Development of a Method for the Watershed Approach to Acid Mine Drainage Abatement[1]

by

David A. Zucker[2]
Jeff G. Skousen[3]
Tim T. Phipps[4]
Jerald J. Fletcher[5]

Abstract Acid mine drainage (AMD) on abandoned mine lands (AML) has become a major priority with many state resource management agencies in West Virginia. This paper describes the watershed approach to the development of a cost effective method to treating AMD from AML. Water in surface streams in the Sovern Run watershed, located in Preston County, West Virginia, has an average effluent pH of 4.0, with metals such as aluminum, magnesium and iron present in significant concentrations. Sovern Run drains directly into a potential smallmouth bass and put-and-take trout fishery. The biological parameters required by each species provide targets to be met through biological treatment of the water. Sample sites were chosen on the basis of location relative to tributaries and acid seeps. Field samples were taken once every week and lab analyses were conducted once every month. Various active, passive, and mechanical AMD technologies are evaluated on the basis of cost, degree of management, and biological effects down-stream.

Additional Key Words: economic reclamation, watershed restoration, acid mine drainage,

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[2] Graduate Research Assistant, West Virginia University, Morgantown, WV 26506

[3] Assistant Professor, West Virginia University, Morgantown, WV 26506

[4] Associate Professor, West Virginia University, Morgantown, WV 26506

[5] Associate Professor, West Virginia University, Morgantown, WV 26506

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Introduction

A complex task associated with acid mine drainage (AMD) from abandoned mine lands (AML) is finding a cost effective strategy for AMD amelioration. Because AML's are abandoned, implementation of an AMD prevention or treatment technique that does not require continual chemical additions or maintenance is important. While technologies for AMD amelioration are available, most are available are not applicable to all AML situations. Total cost[1] is a major factor for AMD treatment programs on AML . This paper discusses a cost effective method of AML AMD abatement using a watershed approach. The idea of using a watershed approach to AMD problems, though not new, has potential to affect larger areas and to clean up downstream pollution problems.

The Sovern Run watershed is a suitable a model for a watershed level approach to AML AMD amelioration for several reasons. First, this watershed had been extensively mined prior to the implementation of the Surface Mining Control and Reclamation Act (SMCRA) in 1977. Second, there are both abandoned surface and deep mines within the watershed boundaries. Third, water from these mines has been polluting Sovern Run with AMD since the mid 1950's. Fourth, Sovern Run discharges into a potential smallmouth bass (*Micropterus dolomieui*) fishery and a put-and-take trout (*Salmonidae sp.*) stream. Finally, according to the West Virginia Division of Natural Resources (WVDNR), if the acid coming from Sovern Run is ameliorated before it discharges into the Big Sandy River, the lower six miles of the Big Sandy can be restored to its full potential as a fishery.

This research uses Sovern Run to model the effects of different AMD amelioration technologies on the ultimate quality of water in the watershed. These technologies are evaluated on the basis of cost, degree of management, and biological effects downstream (trout inhabitable waters).

Purpose and Scope

This research formulates a method of minimizing the cost of AMD abatement at the watershed level subject to achieving a specified environmental goal. Because the environmental degradation caused by AMD from AML is so prevalent in northern West Virginia, the WVDNR and the West Virginia Department of Environmental Protection (WVDEP) have begun channeling funds to address this problem. In particular, recent revisions to Title IV of SMCRA allow AML funds to be used in improving watersheds damaged by pre-law mining operations.

Even though the idea of watershed restoration is not new, previous attempts at the task assumed several factors relating to cost[2]. The specifics of these numbers and their drawbacks will be discussed later. A major factor emphasized in this research is the method used in finding the technology most efficient for specific point sources of AMD, as well as the downstream implications of the technology on the local aquatic ecosystem.

Several technologies are currently used effectively by mine operators to treat AMD on active mining operations. These technologies are usually labor intensive and require a continual source of funds and manpower to operate successfully. This research will evaluate both active[3] and passive[4] chemical treatments, as well as mechanical techniques[5].

Background -Literature

Scott and Bennett (1981) estimated the cost for abatement of abandoned mine drainage on the Cheat River for the WVDNR. Costs for treating an abandoned deep mine were determined by using a unit cost of $1,500/lb of acid[6]. Abandoned surface mining AMD costs were determined by treatment cost per acre of disturbed land and ranged from zero cost to $10,000/acre depending on the acid contributions and the physical condition of the surface mine.

