Beneficial Use of Mine Pool Water for Power Generation

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Biographical Sketch for Presenting Author

John Veil is the manager of the Water Policy Program for Argonne National Laboratory in Washington, DC. He analyzes a variety of energy industry water and waste issues for the Department of Energy and other clients. Mr. Veil has a B.A. in Earth and Planetary Science from Johns Hopkins University, and two M.S. degrees — in Zoology and Civil Engineering — from the University of Maryland. Before joining Argonne, Mr. Veil managed the Industrial Discharge Program for the State of Maryland and had statewide responsibility for industrial water pollution control permitting through the National Pollutant Discharge Elimination System (NPDES), Underground Injection Control (UIC), and oil control programs. Mr. Veil also served as a faculty member of the University of Maryland Department of Zoology for several years. Mr. Veil has published many articles and reports and has made numerous presentations on environmental and energy issues.

Abstract

There are hundreds of active and numerous abandoned underground coal mines throughout the Appalachian region. Many of those mines are completely or partially filled with ground water, thereby creating mine pools. In many cases, the water has low pH and contains elevated levels of iron, other metals, and dissolved solids. When the mine pools overflow into nearby streams, they contribute to poor water quality and stream impairment. At the same time that the coal mining areas of the Appalachian region have an overabundance of mine pool water, large water consumers in the region, and in particular, steam electric power plants, are facing difficulty locating sufficiently large and sustainable supplies of fresh water to use as cooling water in steam condensers. The U.S. Department of Energy (DOE) through its National Energy Technology Laboratory (NETL) recognizes the potential for mine pools to serve as cooling water sources and is sponsoring a series of studies to better characterize and understand the nature of the mine pool resource and the issues that may arise as mine pool water is put to an industrial use (Feeley 2003). This paper describes work underway by Argonne National Laboratory to evaluate some of the technical, policy, and regulatory issues surrounding the use of mine pool water, with a particular focus on mines in Pennsylvania and West Virginia.

Introduction

Coal has been mined from the Appalachian coal basin of the eastern United States for over two centuries. The main method of extraction for most of those years was underground mining. As the underground mines closed in the coal fields of Pennsylvania and West Virginia, the pumping operations that kept the mines dry ceased operations. Over time, ground water accumulated in the voids left by the mining operations, creating large underground pools of water. The water quality varies as the result of the chemistry of the individual coal seam of the mine, the residence time of water in the mine, and the method of mining. These pools, some of which are already overflowing and others, which may overflow in the next few years, can present threats to surface water quality.

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[1] Argonne's work on this project was funded by the U.S. Department of Energy, National Energy Technology Laboratory, under contract W-31-109-Eng-38.

Most electric power plants use large volumes of water to condense steam. In many locations around the country, the existing surface water supplies are not large enough to accommodate additional withdrawals for new power plants. This paper describes portions of the analysis that Argonne National Laboratory is conducting for DOE/NETL to evaluate the feasibility of using mine pool water as a source of power plant cooling water. If mine pool water can be used in power plants, it will offer a dual benefit. First of all, the power plants will have more flexibility in siting, and secondly, use of the water will help to avoid or postpone undesirable contamination of surface water bodies by mine pool water.

How Much Water is Available?

Coal underlies about one third of Pennsylvania, with anthracite coal in the northeastern and north-central portion of the state and bituminous coal in the western portion. Much of West Virginia is underlain by bituminous coal beds. The Pennsylvania Department of Environmental Protection (PADEP) estimates that there are between 10,000 and 15,000 abandoned underground mines in Pennsylvania. The West Virginia Geological and Economic Survey (WVGES) estimates that there is an equal or greater number of abandoned underground mines in West Virginia. Detailed data on the number of underground mines and the total volume of water in the mine pools is not well developed across the region. The National Mineland Reclamation Center (NMRC) at West Virginia University is undertaking a four-year effort to map the underground mines and their associated mine pools of the Pittsburgh coal seam in western Pennsylvania and in the northern coal field of West Virginia. The Pittsburgh coal seam is a significant coal resource that underlies western Pennsylvania and northern West Virginia. To date, NMRC has mapped 130 underground coal mines in both Pennsylvania and West Virginia.[2] NMRC has estimated the combined storage volume of these mines to be 250 billion gallons (768,000 acre-ft).

