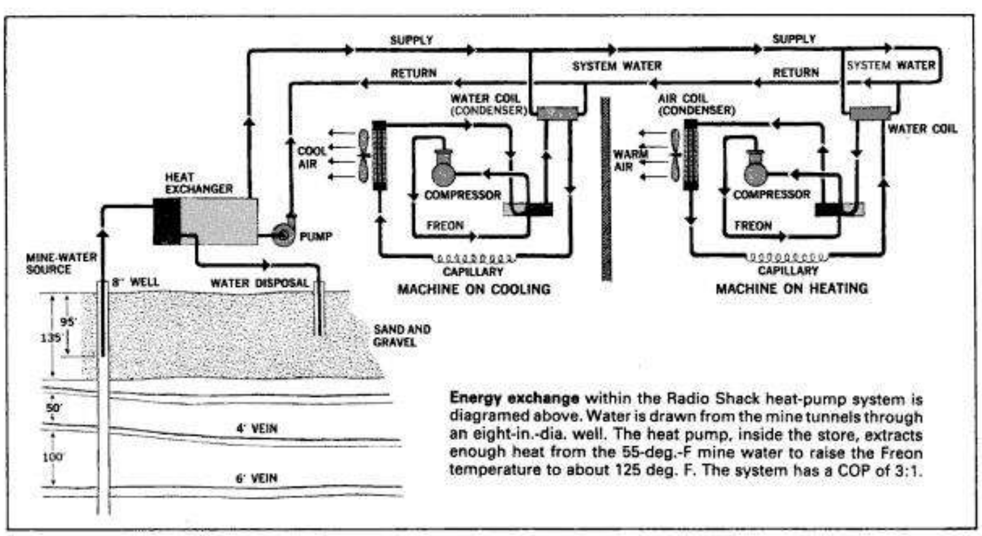
KINGSTON COMMUNITY CENTER		
ESTIMATED ANNUAL HEATING COST		
FUEL OIL	$40,000	500%
ELECTRIC RESISTANCE	$24,000	300%
GAS	$14,000	175%
MINEPOOL HEAT PUMP	$8,000	-

Source: IMWA[26]
Updated by MCK 2012

I have been in the building during both heating and cooling seasons, and it seems comfortable even in the gymnasium section. The Kingston Community Center may have the nation's oldest continuously operating minepool geothermal system.

<u>Previous Projects</u>

A Popular Science article reported in 1981 that the Radio Shack in the Wyoming (north of Kingston) Midway Shopping Center was being heated and cooled by mine water. Starting in 1979, and for some twenty years until the store moved to another location, the 3200 sq.ft. store used a commercial heat pump system utilizing the minepool as its heat sink.



Energy exchange within the Radio Shack heat-pump system is diagramed above. Water is drawn from the mine tunnels through an eight-in.-dia. well. The heat pump, inside the store, extracts enough heat from the 55-deg.-F mine water to raise the Freon temperature to about 125 deg. F. The system has a COP of 3:1.

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The author expressed that "using the flooded coal mines as a heat sink with heat-pump technology might turn what once was a disaster (the Knox Mine disaster causing flooding of the underground mines) into a bonanza for Northeast Pennsylvania."[31]

Also in Kingston, First Hospital Wyoming Valley - Nesbitt Memorial Medical Center utilized a geothermal heat pump system for cooling and for some of its heating for 25 years starting in the early 1980s. This system had early problems with its production well collapsing because of subsidence, and with sediment buildup in the heat exchanger and pump abrasion due to silty sediment, likely from material that had earlier been backflushed into the mine for subsidence support. However, after those problems, the system operated well for some 20 years, with only regular cleanouts of "coal dust" from the heat exchanger.[32]

In Carbondale, Lackawanna County, Adams Cable Service also installed a minepool geothermal system in the early 1980s. The system operated for about ten years, but was removed because of excessive buildup of iron scale in the heat exchanger. The system had a 500-gallon surge tank for the minewater, installed to keep the pump from running continuously, and the tank allowed aeration and oxidation of the water.[33]