Scott and Bennett (1981) further point out that the majority of AMD contributed to the Big Sandy resulted from deep mine drainage in three small watersheds of which the Sovern Run watershed is one. Sovern Run was discharging 1,860 pounds per day of acid or 60% of the total acid load from the three streams. A figure combining $1,500 and $2,500 was used to estimate a total cost of $4.62 million to treat the AMD discharging from Sovern Run. The weight of each cost depended upon the physical characteristics of the respective mine or seep. With treatment, the sport fishery of the Big Sandy River can be greatly improved if remedial action is taken.

The U.S. Environmental Protection Agency (EPA)(1976) published a report on the Campbell's Run watershed in Pennsylvania. This study demonstrated the effectiveness of surface mine reclamation upon water quality in streams receiving mine drainage from abandoned underground mines. There were four major acidity sources within the watershed. These sources had pH values of 2.6, 2.6, 2.8 and 3.0 and acidity levels, in mg/l, of 776, 820, 888, and 600, respectively. Fifty-two acres of abandoned surface mine land were regraded and revegetated to reduce water infiltration into the spoil deep mines. The reclamation was completed at a total cost of $131,650 ($2,500 per acre). Even though the improved water quality could not be directly attributed to reclamation, there was a 43% decrease in acid load to the stream. The reason for the uncertainty was due to other residential, commercial, and interstate construction activities in the study area.

Skelly and Loy (1982) conducted a study of the North Fork Pound River Watershed in West Virginia. The North Fork of the Pound River was impounded in 1966 as a flood control and recreation reservoir by the U.S. Army Corps of Engineers. Extensive contour strip, mountaintop removal, and auger mining took place within the watershed, above the reservoir, about 1968. During September, 1969, a fish kill in the upper end of the reservoir was reported by local residents. Even though no dead fish were observed by inspecting biologists, subsequent investigations of the lake supported the findings of severe biological and chemical degradation. The Virginia State Water Control Board (1971) also reported pH levels as low as 3.5 and not rising above 6.0 anywhere along the reach of the North Fork. They also found high concentrations of iron (0.08 - 18.0 mg/l) and manganese (1.9 - 55.0 mg/l), and severely reduced or absent benthic life in the stream.

Skelly and Loy proposed 28 possible reclamation alternatives based on a detailed breakdown of actual "problem sites" in the mined areas and several alternatives for each site. Reclamation concepts were centered on one sub-basin in the watershed with the concept to be expanded to other affected sub-basins. No single methodology, cost, or concept of reclamation was proposed for all affected areas, but rather a tailored combination of technologies for the site. The methodologies included:

1. isolation or total removal of toxic spoil from the site;
2. slope reduction and regrading;
3. establishment of proper drainage control;
4. revegetation;
5. sealing with low hydraulic conductivities as barriers;
6. lime neutralization;
7. microorganism control;
8. inundation of acid material under a permanent water table.

Skelly and Loy (1979) also prepared a report for the California Regional Water Quality Board on the reclamation of a former copper and sulfur mining operation. The mine was located on the eastern slope of the Sierra Nevada Range in Alpine County, California, along the California-Nevada border. For years the Leviathan Creek, which flowed directly through portions of the mine site, had been severely degraded by a host of pollutants emanating from underground mine workings and the leaching and refuse tailings, and spoil containing pyritic materials. Bryant Creek, another creek polluted by this mine, once supported a substantial trout population, but at the time was totally lifeless, as was Leviathan Creek below the mine site.

There were five major problems with the mined area that were in need of reclamation. These were open pit and spoil areas, mine tunnels, waste dumps, site drainage, and slide areas. The following reclamation options were presented for each of the types of problems, respectively: regrading and run-off diversion; sealing of openings using impervious clay or double bulk-head seals; removal and placement of pyritic waste dump material in clay-line opened pits; reconstruction or relocation of Leviathan Creek; and removal and/or stabilization of slide material.

The methods of AMD abatement proposed in these operations were fairly common techniques in the literature. These studies, in one respect or another, attempted or proposed abatement techniques using the watershed level approach and the effects of such abatement techniques on trout streams, none of the studies include an adequate evaluation of cost.