The Quality of Mine Pool Water

The nature and quality of mine pool water in the coal fields of Pennsylvania and West Virginia has been extensively studied as a result of the impacts of this water when discharged to the environment. Cravotta et al. (1999) observed that mine pool water in these coal fields exhibits a bimodal frequency distribution of pH with two peaks of pH 2.5 to 4 (acidic) and pH 6 to 7 (near-neutral). The mine pool water also exhibits elevated levels of total dissolved solids (TDS), iron, aluminum, sulfate and other dissolved metal ions.

Mine pool water becomes acidic from the reaction of oxygen and water with iron-sulfide-bearing minerals found in the coal, such as pyrite (FeS_2). Near-neutral pH mine pool water results from the buffering of mine pool water with calcareous minerals, such as calcite ($CaCO_3$). There are many factors that affect the chemistry of mine pool water. Wood (1995) suggests that the following factors will affect the pH, acidity, and metals concentrations in the discharged water:

- mineralogy of the coals and overburden;
- quantity of water flowing through the mine;
- residence time, path length and depth of water circulation through the mine;
- availability of oxygen and dissolved oxygen in the mine water;
- mine design (e.g., up-dip versus down-dip);
- active pumping, either within the mine or within the influence of adjacent mines; and
- exposed surface of sulfide minerals.

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[2] Leavitt, Bruce, 2003, personal communication from Leavitt (consultant to National Mineland Reclamation Center) to J.M. Kupar (Argonne National Laboratory).

In light of the elevated levels of TDS, hardness, and the variable nature of pH, the majority of mine pool water will have to be treated to some degree, prior to use in a power plant's cooling water system. Treatment technologies for pH adjustment, removal of TDS, dissolved metal ions, and variables found in mine pool water are well established.

An example of a treatment system that might be used for the treatment of mine pool water for a closed-cycle cooling system makeup includes the following process units.

- Clarification to remove settleable solids
- pH adjustment, horizontal precipitator, coagulation, and flocculation for metals removal
- Multimedia filtration, ion exchange, and carbon adsorption if necessary to remove low TDS

Any water that will be used for boiler feed water will require additional treatment. Cartridge filter units can remove additional sub-micron particles and reverse osmosis and/or ion exchange will provide additional polishing.

Cooling Water Usage

At steam electric power plants, electricity is produced by heating purified water to create high-pressure steam. The steam is expanded in turbines driving the generators that produce electricity. After leaving the turbines, the steam passes through a condenser that has multiple tubes and a large surface area. A large volume of cool water circulates through the tubes, absorbing heat from the steam. Mine pool water could be used for once-through or closed-cycle cooling. At least four operational modes, as described below, are conceivable.

Once-Through Cooling: Once-through cooling systems withdraw large volumes of water — typically in the range of tens of millions to billions of gallons per day from a river, lake, estuary, or ocean. The water is pumped through the condenser in a single pass and returned to the same or a nearby water body.

Mine pools offer two possible modes for once-through cooling. Under Mode 1, *Once-Through with Discharge*, the water is withdrawn from the mine pool, passed through the condenser, and then discharged into a nearby stream (Figure 1).

Under Mode 2, *Once-Through, Return to Pool*, water is withdrawn from the mine pool, passed through the condenser, and then returned to the mine pool either at the surface of the pool or at a lower depth (Figure 2). Because Mode 2 does not reduce the volume of the mine pool, there is little chance that its use in this way would contribute to subsidence of the ground over the mine.

Closed-Cycle Cooling: The second category of cooling uses a closed-cycle cooling system, in which the water used to cool the condenser is not directly discharged but rather is recirculated to a separate structure for cooling (e.g., a cooling tower or cooling pond) before being returned to the condenser. Because evaporation and planned cooling tower blowdown (periodic discharges of portions of the recirculating water to remove build up of solids and other undesirable constituents) removes cooling water from the evaporative system, regular additions of "makeup" cooling water are needed. Makeup volumes are much lower than daily once-through volumes, and may range from hundreds of thousands to millions of gallons per day. Mine pools also offer two possible modes for closed-cycle cooling.

