# Computational methods for acid mine drainage management: decision-making for post-closure decision making

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**Keywords:** Acid mine drainage, passive treatment

**ABSTRACT**
The management of abandoned mine drainage is a complex task as the potential efficacy of a remediation project depends on many variables. Performance data for seven methods of remediation have been incorporated into an interactive computer program (AMDSelect) that evaluates the characteristics of an abandoned mine site and ranks each of the selected methods of remediation for that specific site on a scale of zero to one. The criteria used by AMDSelect's decision-making process are flow, dissolved oxygen, pH, acidity, alkalinity, land area available, hydraulic head, $Fe^{2+}$ and $Fe^{3+}$ concentrations, Al concentration, and Mn concentration. With a further function of the program, the user is able to receive an approximate cost for the project based on the prices of various commodities and equipment. AMDSelect has been applied to several abandoned mine sites in Appalachia and Great Britain to compare the model results to the actual efficacy of remediation. AMDSelect could be the door into a simpler more accessible remediation process.

**INTRODUCTION**
Pyrite in exposed strata weathers in a process of four main reactions that produce acidity and sulphates. Pyrite is first oxidized by oxygen. The first step in the process is shown in Equation (1).

*(1)* $$FeS_{2(s)} + 3.5O_{2(g)} + H_2O \rightarrow Fe^{2+}_{(aq)} + 2SO^{2-}_{4(aq)} + 2H^{+}_{(aq)}$$

In the presence of oxygen, the ferrous iron is then oxidized to ferric iron. This reaction is shown in Equation (2), this process is slow and is catalyzed bacterially (Singer and Stumm 1970). This is generally seen as the rate limiting step (Singer and Stumm 1970).Although this process consumes acidity, in Equation (1), two moles of acidity are produced during the production of one mole of ferrous iron, while Equation (2) consumes only one mole of acidity per mole of ferrous iron.

*(2)* $$Fe^{2+}_{(aq)} + 0.25O_{2(g)} + H^{+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + 0.5H_2O$$

The ferric iron produced in Equation (2) reacts in two different reactions through Equation (3) and Equation (4). The progress of Equation (3) will depend on the solubility of iron hydroxides and oxy-hydroxides.

*(3)* $$Fe^{3+}_{(aq)} + 3H_2O \rightarrow Fe^{3+}(OH)_{3(s)} + 3H^{+}_{(aq)}$$

The remaining ferric iron further oxidizes pyrite. This reaction proceeds much faster than Equation (1) and therefore is the major producer of both acidity and sulfate.

*(4)* $$FeS_{2(s)} + 14Fe^{3+}_{(aq)} + 8H_2O \rightarrow 15Fe^{2+}_{(aq)} + 2SO^{2-}_{4(aq)} + 16H^{+}_{(aq)}$$

The ferrous iron produced in this reaction is later reoxidized to ferric iron and drives the forward reactions in Equations (3) and (4).

The reactions, as written, imply that iron, sulphate, and acidity are simultaneously released into the aqueous phase. However, water is often not abundant enough to transport these and other weathering products away from the mineral surface as they form, so they accumulate in situ as highly soluble compounds on the pyrite surface. These have been termed 'acid generating salts'. Once the water level rises, due to cessation of dewatering, storm events or seasonal water table fluctuations, these salts are dissolved and transported away from the mineral surface. This often leads to a sudden flush of highly toxic water (e.g. Younger and Sapsford 2004).

**Treatment of Acid Mine Drainage**
Each type of remediation incorporates different chemical and biological processes, which ameliorate, mine water quality; consequently, many factors must be taken into consideration when choosing a remediation method. Each acid mine drainage site is different; therefore, different remediation methods or combinations of methods are

effective in cleaning them up. This is a complex problem with complex solutions. This study asks if there is an optimal way to choose a remediation method that would be effective for the given site.

The strengths and weaknesses of remediation methods are well documented. By compiling this information into productive flow charts, the selection process can by simplified. With each method's limits for aspects such as flow, metal content, head drop, dissolved oxygen, pH, and acidity/alkalinity, a specific cleanup site can compare the characteristics of their site to these limits and select an appropriate remediation method. This could create a more efficient way of selecting techniques of remediation on a site-by-site basis.

Active treatment of mine water has been estimated to cost the mining industry in the United States over a million dollars a day (Skousen and Ziemkiewicz 1996), so finding a lower cost, lower maintenance alternative was economically attractive. Many studies have shown that natural attenuation processes, including chemical and biological reactions and dilution, improve mine water quality. This is the basis for passive treatment. Acidity is neutralized in passive systems through mixing with waters that already contain alkalinity, release of alkalinity through the dissolution of minerals, and generation of alkalinity by anaerobic fermentation of organic matter. This effort has resulted in the development of low operating and capital cost, non-hazardous, low maintenance systems (Younger et al. 2002).

