The resource potential of mining discharge water for aquaculture

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More than a century of mining in West Virginia has created a resource for aquaculture development. More than 2 million acres of underground caverns presently exist in the state. Groundwater accumulates in the mine and may flow from it at the lowest opening, usually a borehole or a portal. Existing law requires that the mine operator pump water from inactive mines, if necessary, and treat it to government standards before discharging it into surface streams. Approximately 232 million gallons of water are discharged each day from active and abandoned mines (Jenkins et al. 1995). Nearly three quarters of this resource was deemed available for use by the aquaculture industry. Groundwater temperatures of 13 to 15°C are superior to surface waters for production of salmonids in West Virginia inasmuch as they are near optimum for year-round production. This resource may represent the greatest opportunity for development of Aquaculture in West Virginia at this time.

Aquaculture is one way to develop the economies of rural areas that are home to closed mines. High rates of unemployment are in proximity to high flowing mine sites, which have potential to become aquaculture production centers. The quality and quantity of water are the most important factors for site selection. Sites that maintain consistent flows in excess of 3500 L/m have been identified with a geographical reference to county unemployment (Figure 1).

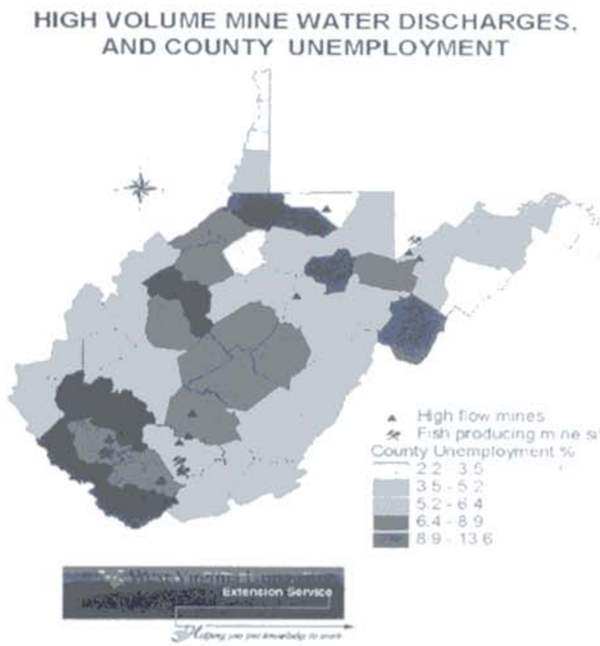

Fig. 1. High volume mine water discharges and county unemployment (Dan Miller)

Northern versus Southern Sites

The quality of the water discharged from a coal mine is influenced greatly by the chemistry of the coal seam and the local geology. In the southern areas of West Virginia, coal seams have low levels of iron and sulfur (pyrite –FeS_2) and the groundwater discharged from the mines can be utilized with minimal or no treatment. Some mine discharges are used for public drinking water with little or no treatment. Simple aeration will remove carbon dioxide and oxidize iron, the two most common parameters of concern. It has been shown that carbon dioxide levels above 30 mg/L will reduce the growth of rainbow trout (Danley 2001). An analysis of the public health aspects of producing trout for human consumption in mine waters was conducted by Heinen (1996). He concluded that mine waters are expected to be suitable for growing salmonids after treatment.

Coal seams in the northern part of West Virginia possess higher levels of iron and sulfur. Groundwater obtained from these mines is acidic and require treatment to conform to federal National Pollution Discharge Elimination System (NPDES) regulations. These treatment facilities aerate the raw mine water before and after application of hydrated lime and may use a flocculent to precipitate iron and other metals. After passing through a settling basin, the water flows into one or more polishing ponds before being released into a stream (Figure 2).

With cooperation from innovative mining companies and support from USDA, the Northeast Regional Aquaculture Center and local organizations, we are investigating the potential for aquaculture as a post-mining land use for rural economic development.

One Step at a Time

Each site is unique and requires careful evaluation. Mine water effluent data have been collected for many years by WVDEP and the coal industry as part of the NPDES permit program. Building on the work conducted by investigators with the Freshwater Institute (Jenkins 1996), we selected only high volume flow sites for investigation. We considered only

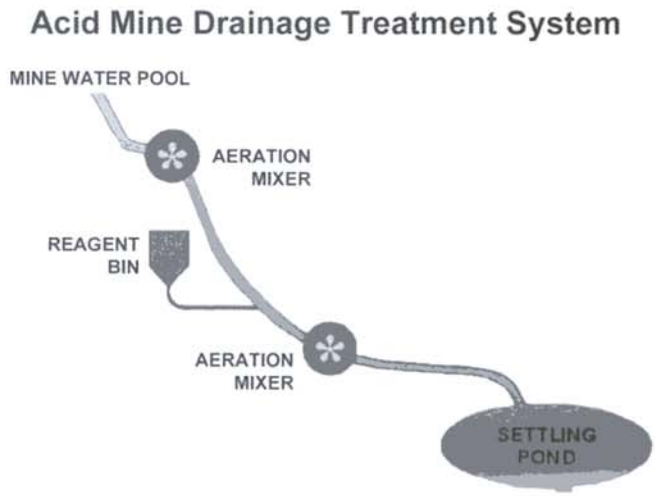

Fig. 2. Flowchart for acid mine water treatment (Ken Semmens and Mike Kridle)