Under Mode 3, *Closed-Cycle, Wet Tower*, makeup water is withdrawn from the mine pool and added to the recirculating cooling system, which uses a wet cooling tower. Some water is lost to evaporation, and blowdown is typically discharged into a nearby stream (Figure 3). Because the volume of makeup water is much lower than that of once-through cooling water for a comparably sized plant, the volume and hydrological recharge rate for the mine pool do not need to be as high as they would under Mode 1.

Mode 3 is the most likely mode of usage of mine pool water. At least six small cogeneration plants have been operating in Pennsylvania's anthracite region for more than ten years and are using mine pool water as their primary water supply. Five of the six plants operate in Mode 3, whereas the sixth plant uses an air-cooled condenser for its main cooling needs and uses the mine pool water as makeup for an auxiliary tower. These are all small generating facilities that use waste coal refuse (culm) as a fuel.

A 600-MW generating unit that will use mine pool water from the southwestern bituminous coal fields of Pennsylvania for cooling under Mode 3 has been proposed along the western Pennsylvania-West Virginia border. The plant will utilize 7,000 gpm of mine pool water from the Shannopin mine as well as several other nearby mines in Greene County, Pennsylvania. The mine pool water will be extracted from the mines and treated at a central treatment facility near the Shannopin mine. Treated water will then be pumped six miles to the power generation facility.

Under Mode 4, *Closed-Cycle, Cooling Loop*, little or no water is withdrawn from the mine pool. Instead, a long, continuous coil of heat-exchange tubing is placed into the mine pool (Figure 4). Warm water or some other heat exchanging fluid is circulated from the condenser through the cooling loop and then back to the condenser. In the absence of leaks, the fluid inside the cooling system never comes in contact with the mine pool. Heat is exchanged through the walls of the cooling loop tubing. This type of system is essentially a giant heat pump.

Downstream Use after Instream Transport:

The four cooling modes described above involve direct withdrawal and use of the mine pool water by the plant.

A fifth mode involves use of the water by a power plant located downstream from the mine pool site. Under Mode 5, *Downstream Use after Instream Transport*, water is withdrawn from the mine, treated if necessary to meet water quality requirements, and then discharged to and transported by a river or stream to a downstream location where it can be used. The river would serve as a conduit for the mine pool water (Figure 5). At the downstream withdrawal location, the power plant would be allowed to withdraw an amount of water equal to or less than the amount previously added at the mine site. Depending on the cooling system employed at the power plant, the transported mine pool water could serve as once-through cooling water or as cooling tower makeup water.

This incremental water volume offers several benefits. Because the augmented river flow would be higher than normal, the mine pool water would further provide additional aquatic habitat for a distance many miles downstream from the point of discharge to the point of withdrawal at the power plant site. The incremental volume would also provide additional flow to dilute permitted and unpermitted discharges to the stream. Companies that plan to operate under Mode 5 should make sure that the additional mine discharges to the stream will not cause unacceptable levels of erosion or flooding.

Previously, Mode 5 has been just an interesting concept. However, beginning in the summer of 2003, a large nuclear power plant owned and operated by Exelon Corporation in Limerick, Pennsylvania will conduct a trial to use mine pool water from a source located more than 70 miles upstream. The water will be discharged by a coal mine into a tributary to the Schuylkill River, and the river will transport the water to the power plant. If the trial is successful, Exelon may look for additional mine pool water sources to supplement its water supplies.

Under the most generic form of Mode 5 operation, the mine releases the same or a higher volume of water, which is subsequently withdrawn by a downstream user. Presumably, a power plant would have relatively consistent water supply needs throughout the year so this would lead to relatively constant mine pool releases. However, any regulatory requirements for releasing treated mine water to a stream need not stipulate a constant volume at all times. The state agencies responsible for natural resources and environmental protection may actually prefer and welcome a discharge volume higher than needed by the power plant during dry or low-flow periods, and a lower than needed volume during normal or high-flow conditions. Innovative scheduling of mine pool discharges can provide even greater environmental benefits.