John Wesley A.M.E. Zion Church is a historic church in the Hill District of Pittsburgh, Pennsylvania. In 2006, PADEP BAMR installed piping to prevent flooding of the church by abandoned mine water draining from a small (100-acre) 1800s abandoned mine under the City. In 2008, an Energy Harvest grant from PADEP and grants from the Foundation for Pennsylvania Watersheds (FPW) provided funds to construct a geothermal circuit to capture the energy from the mine drainage to heat and cool the church, and to provide for heating and cooling to a potential development next to the church. The mine water passes through an underground vault with a Slim Jim Geo Lake Plate heat exchanger, and safely drains into the stormwater and sanitary sewer drainage system beneath the street. The project, which was awarded a 2009 Green Building Leader Award from PennFuture, was expected to save the church some 75-80% on its heating bill and provide central air conditioning. It operated with no problems for about a year, when the church stopped being used due to some restoration needs. The vault was built to accept 6 heat exchangers, which would provide heating and cooling for a development of approximately 40,000 sq.ft., and an additional vault could be added for an another 40,000. The Hill House Economic Development Corporation, Pittsburgh Housing Authority and a private developer had proposed a mixed use (senior living and storefronts) $10 Million, 60,000 sq.ft. LEED certified development on the Wesley AME Charities owned property next door to the church, but the project and other options remain in limbo. Opportunity still remains with this project, and Wesley AME Charities is still committed to seeing the mine water geothermal system put to use. [34]

These are the only minepool geothermal efforts in Pennsylvania I have been able to verify, although I am sure there are more people living over minepools that have put a well down to harvest the energy. Three of those mentioned above occurred to people during their review of the first draft of this paper, and there are "urban legends" about a doctor's office in Kingston, a fire hall in Mahanoy City or Minersville, a knitting mill in the Wyoming valley in the 1960s, and others that I haven't been able to locate or unearth additional information on. The internet makes finding today's "news" easier, but not so much for the past. The previously cited International Mine Water Association 1982 Conference Proceedings[26] were just scanned this spring, so I would not have been able to access that good source if I had attempted this paper last year.

Potential Projects

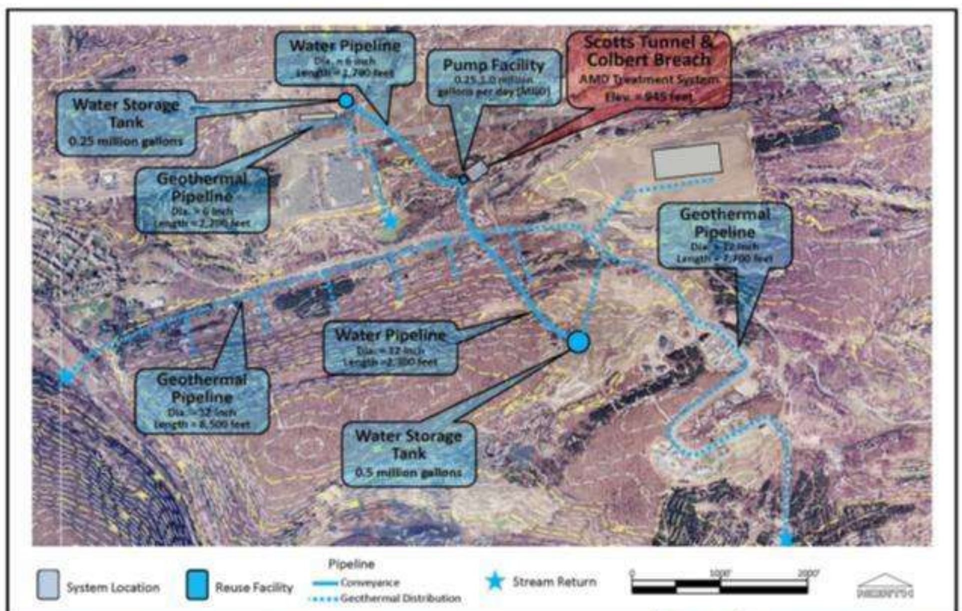
Several additional Pennsylvania systems have been given feasibility grants to investigate the possibility of additional minepool geothermal systems.

In Johnstown, Cambria County, an ambitious project to treat mine drainage from the Bethlehem Pool which underlies 4,969 acres of the Johnstown area and contains 3.89 billion gallons of water is currently being considered. To offset treatment costs, project developers are looking into producing geothermal energy from the minepool. This project would be a model in resource-recovery by using the value of the energy to pay for treatment of the Inclined Plane Discharge. The geothermal energy might be used to create a geothermal heating district to heat and cool homes and/or businesses in downtown Johnstown.[35] The Greater Johnstown Watershed Association (GJWSA) has received grants from the Foundation for Pennsylvania Watersheds, the Community Foundation for the Alleghenies, and the PENELEC energy fund to perform a marketing/feasibility study on the potential energy customers. An additional grant has been obtained from the Appalachian Regional Commission, and grants are being solicited for other portions of the project. The project is being managed by the Pennsylvania Environmental Council.