those sites that would maintain a flow rate of 3500 L/min, a volume adequate for commercial production of salmonids in flowing water systems. Site visits were conducted in the year 2000 to confirm the flows with a flow meter. Compared to data presented in 1996, significant changes in flows were noted that resulted in many sites with flows below the amount previously reported. Mining activities and seasonal precipitation contributed to the dynamic nature of the flows.

If the flow was near 3500 L/min, a water sample was taken to be analyzed for iron, aluminum, manganese, calcium, magnesium, alkalinity, pH, oxygen, carbon dioxide, temperature, and conductivity to see if these parameters are acceptable for fish production. Suspended and settleable solids were also measured. In general, alkalinity and conductivity levels were found to be high. Some ions (calcium and sulfate) were higher than recommended levels, and will be discussed later. Field notes were made indicating the presence of important infrastructure, including road conditions, power lines, buildings, ponds, and security. Vegetation, slope, and proximity to major roads and markets were also noted.

Consol Energy and Eastern Associated Coal Corp. has partnered with investigators at West Virginia University to conduct simple studies to determine if fish would survive in water at six different mine sites. Some observations from the work are described below:

Minimal Flow Rate

Estimation of minimum flow is an important consideration in facility design and the associated business plan for a particular site. The West Virginia Mine Water Inventory Site Summary contains minimum and average flow data from 60 sites. Average minimum flow volume was only 45 percent of average flow volume. Based on this data, a site with 3500 L/min average flow rate, would be expected to decrease to a minimum flow of 1575 L/min.

A number of commercial aquaculture facilities have been built nationwide, anticipating higher flow rates than the water source has provided. During low flows this can have serious consequences on the operation. Long-term historical flow records must be accurate and scrutinized before the engineering work begins and production levels can be determined. Even when the water is pumped from a large mine it is possible to run low on water. The water source in closed mines can be compromised or lost, from mining operations in a lower coal seam that allows water to drop to a lower level.

Temperature

Many flowing water aquaculture facilities in the eastern U.S. use surface water. This results in water temperatures for production of trout above optimum during the heat of the summer and below optimum for growth during the cold of the winter. Like springs, groundwater discharged from a mine maintains a constant temperature (13-15°C) all year long – a temperature suitable for year round production of salmonids.

Acid Mine Drainage (AMD) treatment plants are designed with settling ponds and polishing ponds. If the polishing pond is large enough and the exchange rate is low enough, the temperature of water discharged from the treatment plant will take on the character of surface water. Monitoring the temperature throughout the year is necessary to assure that the proper species is selected for the water resource. Locating the culture facilities close to the discharge area will stabilize temperatures.

In 2001, a polishing pond at the Tygart River AMD treatment plant received 8,000 L/min. five days a week. Trout in the pond were subjected to weekend temperatures exceeding 22°C during the summer. In 2002, pumping volumes at the Tygart River mine decreased to the point where the pumps remained off for as long as 4 days. In this case, water temperature of the polishing pond during the summer months exceeded the required temperature range for salmonid production.

Swimming Under the Influence (SUI): Carbon Dioxide

In the discharges from southern sites, it is common to have high carbon dioxide levels in the water. The Bishop mine drains a 12,000-acre minefield with a flow volume ranging from 12,000 L/min to 60,000 L/min. Of the parameters measured, only carbon dioxide was shown to be unacceptable for fish production.

A small portion of the water from the Bishop mine was diverted for an experiment comparing survival in water where carbon dioxide was removed as it passed through a trickling tower. Two fish tanks were placed adjacent to the tower. The control tank received untreated mine water and the treated tank received water after it passed through the tower. During the 12-week study with Arctic char the fish in the untreated tank were swimming in a state of perpetual inebriation. They ate poorly and swam in a listless fashion. The trickling tower reduced average carbon dioxide concentration from 137 to 25 mg/L. Survival was 100 percent in the tank receiving water with carbon dioxide stripped out, and 31 percent where carbon dioxide was not removed from the water source.

Manganese and Iron

Environmental regulatory permits place limits on the amount of iron, manganese, aluminum, suspended solids, and pH of water discharged from AMD treatment plants. Manganese, although not toxic, is used as an indicator metal because it is the last metal to precipitate during the addition of hydrated lime, which is needed to raise the pH for the precipitation of iron and aluminum (Robbins *et al.* 1997). The national standard for manganese discharge is 2.0 ppm. Most sites in West Virginia must meet a higher standard of 1.0 ppm. One site where the higher standard of 1.0 ppm was required was chosen as a study location.