Cooling Water Volume Needed: If mine pool water is to be used by power plants, the availability of sufficient water must be sustained for the life of the plant, generally at least several decades. Argonne has made some preliminary rough estimates of the volume of water needed to cool a 400-MW power plant. These have not yet been published, and therefore should not be taken as detailed volumetric requirements. For once-through (Mode 1) operation, the flow volume is estimated at 254,000 gpm (365 million gallons per day or MGD). The total volume needed for withdrawal at this rate for 50 years is nearly 7 trillion gallons. This volume is probably not practically or economically available. For supplying cooling tower makeup water (Mode 3 operation), a much smaller but still large volume of water is needed. Assuming a range of makeup water flows (2 to 30% of the recirculating cooling water flow), the needed flow rate is 4,000 to 60,000 gpm (6 to 86 MGD). The fifty-year total volume ranges from 105 billion to 1.6 trillion gallons. This may or not be sustainable depending on the local hydrological conditions at the mine pool site.

Siting Considerations and Transportation Issues

Siting decisions for power plants must consider many factors. In addition to the proximity to fuel supply and ash disposal, securing a dependable and adequate water supply plays a critical role. The ideal candidate power plant for using mine pool water would be built within a relatively short distance from the mine pool. This may not be practical, however. Many coal mines are located in rugged terrain. The most desirable location for a hypothetical power plant may be very distant from an underground mine site. If the selected site lacks sufficient water resources but is otherwise a good candidate, project sponsors may consider transporting mine pool water over long distances from the mine(s) to the power plant.

The most obvious transportation means is a pipeline with associated pumping stations that would convey the water to the plant. Modern engineering methods can pipe high volumes of fluids over large distances. But even though the technology and capability to construct a pipeline exists, there may be circumstances under which construction of such a pipe would involve unacceptable costs or face permitting challenges, such as the need to obtain a wetlands permit or secure rights-of-way to traverse someone's property.

If mine pool water is used under Mode 5, it will generally be necessary to treat the mine pool water so that water discharge requirements can be met. Such treatment will probably be costly because substantial volumes of water are involved. It is assumed that the power company will bear the treatment costs and that such costs will be lower than those associated with building a pipeline or arranging for an alternate source of water. At specific mine pool locations where overflow is imminent, local and state agencies may be willing to work with downstream users to share the cost of treatment and avoid or minimize significant environmental degradation caused by overflowing mine pools.

The quality of the mine pool water will affect the costs associated with 1) treating the water to meet cooling system influent requirements, treating the water for use as boiler feed water (if applicable), and 3) operating and maintaining the treatment system. The water's pH, hardness, mineral content, and suspended solids level are but a few of the variables that will affect the cost of the treatment system**.** The quality of the water may also affect the materials of construction for both the water treatment system and sub-system components of the power plants cooling system (such as piping, heat exchangers, and pumps).

Regulatory Considerations

Although the six small Pennsylvania plants mentioned above have been using mine pool water for many years, they have conducted relatively small-scale operations that use small volumes of water. Regulatory issues have been straightforward. If mine pools are to be used more widely in the future, particularly when more significant volumes of water are withdrawn for larger power plants, many regulatory and policy questions must be answered. It is well understood that water discharged from either mines or power plants to surface water bodies must be covered under National Pollutant Discharge Elimination System (NPDES) permits. Heated water returned to a mine may be subject to requirements under the Underground Injection Control (UIC) program, but since mine pool water has never been used in that cooling mode before (Modes 2 or 4 in this report), the actual requirements are not known. Withdrawal of water from the mines in quantities sufficient for power plant purposes will generally require some type of permission from a river basin commission or state agency. Fees will be charged for the use of large volumes of water. Transport of water from one jurisdiction to another will require complex coordination.

Economics

Only limited cost data are available for the few facilities currently using mine pool water. The costs of pumping, piping, and treating mine pool water are highly site-specific and can be substantial. In some regions, no other sources of water are available in sufficient quantities; therefore, without using mine pool water, power plants cannot operate economically in those locations.