The Foundation for Pennsylvania Watersheds has awarded grants for both the Wesley A.M.E. Church and Inclined Plane projects as well as for construction of an abandoned mine drainage (AMD)/geothermal project at Six Mile Run, Bedford County. The Six Mile Run Project would have used treated AMD from a PADEP Growing Greener project to heat and cool the Six Mile Run Volunteer Fire Company's new fire hall. The fire company was dissuaded from proceeding after discussions with a local architect.[36]

Growing Greener has been the largest single investment of state funds in Pennsylvania's history to address Pennsylvania's critical environmental concerns. Signed into law in 1999, funding was authorized through 2012. PADEP's portion of Growing Greener was $547.7 million. PADEP has allocated these funds in part for grants for watershed restoration, watershed protection, AMD and abandoned mine reclamation.[37]

In Coal Township, Northumberland County, the County Conservation District and the Shamokin Creek Restoration Alliance, working with Dietz-Gourley Consulting, State College, used a PADEP Growing Greener Grant and a FPW grant to conduct a "feasibility study" to treat Quaker Run, a tributary of Shamokin Creek, which is heavily impacted by AMD from three sources. The study also explored options for passive and/or active treatment and the potential beneficial reuse of the treated water. A number of beneficial reuses were identified including evaporative cooling water, industrial process water, and low-temperature geothermal for heating and cooling. A conceptual layout for a mine drainage treated water distribution system, referred to as a "Geothermal District", is depicted below.



Conceptual Layout of the Scotts Tunnel & Colbert Breach
Open Loop Geothermal District(s) in the Shamokin Creek Feasibility Study
Project Area (Walmart Retail Center, SEEDCO Industrial Park & Northwest Academy).

Dietz-Gourley Consulting, LLC
1215 Deerfield Drive
State College, PA 16803

"In this system the treated water would be distributed to facilities for operation of heat pumps to either provide air conditioning in the summer or heating in the winter. It is the unique temperature of the mine water (50-55°F) that allows geothermal cooling and heating to work effectively and efficiently, providing savings of between 60 and 80% compared to typical HVAC systems." The "Feasibility Study" indicated long term sustainable treatment of the discharges would be achievable with revenues generated from water and solids beneficial reuse.[38]

The Toby Creek Watershed Association has a Growing Greener financed project in Horton Township, Elk County that retrofitted activated iron solids treatment in the existing plant to eliminate the use of costly potassium permanganate oxidant. The grant was to also investigate energy recovery by installation of a geothermal heating system using the treated Blue Valley AMD discharge as the source water; however the geothermal component was removed to use that money for operation of the AMD treatment plant.

Austin J. Burke, President of the Greater Scranton Chamber of Commerce and the Scranton Lackawanna Industrial Building Company (SLIBCO), is one of the biggest boosters of minepool geothermal systems in the area. The Marywood project was done while he was Secretary of Pennsylvania's Department of Community & Economic Development. He has been boosting projects for use of systems like the one at Marywood, especially those which would use the cool, constant-temperature, water to help control manufacturing processes or for computer room climate control, and has encouraged Ben Franklin Technology Partners (BFTP) of Northeastern Pennsylvania to support these projects in the Scranton area. Ben Franklin has funded Northampton Community College's Emerging Technology Applications Center to do assessments of geothermal applications that would utilize mine water as a method to reduce energy costs in manufacturing processes for Noble Biomaterials and Quadrant EPP, both of Scranton, Lackawanna County.

Noble Biomaterials develops, manufactures, sells, and markets advanced antimicrobial technologies designed to manage bacterial contamination for medical, defense, industrial, and consumer markets. This completed assessment was to determine if geothermal processes could be utilized to control the temperature of water used in production and to provide environmental humidity and temperature control in critical areas of the plant. Apparently the project will not progress because of the project's capital costs and their need for process water with high temperatures.

The assessment for Quadrant, which produces engineered polymer products in sheets, rods, and tubes, began in May. The investment will allow the company to assess the feasibility of displacing the need for chilled process water using mechanical refrigeration with mine water as a coolant. Quadrant management has hopes for the project.

In 2007 both Wilkes-Barre and Scranton had groups who had minepool district heating proposals, utilizing the old steam heat systems. Lackawanna County went so far as to establish a Lackawanna Authority for Innovative Renewable Energy (AIRE) to promote the process.[30,39] Neither effort has made any progress, and nothing has been heard of them for four years.

It appears that the author of the 1981 Popular Science article was being overly optimistic in his hope for utilization of minepool geothermal systems in Pennsylvania. The possibilities for use of geothermal energy from minepools seem to be unlimited, yet only a few facilities are looking at, while even less are using this apparently great energy source.