When trout were stocked in the final one-acre polishing pond of this site, the trout did not survive. The pond received a constant flow of 15,000 L/min. Temperature, oxygen, pH, and conductivity were monitored on an hourly basis using YSI sonde. Data from the sonde revealed a pH between 8.8 and 9.0.

The mining company that operates the AMD treatment plant explained that the high pH levels were required so that water quality permit conditions would not be violated. They needed to keep the pH close to 9 to maintain manganese levels below 1.0 ppm. Ironically, this has resulted in water quality that is not tolerated by trout.

Ten miles away, just across the Maryland boarder, another AMD treatment plant is permitted to discharge manganese at 2.0 ppm using the same treatment process for water from the same coal seam, the Freeport seam. This facility has been efficiently producing healthy trout in net pens suspended in the outflow of the AMD treatment plant since 1994. (http://www.gcnet.net/mettiki). The low cost trout production facility is operated by the Maryland Department of Natural Resources and stocks trout with good appearance, some as large as 3 kg, for public recreational fishing.

Other Water Quality Parameters

The treatment of acid mine discharges often uses hydrated lime ($Ca(OH)_2$) that may raise the hardness and total dissolved solids to over 1500 mg/L as $CaCO_3$. Sulfates at greater than 1100mg/l were often found to be above the criteria for salmonids (Heinen 1996), without showing any obvious impact on the fish. A detailed study of trout survival and mine water quality was conducted at one site and suggested that the high ionic strength found in some mine waters plays a role in reducing the "active" concentrations of metal ions in solution (Tierney 2002). This relationship may explain why certain dissolved elements may not be as detrimental to fish as previously thought.

Long-term monitoring of acid mine discharges has shown a slow reduction in acidity as the water flushes through the mine and oxidizes the acid forming pyrite. After mining is completed, it may take years for water to fill the mine. As these mined basins fill with water, new reservoirs are created. These new reservoirs will be evaluated for their potential use in the culture of fish.

Bioaccumulation

Fish flesh was examined for accumulation of metals at one AMD treatment site. Rainbow trout in a cage were fed a high-energy diet over a 203-day period. EPA approved methods were used for tissue analysis of metals resulting in undetectable levels of toxic metals.

Second Life for AMD Treatment Plant

What does one do with an AMD treatment plant when it is no longer needed? Current law states that the site must be reclaimed to the previous use or a more desirable use. At the Guyses Run AMD plant the existing infrastructure includes two 100,000 gallon concrete basins, three fenced ponds, electricity, all season road access, and two block buildings connected to municipal water. We are assessing whether the site is a suitable fee fishing venue. Channel catfish, largemouth bass and hybrid bluegill stocked in cages survived and grew well. Temperature, oxygen and pH readings were collected using YSI sondes and remained within the recommended range throughout the year.

The mining permit for this site was modified to allow for a commercial fish operation. After a public hearing, the company addressed all of the issues of concern and received approval from the West Virginia Department of Environmental Protection (WVDEP) for the modifications. The estimated cost of developing the site for recreational fishing may compare favorably to the reclamation cost of returning the land to its original use as a pasture.

The site became a class project for students enrolled in a Landscape Architecture design class at West Virginia University in spring of 2002. Many creative ideas involving recreational fishing were presented and the best ideas were included in the final design during a summer class project. This work will be used to show potential investors some options for the site accompanied by an estimated cost for development.

Industry Development

Facilities at six locations produce salmonids for food or recreation utilizing water discharged from a mine or AMD treatment plant in Pennsylvania, Maryland and West Virginia. Facility design varies from Mettiki's net pens, to flow through tanks (High Appalachian), to a system reusing over 80 percent of the mine water flow. Rainbow trout, Arctic char, cutthroat trout and brown trout are grown. Rainbow trout and Arctic char are marketed as food fish primarily in the eastern U.S. The Arctic char production from southern West Virginia has been successful in marketing the newly cultured species, under the brand name *ISIS*, from an intensive recirculating system (Simmons *et al.* 2001).

Also, opportunity may exist in recreational markets. Southern West Virginia draws tourists from all over the country to experience the white water rafting found on the Gauley and New Rivers. Additional activities for the outdoor enthusiasts, such as family oriented fee fishing sites, could increase the length of time these visitors spend in West Virginia. Fee fishing can be used as a market tool to maximize economic development in areas that have been depressed since the mines have shut down. Most of the high flow mine sites are concentrated in the southern part of West Virginia, which has been economically depressed since the closing of the coal mines.

Development of the aquaculture industry based on the mine

(continued on page 70)

(Continued from page 59)

water resource must also address effluent, economic, and marketing concerns. Research at West Virginia University is focused presently on these critical factors. As freshwater sources become limited, the groundwater resource obtained from mines is expected to become more important for West Virginia. We will continue to assess the opportunity and develop strategies to integrate aquaculture as a post mining land use.

Notes

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