Materials and Methods

Description of Watershed

The Sovern Run watershed is located at the northwestern boundary of Preston County near Valley Point, WV, about 15 miles east-south-east of Morgantown, WV (see figure 1). The perimeter of the Sovern Run watershed is 11.0 miles in length encompassing an area roughly 6,000 acres. With a northwest slope, the watershed drains from 2100 ft in the south-east to the Big Sandy River at 1300 ft in the northwest.

Sovern Run is classified as a permanent second order, lotic (flowing water) aquatic ecosystem. The main

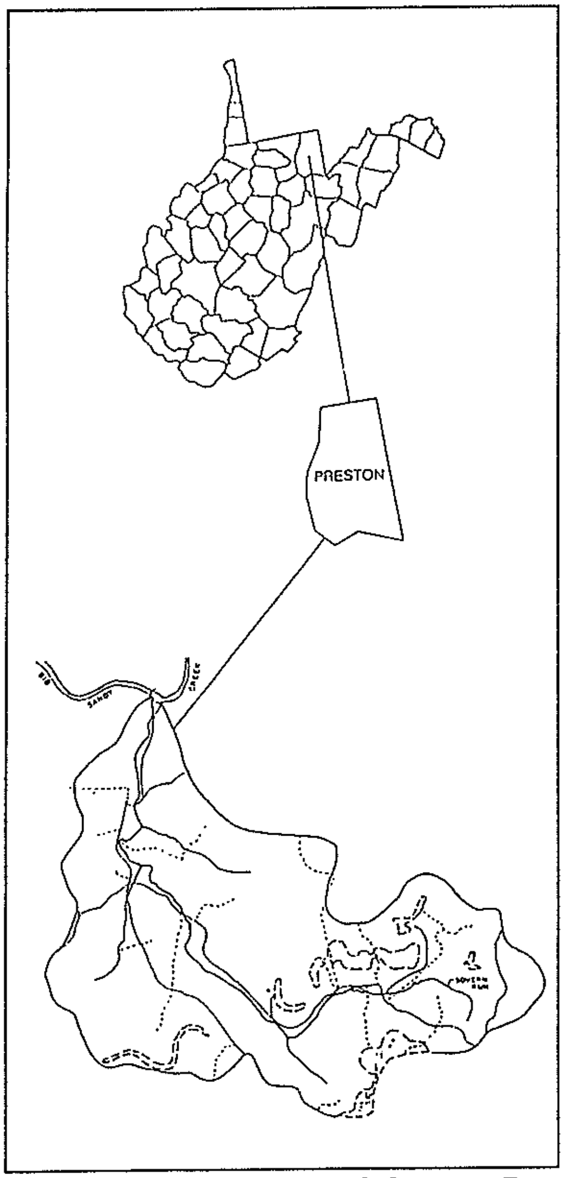

Figure 1 Location of Sovern Run In West Virginia.

channel of Sovern Run is about 4.7 miles in length (see figure 2), while the total length of the main channel plus permanent and intermittent tributaries is 6.6 miles. The left fork of the head waters originates at about 2000 ft from a low gradient, vegetated, emergent wetland (marsh) area containing various types of wet meadow grasses and cattails (*Typha* sp.). The right fork begins from several springs at about the 1900 ft level. After these two tributaries join, the stream encounters larger amounts of surface runoff from nearby roads and farms around 1800 ft. This portion of the stream ranges in depth from about two inches to one and one-half feet and has a width range from one to three feet.

One large wetland area is located at 1850 ft, 0.45 miles downstream of where the two forks meet, and then Sovern Run is joined by three tributaries at 1800 ft, 1650 ft, and 1600 ft respectively. The first tributary is exactly one mile downstream of the location where the two forks meet. The next tributary is three miles downstream, and the final tributary meets Sovern Run another 0.4 miles downstream (see figure 2). The stream widens in the portion around the wetland from four to almost eight feet, with depths from six inches to three feet. From this point on, normal surface and ground water sources contribute to the stream and no other water from mining operations enter the stream.