Why aren't we using minepool geothermal in Pennsylvania?

There are a number of opinions why there has not been more use of minepool geothermal in Pennsylvania, mainly these:

- Lack of knowledge about minepools
- Legal and regulatory questions
- Lack of knowledge about technology
- Lack of knowledge about economics
- Lack of investment/new building in region
- Risks involved
- Reputation of mining

Lack of knowledge about minepools

EPCAMR made a number of worthy recommendations for further work that is needed "before mine water resources can be more fully utilized" in their *2011 Mine Water Resources of the Anthracite Region of Eastern Pennsylvania*, and many of them were to better define and characterize the Commonwealth's minepools. (This is a good reference, and anyone interested in anthracite minepools should take time to read it.)[40]

There is a lack of information about the extent and locations of minepools, even in government agencies. Ohio, Indiana, West Virginia, and Pennsylvania are all at various stages of surveying, outlining, and defining their minepools.

In the 1940s and 1950s the USBM had dozens of engineers and scientists studying minepools in the anthracite region. Between 1940 and 1955, they issued some 57 publications. Today, there are no active projects looking at the mine pools of the anthracite region. In 1968 the Pennsylvania legislature enacted "The Land and Water Conservation and Reclamation Act" and a $500 million bond issue to finance it. The abandoned mine portion was known as Operation Scarlift. A central component of Operation Scarlift was identification and monitoring of AMD discharges from abandoned deep mines throughout Pennsylvania. More than 80 mine drainage watershed studies were produced by consultants between 1968 and 1982, and many of these remain the best descriptions and outlines of the minepools and AMD problems in the watersheds. In 1985, the PADEP Bureau of Abandoned Mine Reclamation (BAMR) Wilkes-Barre District Office had eight technicians available to monitor minepools through measurements of boreholes, shafts, and discharges, today there are none, although the new Bureau of Conservation and Conservation may plan to replace the technician that retired this year.

People are not really aware of the minepools beneath their feet. The public's attention is drawn to the minepools when something bad happens. In 2007, a borehole in the Nanticoke area of the Wyoming Valley failed resulting in flooding of neighborhoods similar to the flooding caused by rising minepools in the early 1970s. This event prompted drilling the original borehole and caused the press to write about the minepools for a couple months. And, of course in 2002, minepools were part of national news as we watched newspapers and television as the Quecreek miners were rescued from the mine beneath Somerset County after they mined into an ill-defined minepool.

<u>Legal and regulatory questions</u>

There needs to be a clarification and better understanding of water ownership rights and obligations, as well as the permissions and permitting required for drilling, withdrawal and injection. Marywood addressed this issue by approaching the mineral rights owner who had no objection to the use of the water in the way Marywood proposed. Pennsylvania's groundwater law is based on the "American Rule", which provides that a landowner may withdraw groundwater from beneath the property for "natural and ordinary" usage, whereas extraction for use off-site is "unreasonable" and "unlawful". In light of the benefits associated with the withdrawal, treatment, and use of the mine pool water, PADEP continues to explore resolutions to minepool ownership issues.[40]

These issues are also complicated by the potential liability of affecting the abandoned mine drainage discharge. Pennsylvania did some work on this in its Mining and Reclamation Advisory Board (MRAB) Orphan Mine Discharge Task Force Action Plan several years ago.[41] Many of the recommendations of the Plan could be used in marketing interest in minepool geothermal systems. Recent interest in utilization of mine drainage in hydraulic fracturing of gas wells likely will increase the clarification of these issues.

<u>Lack of knowledge about heat pump technology</u>

A problem in comprehending this technology is that it is difficult to understand how heat extracted from 55º water can heat anything. I was aware of GHPs when I replaced the air-source heat pump in my home (not over a minepool) five years ago but couldn't find a contractor that had expertise in the field. More HVAC contactors are informed and involved today, but it still isn't a large pool to choose from, and HVAC contractors that are involved complain that architects "are the ones holding back GHP because they don't understand the calculations". The people that installed the equipment in the 1980s were certainly "thinking outside the box".