Environmental Considerations

Environmental benefits can result from the use of mine pool water at some locations. Throughout the coal regions of Pennsylvania and West Virginia, numerous mines are currently discharging to streams and rivers and others will soon overflow. Much of this water has undesirable qualities (low pH; high iron, manganese, and TDS) and will cause degradation of the receiving water bodies. Any mine pool water that is removed from the pool by a power company represents water that will not contaminate the downstream portions of that stream or river. The authors are not aware of any circumstances yet under which government water resource or environmental agencies have offered financial incentives to potential users of the mine pool water, but as several large contaminated mine pools approach the overflow point, incentives may become part of a strategy to protect water quality. In any case, the concept of using an undesirable commodity (too much contaminated water) as a resource is quite attractive.

Final Thoughts

As fresh water supplies become increasingly limited, power companies will look for alternate water sources in order to site new power plants. Mine pools represents a nearly untapped resource that offers some potential for use at power plants and other industries. This paper outlines some basic information about the resource and how it might be used. Many questions remain unanswered. DOE/NETL plans to continue investigation of mine pools.

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Once-Through Cooling Modes

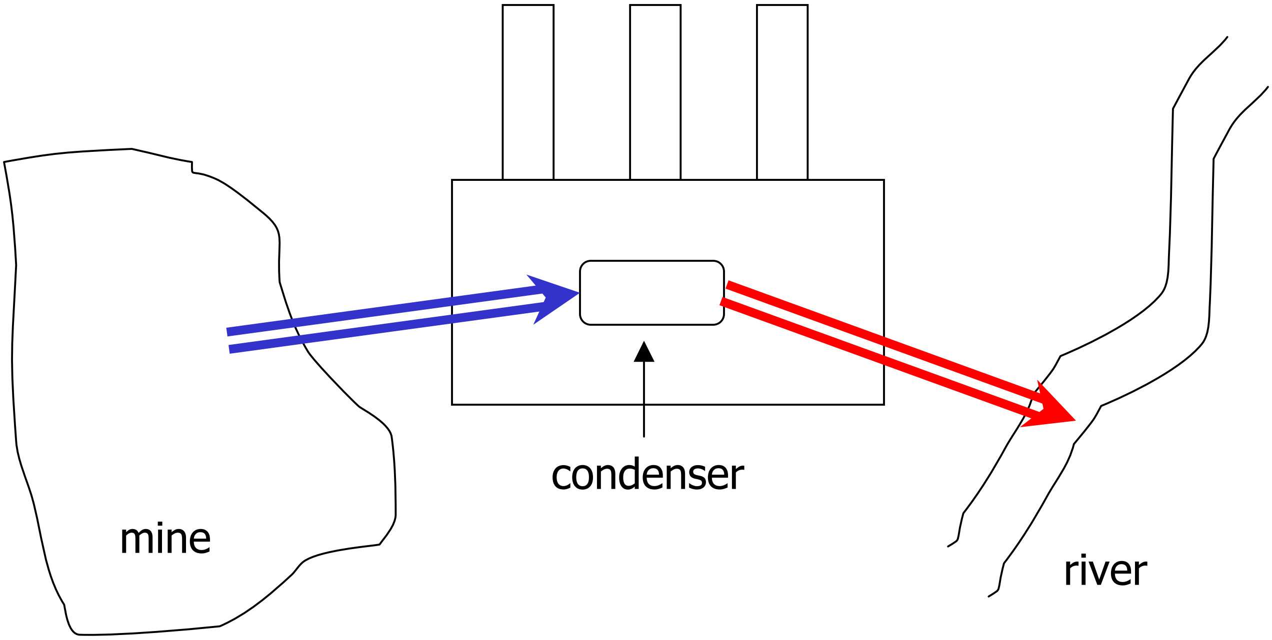

Figure 1: Mode 1 – Once-Through with Discharge

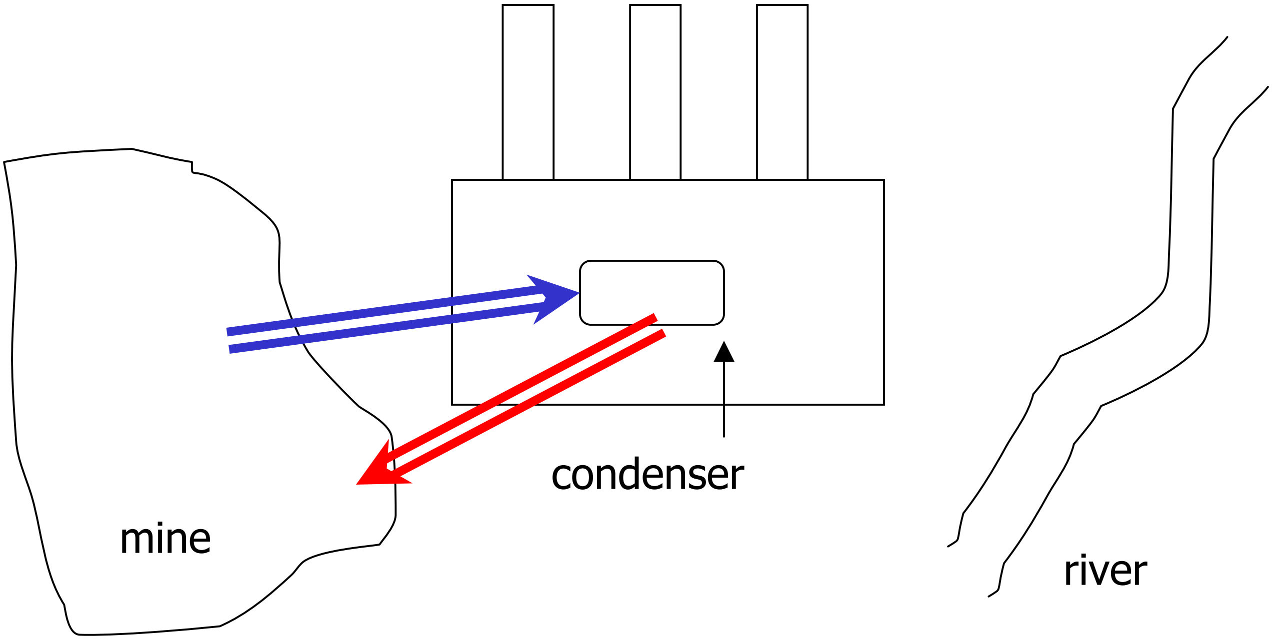

Figure 2: Mode 2 – Once-Through, Return to Pool

Closed-Cycle Cooling Modes

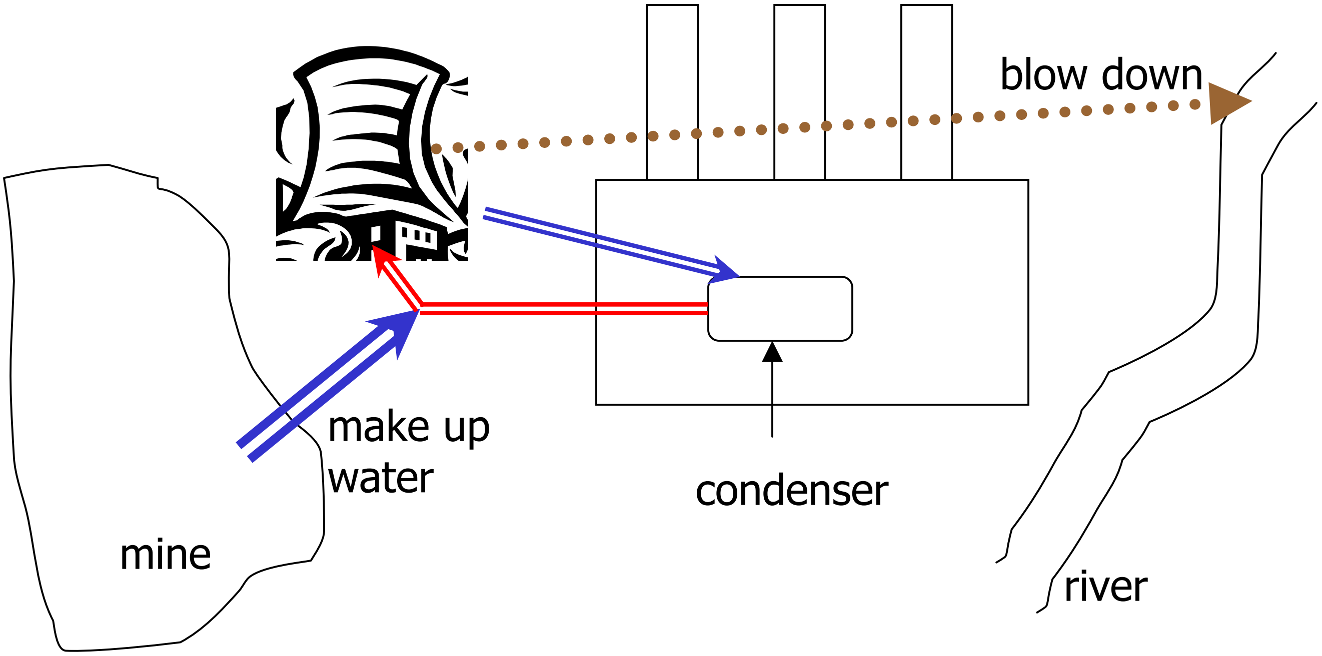

Figure 3: Mode 3 – Closed-Cycle, Wet Tower

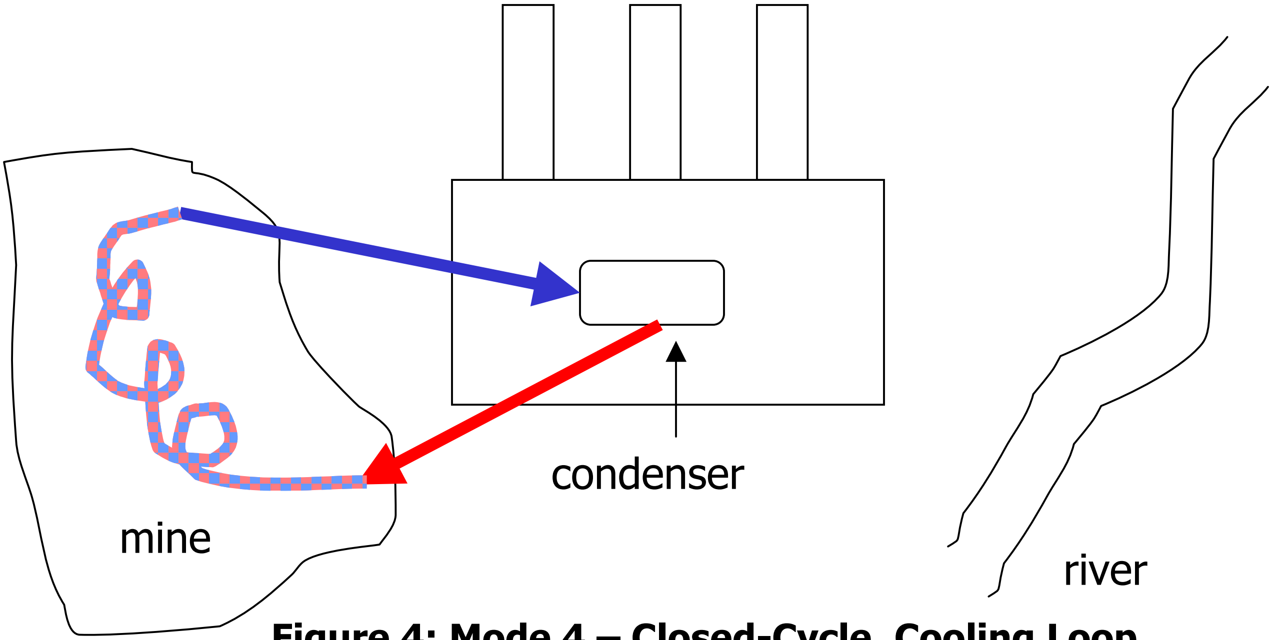

Figure 4: Mode 4 – Closed-Cycle, Cooling Loop

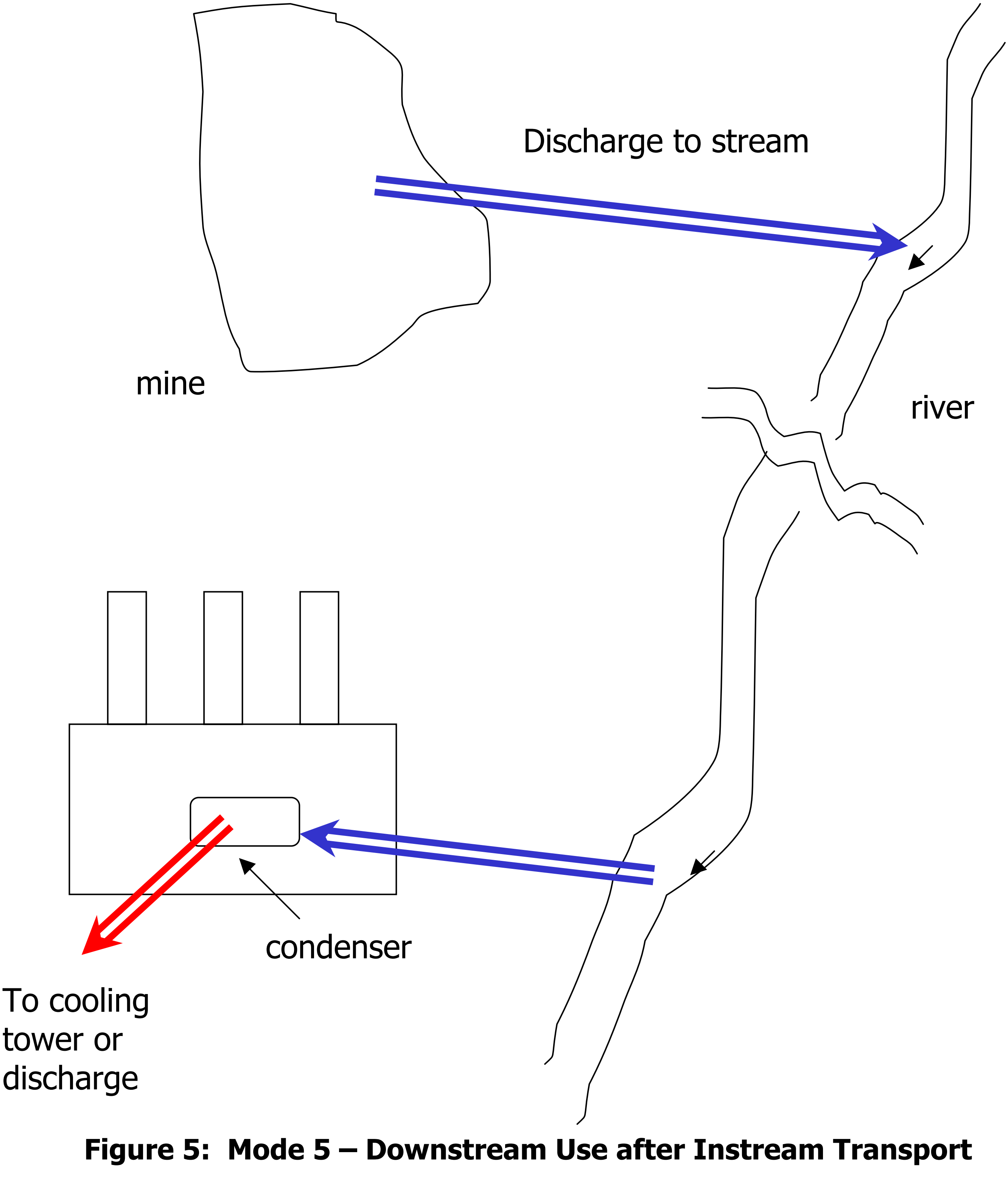

Figure 5: Mode 5 – Downstream Use after Instream Transport