Temperature within the watershed ranges from 80 to 88°F in July to 20 to 26°F in January. Precipitation on the average is about 46-48 inches per year. The annual water loss, i.e. precipitation minus runoff, is about 1.25-1.55 cfs per square mile, and the annual average runoff is between 1.93 and 2.32 cfs per square mile (West Virginia Department of Natural Resources 1967).

The geology of the Sovern Run watershed is primarily composed of two Pennsylvanian system groups. The Allegheny group makes up most of the watershed composed of massive coarse-

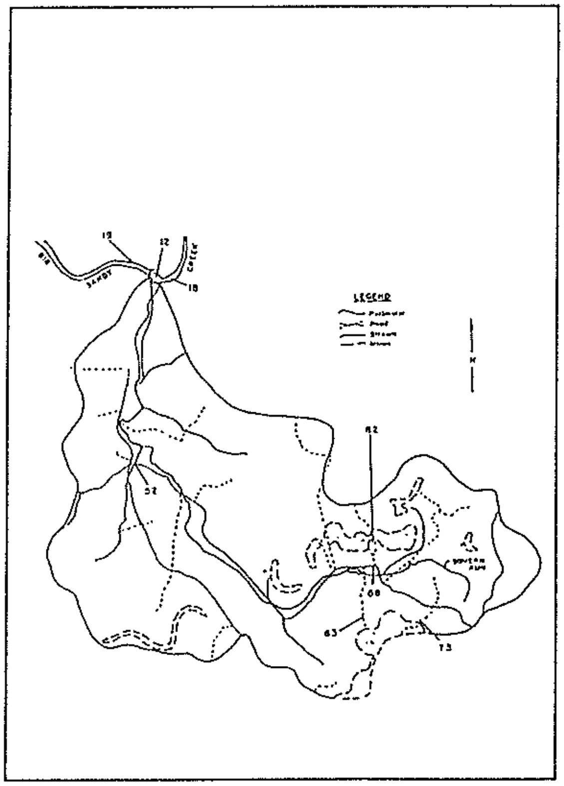

Figure 2 Sovern Run Watershed and Sampling Locations

grained sandstone, sandy shales and siltstone, and several important coals. General characteristics of the water in this group are moderately hard, high in iron, and low in chloride and dissolved solids. The Conemaugh group makes up a lesser portion of the watershed and also has massive coarse-grained sandstone at the base, minor beds of coal, and some limestone. The water is characterized as moderately hard, low in iron, chloride, and dissolved solids (West Virginia Department of Natural Resources 1967).

The mining history of this watershed (see figure 2) dates back to the mid 1950's. There are several surface mines, most being poorly reclaimed. The majority of these mines extracted coal from the Upper Freeport seam. Most mines were small contour, surface operations, and relatively small deep mines. In the upper portions of the watershed, part of a large mountain top removal operation existed. In addition, there is currently an active deep mine within the watershed boundary. This deep mine has effluent which has been characterized as acidic and high in metals. The operators have chosen to treat their 40 GPM effluent with anhydrous ammonia to raise pH and precipitate the metals in treatments ponds before discharging into receiving streams.

Study Methods

Accurately diagnosing the effect of AMD from Sovern Run on the Big Sandy River is critical in this study as well as to the subsequent cost analysis. Our study involves five steps. The first is to assess the effects of AMD from Sovern Run on the Big Sandy River. This requires assessing water quality in the Big Sandy above and below the mouth of Sovern Run. Our initial findings indicate that eliminating AMD in Sovern Run will bring water quality in the Big Sandy up to levels that can support a smallmouth bass fishery. Second, we need to identify and sample all AMD seeps and all tributaries that discharge into the Sovern Run Watershed. This is underway using a combination of existing data and semi-monthly sampling. Several water quality parameters at each sampling location are recorded on the average of twice a month. These parameters include pH, conductivity (μS/cm), and water temperature (^{o}F). A majority of these parameters are recorded with a digital meter while once each month, water samples are sent to a laboratory for analysis to maintain accuracy. Laboratory analysis consists of: pH, electrical conductivity (mmhos), acidity (meq/l), alkalinity (meq/l), total iron (mg/l), total manganese (mg/l), total copper (mg/l), and sulfates (mg/l).