Lack of knowledge about minepool geothermal economics

It appears to me that the economics of minepool geothermal are good, as shown above on pages 5 and 9, and that usage of minepool water as a constant temperature bath for computer applications or manufacturing processes has the best chance for success. Exploitation of the method for heating has been limited in the past due to relatively low conventional energy costs, and is still affected by current low gas pricing. A DOE project to install minepool geothermal systems at University of Scranton, the Scranton Army Ammunition Plant, and at a public housing project in Scranton in the 1980s[26] was deemed not feasible because of pumping costs.[42]

I have not been able to duplicate many of the published cost and comparative calculations on geothermal heat pumps. They all seem to have some assumptions that I can't find. Much of the published information indicates that the investment involved is not great, but that does not seem to be the case. The Ball State system is estimated to cost between $66 million (early estimates) to $83 million (current guesses) and will save $2 million annually.[10] Also, in my discussions with Noble Biomaterials people, they cited the high estimated capital cost of their proposed project.

I recently used an on-line calculator to look at a system for my 2400 sq.ft. home. Estimated cost of installation of a ground-source heat pump and ground loops, with no ductwork, was "in the ballpark of" $23,250 (about $10,700 for the ground loop system and $12,500 for the heat pump). That would result in a cost to me of $15,190 "including the recent 30% federal tax credit", and a $1,085 PPL rebate.[43] That seems like a lot of money compared to my air-source heat pump which cost $5,578.45 five years ago.

The "savings calculator" also indicated that I would "avoid paying $43,435 too much over the next 15 years to heat/cool (my) home", which would be pretty great because I only pay about $200/month for my electricity in an all-electric home ($36,000 over 15 years). This should be a good way of promoting an "unknown" technology – they say that only "2 out of 10 homeowners know what a geothermal heating and cooling system is" – but I'm wary of trusting something that has this kind of inconsistencies as part of its promotion.

Grants have been important in the small amount of promotion the technology has had. Likely a grant which would build a functioning system, monitor and report the results would be the best way of promoting minepool geothermal. The Commonwealth of Pennsylvania offers some fourteen different grant or loan programs that apply to geothermal systems, non-profits like FPW and government supported agencies like BFTP also provide funding and expertise.

However, a process that has been functioning for 30 years really shouldn't need a grant if the process is a good, economical one. Depending upon grants may limit the possibilities, and may promote unsustainable technology. If we are unable to do anything without a grant, our efforts are directed into getting grants rather than solving problems. Most grants have no requirement for follow-up monitoring or reports of their results. It's too bad that the past 30 years of operation of the Kingston system wasn't monitored and studied - maybe a paper some other day?

The United State Environmental Protection Agency (EPA) is encouraging renewable energy development on current and formerly contaminated land and mine sites. This initiative identifies the renewable energy potential of these sites and provides other useful resources for anyone interested in reusing these sites for renewable energy development, and has issued a *Handbook on Siting Renewable Energy Projects While Addressing Environmental Issues* (pdf) that mentions geothermal but not *minepool geothermal.*[44]

Lack of investment/development in region

But of course, the technology should stand on its own economic merit, and there hasn't been much building in the areas over mine pools. GSHPs can be difficult and costly to install in retrofit applications. The Pennsylvania coal regions are not areas where large "green" housing developments are going up and never have been. There has been some discussion about utilizing the old steam heat systems in Scranton and Wilkes-Barre in district heating, but it has met with under-enthusiastic response. Industrial development has declined for the past couple years, but the only real growth has been in industrial parks, mostly located on reclaimed mine lands. Local developers, especially SLIBCO and to a lesser extent Hazleton's CAN DO, have boosted minepool geothermal, but to no avail.

Risks involved

Like minepools, very little common knowledge about mines and mining exists. "My granddad worked in the mines" is the extent most people know except for the annual commemoration of the disasters; the news coverage of miners trapped in Chile, or some-such. The risks and uncertainties of drilling into a mine, hitting the mine opening with the hole, potential failure and subsidence of the boring, water quality, avoiding pollution of the minewater, and collapse of mine workings caused by drilling, are certainly concerns for a developer looking at minepool geothermal. Water quality, buildup of yellow-boy, and corrosiveness of some mine waters are all concerns to be addressed when a minepool is being used.

In one of the earliest (1556) books about mining, Re De Metallica (Latin for "On the Nature of Minerals"), Georgius Agricola wrote, "It is necessary that those who take an interest in the methods of mining should read these books studiously and diligently; or on every point they should consult expert mining people; though they will discover few who are skilled in the whole art."[45] And that is good advice for today also – remember I'll be retiring one of these days and will likely be one of the "expert mining people" who would be available to "consult".

Reputation of mining

However, the #1 opinion on why we don't have more systems involving minepools is just simply that people, especially people in the coal regions, just don't like coal and mining.

It's still coal country, even where there's hardly any coal mined anymore. The old timers still mine coal in the bars and can point to where they used to work under this street or that, but most people don't know anything about the mines except for the culm piles (in eastern Pennsylvania – gob piles in western) that the ATVers kick up dust on each weekend, the orange-bottomed creeks (east – vs. “cricks” in west), the illegal dumps in the “strippins”, and the fire that’s burning underground –or not depending on who you talk to. People still are from the “patch”, one of the remnants of company houses (maybe a double-block in the east and a duplex in the west) near the mine like William Penn or Brady’s Bend. The onion domes of the eastern rite churches are still in town, but the breakers and beehive ovens are fallen or torn down. The Fell Tavern, where anthracite was first burned, is now a parking lot. Those who worked in the mines, whose livelihood depended on the hard, often dirty work, didn’t hate coal mining like the public does today.

Robert F. Kennedy, Jr., president of the environmental advocacy group Waterkeeper Alliance, in a May protest to a proposal to export coal from West Coast ports said “Coal will undermine everything that you love...I’ve seen what it’s done to small Appalachian towns. Its ruined democracy, corrupted politicians and literally drove people out of town. Do not let it corrupt this community. You are at the front lines of this battle…Anybody who touches coal gets poisoned by it. You don’t just get sick. It poisons democracy, it poisons communities, it poisons values.”[46]

Summary to “Why?”

The PA DEP MRAB in 2003 formed a task force to explore innovative approaches dealing with re-use and recycling of mine water as one alternative to treatment as well as to explore funding of long-term treatment and issued an *Action Plan for MRAB Orphan Mine Discharge Task Force*. This never used the word *geothermal*. Pennsylvania Senate Bill 1346 (Session of 2011), amending Title 27 (Environmental Resources) of the Pennsylvania Consolidated Statutes, providing for use of mine drainage water has been amended and reported from committee, and neither it nor its amendment mention *geothermal*.[47]

In the US DOE Geothermal Technologies Program’s 2010 *Low Temperature, Coproduced, and Geopressured Geothermal Technology Strategic Action Plan*[48] and its 2009 *Ground Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers*[8], none of the words *mine, minepool or minewater* were used.

If you Google *“Michael C. Korb”* you get “about 2320 results”, and if you Google *“mine pool geothermal”* you get “about 306 results”. I know I’m a legend in my own mind, but it ought to be a little closer than that! More people should be more interested in inquiring about minepool geothermal than about Mike Korb. The public, architects, contractors, and developers all need more information about minepool availability, about minewater, about legal and regulatory questions, about heat pump technology and the economics of minepool geothermal; and there has to be a better understanding of the risks involved with utilizing minepools, and the tools that can be used to minimize these risks. We have to start building houses, commercial buildings, and industry in the coal regions. Perhaps utilizing the old mines as a “green” energy source will help put the pride of the coal region’s heritage back into the community.

To paraphrase from a presentation, *U.S. Mining Regions – The Saudi Arabia of Geothermal Energy*[25] by Terry Ackman and George Watzlaf,

“Water from a mine is a terrible thing to waste.”

References

Biography for Mike Korb

Mike has worked for BAMR for the past 4½ years and was one of the advisors for the DEP/ARRA grant given to Marywood for the minepool geothermal project.

A Mining Engineering graduate of the Missouri School of Mines (Missouri University of Science and Technology), Rolla Missouri, Mike has more than 45 years' experience in the mining industry, 30 years in anthracite.

Mike and his wife Pat live in Hobbie, Luzerne County with their orange cat Moochie.

Cover photo by Michael Korb of original, ca. 1955 art, by James Edwards, Heart of the Earth, 2012

[1] Frank Adams, Pennsylvania's Northern Anthracite Coal Field, 1870 – 1970 - Marvine Colliery, http://www.northernfield.info/operationReport.php?oname=Marvine&cid=16150, 2011

[2] Dorothy Allen Silva, HAER No. PA-183-A, HAER, National Park Service, DOI, http://lcweb2.loc.gov/pnp/habshaer/pa/pa2800/pa2879/data/pa2879data.pdf, 1990

[3] Marywood University website, www.marywood.edu, 2012

[4] Stephen Daiute, GPI, and Marywood University, Marywood University Geothermal Energy Pilot Project Update, PA DEP ARRA Reporting & Tracking System, 2010, http://www.gpinet.com/userfiles/file/GPI%20Scranton%20-%20New%20Geothermal%20Project%20Achieves%20LEED%20Gold.pdf, 2011

[5] Charles Cravotta, personal communication from Cravotta (USGS) to Korb, 2012

[6] US DOE, EERE, A History of Geothermal Energy in the United States, http://www1.eere.energy.gov/geothermal/history.html, 2011