The third step is to construct a water flow model that links chemical discharge from each seep to water quality at the mouth of Sovern Run. The model that is currently being considered uses the ideas of advection and dispersion. Advection is the transport of contaminants by the mean velocity of water as it flows in an open or closed channel or through a porous medium. Dispersion is the extent to which a contaminant is concentrated in a medium as the medium moves in a specified direction (Tchobanoglous and Schroeder 1985). Using the gathered data in conjunction with this model, the Sovern Run watershed will be modeled using a computer simulation. The computer procedure we will use is detailed later in this paper.

The fourth step is to compare alternative treatment systems in terms of their cost effectiveness, degree of management, and biological affects downstream. Costs for each technology will be compared for various water quality and flow regimes, as well as types of mines[7]. Management for each technology will primarily be evaluated on the level of training/experience required to operate, install, and/or maintain the system. Biological effects downstream will be analyzed using the requirements of the most sensitive and potentially beneficial species to the particular contaminant; in our case these species are smallmouth bass and rainbow trout (*Salmo gairdneri*).

The final step is to compare the total cost of the most efficient set of technologies with the benefits generated by restoration. All the costs that a specific technology will require can be quantified quite easily. For example, labor, electricity, maintenance, and reagent market prices are a reasonable representation of the value to correct the problem. Benefits such as improved fishing opportunities or improved aesthetic quality are not easily quantified because they are values individual place on non-market goods. Economists have developed several methods to estimate an individuals benefits. The most applicable methods to this project are the travel cost method (TCM) and the contingent valuation method (CVM).

The travel cost method attempts to put a monetary value on the benefit an individual gains from a particular site by finding the cost the individual incurred to travel to that site. This cost of travel is then used as a proxy of an individual's benefits. The contingent valuation method estimates the benefits of a particular individual for a site by asking direct questions about how much they would be willing to pay for certain environmental quality levels or other aspects relating to the improvement or maintenance of the activity or site.

In this study we will not be conducting our own TCM or CVM survey, but will extrapolate from existing studies of similar situations that have estimated the benefits of fishing. This method of extrapolation is called the user day method. We will estimate the number of additional fishing days that will be generated by the restoration of the Big Sandy fishery and then value each fishing day based on professionally accepted values for this region. In this manner, we will arrive at an estimate of the benefits generated by the restoration or improvement of fishing on the Big Sandy.

It should be noted that additional benefits may be generated by the restoration, including improved water quality on the Cheat River (Big Sandy is a tributary of the Cheat) and improved aesthetic value of the Sovern Run watershed. We will not attempt to value these additional benefits in this study.

Background - Data

Water quality data for the Sovern Run watershed have been collected from four sources with the earliest recordings in late 1977. These sources are: the West Virginia Division of Natural Resources - Fisheries; the West Virginia Chapter of Trout Unlimited; various West Virginia University Professors; and one hired field technician and one graduate student. The researchers are aware of both the good and bad aspects of this data.

Each group, agency, or individual that collected water quality data probably used different measuring tools. For example, Trout Unlimited may have used an inexpensive field kit, while the WVDNR probably used a more sophisticated, electronic measuring device. While this does not present a major problem, care must be taken in the interpretation of the data. Another problem relates to the actual location of the sampling site. For example, even though two individuals report taking water samples in the same location, the exact place of where the sample was taken is difficult to determine.

The good aspects of this data are clear. For each sample taken, there was always a pH reading taken in the field. There were also test results available relating to metal concentrations over different time periods. In addition, many of the individuals who did the sampling are still members or employed by the respective agency or group and can be contacted if the need arises.

Results

Notable points in the watershed are near the mouth of Sovern Run and two deep mines in the upper portion of the watershed. Table 1.0 shows various water quality parameters for 8 locations in these areas.

Types of Remedies and Costs

Chemical treatment of AMD is used extensively on effluent from mines that received permits after the invocation of the 1977 SMCRA law. Two types of AMD treatment, systems are recognized: passive, and active. A third system, mechanical treatments will be used to refer to land regrading, topsoiling and revegetation of abandoned surface mines, and daylighting of old underground mines. The active systems include variations on dispensing chemicals such as hydrated lime, soda ash briquettes, caustic soda, and ammonia. Passive systems use biological treatment (natural or constructed wetlands) or minerals in certain locations (anoxic limestone drains). An appropriate AMD treatment system for an abandoned mine is probably different than the system of choice for a active mine.