[7] US DOE, EERE, Geothermal Heat Pumps, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640, 2011

[8] Navigant Consulting submitted to US DOE EERE Geothermal Technologies Program, Ground Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers, http://www1.eere.energy.gov/geothermal/pdfs/gshp_overview.pdf, 2009

[9] Ball State University, Going Geothermal, http://cms.bsu.edu/About/Geothermal.aspx, 2012

[10] James Lowe, Paradigm Shift: Burning Coal to Geothermal, http://www.stategeothermaldata.org/sites/stategeothermaldata.org/files/presentation_files/Paradigm_Shift-Burning_Coal_to_Geothermal.pdf, 2011

[11] US DOE, EERE, Energy Savers-Types of Heat Pumps, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650, 2011

[12] John A. Veil, John M. Kupar, and Markus G. Puder, Use of Mine Pool Water for Power Plant Cooling, Argonne National Laboratory for the US DOE National Energy Technology Laboratory (NETL) Contract W-31-109-Eng-38, www.evs.anl.gov/pub/doc/ANL-MinePoolReport.pdf, 2003

[13] Paul Ziemkiewicz, Bruce Leavitt, Jim Stiles, Joe Donovan, West Virginia Water Research Institute West Virginia University, The Potential for Using Mine Water to Supply Electric Generating Stations, Sandia National Laboratories Energy-Water, Eastern Region Needs Workshop, http://www.sandia.gov/energy-water/EastPresentations/PotentialForMineWater.pdf, 2005

[14] Terry E. Ackman, personal communication from Ackman (DOE retired) to Korb, 2012

[15] D. J. Growitz, L. A. Reed, L.A., and M. M. Beard, USGS, Reconnaissance of Mine Drainage in the Coal Fields of Eastern Pennsylvania, USGS WRIR 83-4274, http://pubs.usgs.gov/wri/1983/4274/report.pdf 1983

[16] S. H. Ash, USBM Bulletin 508 Mine-Drainage Problems Anthracite Region of Pennsylvania, http://oldforgecoalmine.com/USBM-508_Acid%20Mine%20Drainage%20Problems%20Anthracite%20Region%20Pa.pdf ,1951

[17] D.J. Goode, C.A. Cravotta III, R.J. Hornberger, M.A. Hewitt, R.E. Hughes, D.J. Koury, and L.W. Eicholtz, Water budgets and groundwater volumes for abandoned underground mines in the Western Middle Anthracite Coalfield, Schuylkill, Columbia, and Northumberland Counties, Pennsylvania—Preliminary estimates with identification of data needs: USGS SIR 2010–5261, http://pubs.usgs.gov/sir/2010/5261/support/sir2010-5261.pdf, 2011

[18] Charles R. Wood, USGS, Water Quality of Large Discharges from Mines in the Anthracite Region of Eastern Pennsylvania, USGS WRIR 95-4243, http://pubs.er.usgs.gov/publication/wri954243, 1996

[19] Brian Oram, B.F. Environmental Consultants Inc., Laboratory Results - Marywood – 8 Hour Test and Purging Evaluation, unpublished, 2010

[20] Bernie McGurl, personal communication from McGurl (Lackawanna River Corridor Association) to Michael Korb (PADEP BAMR), 2012

[21] Dr. Brian Redmond, personal communication from Redmond (Wilkes Univ.) to Korb, 2012

[22] Natural Resources Canada, Office of Energy Efficiency, Geothermal Mine Water as an Energy Source for Heat Pumps, http://oee.nrcan.gc.ca/publications/infosource/pub/ici/caddet/english/r122.cfm?attr+20, 2005

[23] Minewater Project, Mine water as a Renewable Energy Resource, http://www.promoscene-database.eu/fileadmin/promoscene/downloads/Others/Minewater_Good_Practice_Guide.pdf, 2008

[24] Geothermal Heat Pump Consortium, Inc., Municipal Building Park Hills, Missouri, http://www.geoexchange.org/downloads/cs-064.pdf, 1997

[25] Terry E. Ackman and George Watzlaf, US DOE, NETL, U.S. Mining Regions –The Saudi Arabia of Geothermal Energy, http://www.netl.doe.gov/energy-analyses/pubs/EUEC_07_Ackman.pdf, 2007

[26] J.F. Schubert and M.J. McDaniel, Argonne National Lab, Using Mine Water for Heating and Cooling - IMWA Proceedings 1982, http://www.imwa.info/docs/imwa_1982/IMWA1982_Schubert_063.pdf, ©International Mine Water Association 2012

[27] James Palumbo, personal communication from Palumbo (QUAD3 Group) to Korb, 2012

[28] Gregory Kriner, personal communication from Kriner (Kingston Parks & Recreation) to Korb, 2012

[29] Dr. Brian Redmond, Kingston Recreation Center Mine Water Supply Project, unpublished, 1981

[30] Times Leader, Two Entrepreneurs Say They Have Plans to Use Mines for Geothermal System, http://www.timesleader.com/news/hottopics/progress/Two_entrepreneurs_say_they_have_plans_to_use_mines_for_geothermal_system_05-28-2008.html, July 30, 2008

[31] Edward Moran, Mine Water Powers heat Pump, Popular Science Vol.218, No.4 P.64, http://books.google.com/books/about/Popular_Science.html?id=b_UB360a444C, April 1981.

[32] Craig Cottle, personal communication from Cottle (Nesbitt Hospital Maintenance) to Korb, 2012

[33] John Wallis, personal communication from Wallis (Retired Chief Engineer, Adams Cable Service) to Michael Korb, 2012

[34] Darwin Burtner, personal communication from Burtner (Western Pennsylvania Geothermal Heating and Cooling, Inc.) to Korb, 2012; Holly Cairns, personal communication from Cairns (PADEP) to Korb, 2012; and Burtner, Cairns, Calvin Cash, John Wesley A.M.E. Zion Church AMD Geothermal Project, presented at 2009 PA AML Conference, http://2009.treatminewater.com/images/CCashPittsburghGeothermal.pdf, 2009

[35] Uldis Kaktins, GJWSA, Geothermal Energy: using Abandoned Mine Drainage as a Source, 2009 PA AML Conference, http://2009.treatminewater.com/images/UKaktins_Inclined_plane_study.pdf, 2009

[36] Branden S. Diehl, personal communication from Diehl (Earth Wise Consulting) to Michael Korb, 2012

[37] PA DEP, What is Growing Greener?, http://www.portal.state.pa.us/portal/server.pt/community/growing_greener/13958/what_is_growing_greener_/588899, 2012

[38] Dr. Jon Dietz, Dietz-Gourley Consulting, Shamokin Creek Feasibility Study, 2011

[39] Rory Sweeney, Times Leader, Mine Tunnels Seen as Assets, http://www.timesleader.com/stories/Mine-tunnels-seen-as-assets,109353, Oct. 31, 2007

[40] Robert E. Hughes, Michael A. Hewitt, et. al., Mine Water Resources of the Anthracite Region of Eastern Pennsylvania, http://www.epcamr.org/storage/projects/MinePoolMapping/Mine_Water_Resources_of_the_Anthracite_Coal_Fields_-_Report.pdf, 2011

[41] PA DEP MRAB, Action Plan for MRAB Orphan Mine Discharge Task Force, http://www.dep.state.pa.us/dep/subject/advcoun/minrec/MRAB_2004/ActionPlanMRABOrphanMineDischargeTaskForceResolutions.doc, 2003

[42] Eugene J. Peters, P.E., personal communication from Peters (Peters Design Group) to Korb, 2012

[43] Geothermal Genius, Geothermal is Genius, http://www.geothermalgenius.org/, 2012

[44] US EPA, RE-Powering America's Land - Siting Renewable Energy on Potentially Contaminated Land and Mine Sites, http://www.epa.gov/renewableenergyland/, 2012

[45] Georgius Agricola, Lou Henry Hoover and Herbert Clark Hoover (translators),- De Re Metallica, http://openlibrary.org/works/OL3777463W/De_re_metallica, 1950 – English translation from the first Latin edition of 1556

[46] Angie Tarantino, The EnvironmentalBlog.org, Robert F Kennedy Jr. Rallies Anti-Coal in Portland Oregon, http://www.theenvironmentalblog.org/2012/05/robert-kennedy-rallies-anti-coal-portland-oregon/, 2012

[47] Senators Richard A. Kasunic, Yudichak, Solobay, Hughes and Fontana, Pennsylvania Senate Bill 1346 (Session of 2011), http://www.legis.state.pa.us/CFDOCS/Legis/PN/Public/btCheck.cfm?txtType=DOC&sessYr=2011&sessInd=0&billBody=S&billTyp=B&billNbr=1346&pn=2208, 2011, amended 2012

[48] Energetics Incorporated, prepared for US DOE EERE Geothermal Technologies Program, Low Temperature, Coproduced, and Geopressured Geothermal Technology Strategic Action Plan, http://www1.eere.energy.gov/geothermal/pdfs/ltcg_strategic_action_plan.pdf, 2010