Passive systems are assumed to be the preferred choice of AMD abatement

Table 1.0 Water quality (lab results) of 8 sampling stations

Samp. I.D.*	pH	Elec. Cond. mmhos	Acid. meq/l	Alk. meq/l	Iron ppm	Mn ppm	Cu ppm	Zinc ppm	SO_4^{-2} ppm
12	3.7	0.145	0.79	0	1.0	2.4	0.05	0.15	72.3
18	5.9	0.071	0.12	0.14	ND	1.1	0.05	0.05	67.7
19	4.3	0.096	0.28	0.18	ND	1.4	0.05	0.05	36.6
52	6.1	0.055	0.11	0.16	ND	0.8	0.05	ND	10.3
56	3.0	0.860	6.24	0	20.8	7.0	0.2	1.05	540.8
62	2.8	1.35	10.99	0	46.6	8.4	0.4	1.35	844.6
63	3.9	0.135	0.95	0	ND	1.7	ND	0.7	63
73	2.9	1.40	14.64	0	10.4	12.8	0.3	2.8	1143

* - Sample identification numbers pertain to sample points on Figure 2.

due to the lower costs of maintenance. The use of passive technology to treat AMD is a fairly new concept. Anoxic limestone drains (ALDs) offer a technology to treat deep mine discharges that are low in dissolved oxygen (Nairn et al. 1991, Skousen 1991). Wetlands have been used for AMD treatment over the past ten years and have shown valuable results. Brodie et al. (1991) describe the use of ALDs in conjunction with wetlands to treat AMD.

Active technologies are usually more costly then passive technologies due to the added expenses of maintenance, supply of chemicals, and electricity Fletcher et al. (1991). If passive technology is not currently sophisticated enough to handle the acid load of a particular acid seep or discharge, active or mechanical technology is a viable option.

Modeling

The objectives of this research include: modeling the watershed using concepts of advection and dispersion; Monte Carlo simulation of different storm events; and determination of a cost effective method of AML AMD abatement. Currently these objectives seem realistic and capable of being completed.

After the model of the Sovern Run watershed has been developed, it will be used to perform Monte Carlo simulations of different size storm events. For example, we plan to simulate 5, 50, and 100 year storm events to give an approximation of the level of acid from each seep, total acid load entering the Big Sandy River, variations in flow or any other piece of information requested from the model, and compare the simulated water quality levels our biological parameters. The most valuable piece of information resulting from this study should be the determination of the effectiveness of the watershed level method to AML AMD abatement. This method will be based on the concepts, ideas, and literature presented in this paper and numerous other reports and papers that deal with this topic.

Conclusion

Now that the state of West Virginia is directing funds to the abatement of AMD on AML's, a need has developed to find a cost effective method of carrying out such a procedure. By evaluating passive and active AMD treatment systems according to both cost and effectiveness, an approach to complete watershed restoration may be achieved. This method will allow state and federal agencies to formulate effectively and carry out a cost effective AMD abatement program for AML for a watershed. Each project will be unique but the cost evaluation of treatment alternatives and benefits derived may be approached in a similar fashion. The framework of evaluation will provide a foundation from which resource managers can make rational cost effective decisions.

Acknowledgements

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Endnotes:

1. Total cost is the sum of installation costs plus variable costs. For example, an installation cost might be the out-of-pocket cost to purchase a piece of equipment. Variable cost on the other hand would be the out-of-pocket cost for the gas to run that piece of equipment.

2. Past research has assumed the total costs of treatment technologies without specifying the breakdown of where and how this total cost was derived. This breakdown is imperative to adapt a method to different types of AMD sites and seeps.

3. Active technologies are characterized as having annual costs comprised of maintenance, labor, reagent, and in some cases electricity.

4. Passive systems are characterized as having a one time installation cost, and no annual costs.

5. Mechanical techniques are comprised of all techniques that do not use chemicals strictly to ameliorate the affected water. For example, day-lighting of abandoned deep mine workings by surface mining is a mechanical technique.

6. The criteria Scott and Bennett used to arrive at this figure is not well documented in their paper and what is documented seems quite arbitrary.

7. We are assuming AMD from a deep mine should be treated differently from a contour strip operation.