***Aerobic Wetlands (Reed Beds)***

Aerobic wetlands consist of large ponds hosting dense stands of reeds, through which mine water moves by surface flow. In the wetland cell, oxidation reactions take place to promote the precipitation and settling of reactive metals. Since these oxidation reactions reduce the pH of the water and create acidity, aerobic wetlands are most effective for net alkaline waters. This makes this method of remediation unique; very few methods specifically reclaim net alkaline water. Since the water already contains sufficient alkalinity, metals will precipitate given sufficient residence time. The wetland size should be adequate for this residence time—a general guideline is 20 grams of iron removal per square meter of wetland per day (20 gmd) and 0.5 grams of manganese removal per square meter of wetland per day (0.5 gmd). Wetland plants will aid in physical filtration and may uptake a significant amount of metals once concentrations are at 'polishing' concentrations of around 1 mg/L or less (Batty and Younger 2002). Since oxygen may be limiting, aerobic conditions should also be maintained with shallow flow, constructed waterfalls, or rip-rap ditches (Skousen et al. 1996).

***Compost Wetlands***

Compost (or "anaerobic) wetlands are constructed with a submerged substrate generally of spent mushroom compost or horse manure compost with water flowing horizontally through and above the substrate. The compost usually contains about ten percent calcium carbonate. These systems rely on diffusion of alkalinity from the substrate to the flowing water. Sizing of anaerobic wetlands is based on a guideline of 5 grams of iron removal per meter squared per day (Skousen et al. 1996).

***Open Limestone Channel (OLC)***

An open limestone channel is an open, free-flowing channel lined with coarse limestone gravel. Limestone armouring is the biggest setback when using an open limestone channel to remediate AMD, because the channel is open to atmospheric oxygen, driving armour-producing reactions to proceed. Armoured limestone is said to be one-fifth as effective as unarmoured limestone (Ziemkiewicz et al. 1996). Some suggest that armouring may be reduced with turbulence or high flow in the channel, although this has not been effective in practice. Suggested residence time for the most effective remediation is from one to three hours.

***Diversion Well***

A diversion well is a simple way of adding alkalinity to net acidic waters while largely preventing limestone armouring. A large amount of head drop is required for this system to work. Water is diverted from the stream into a pipe, and then flushed with high flow through high quality, crushed limestone, in which it causes fluidized bed conditions. The water then moves upward through the diversion well and is returned to the stream through an outflow pipe (dep.state.pa.us).

To ensure that the water keeps the limestone fluidized and continues through the well, flow should be between 6.2 and 255 litres per second; the ideal flow is about 25.5 L/s. Also to ensure enough hydraulic power to keep the diversion well functioning, the site should have at least eight feet of hydraulic head (ten to twelve feet is ideal). This can be artificially created by constructing a dam leading into the diversion well. This method of remediation is meant for net acidic waters and is most efficient if the pH is above 4 (Stoertz 1999).

***Anoxic Limestone Drain (ALD)***

Anoxic limestone drains are buried trenches of limestone…designed simply to add alkalinity to the mine drainage, changing net acidic water to net alkaline water, raising pH values. After the water leaves the drain, settling ponds must be provided to allow oxidation and precipitation. This method separates the addition of alkalinity and the oxidation/precipitation processes, thus reducing potential armouring of the limestone. Aluminium floc will still form in the absence of oxygen and may limit the flow through the drain. Retention time in the limestone drain should be about fifteen hours (Baker 1999).

***Reducing and Alkalinity Producing Systems (RAPS) (a.k.a. Successive Alkalinity Producing Systems (SAPS))***
Reducing and alkalinity producing systems combine ALD technology with bacterial sulfate reduction mechanisms. These systems originally consisted of three layers from top to bottom: standing water (1-2 m), rich organic compost (0.5 m), and limestone (0.5-1 m), although a mixed substrate is now more commonly used. The flow through these cells of the RAPS is vertical and the water exits through a perforated pipe in the bottom layer. Oxygen and iron content are reduced in the compost layer of the system. These RAPS must be placed in succession with wetland cells for the oxidation of iron. Originally, it was though that many RAPS would need to be used in series (Kepler and McCleary 1994), but they are now generally used without succession. These systems are to be used in net acidic conditions and can accept more acid loading per unit area than anaerobic wetlands—SAPS can neutralize up to thirty to fifty $g/m^2day$; additionally, they typically are most effective with 2-3 metres of head drop (Watzlaf and Hyman 1995, Baker 1999).

***Instream Dosing***
Instream dosing is possibly the most simple method of acid mine drainage remediation. Generally with the use of a rotary drum (a machine that distributes a proper amount of limestone into a polluted stream), limestone or some other buffer (see introduction to AMD remediation) is added straight to the water to neutralize the acid, increase the pH, and cause oxidation and precipitation of metals. Like an open limestone channel, the reactions between limestone and iron are open to oxygen, so large amounts of limestone are needed to counteract the inefficiency of armoured limestone.

**STUDY AREAS**
The decision-making software developed in this study has been applied to adits and tailings piles in the Sunday, Monday, and Raccoon Creek Watersheds in south eastern Ohio (U.S.A.) and in Cornwall, Yorkshire, Durham, and Scotland in the United Kingdom. A few of these case studies are presented here.

**Model Description**

***Model Inputs***
A user interface (Figure 1) gives the user a chance to enter certain characteristics about their prospective cleanup site. These characteristics include flow, dissolved oxygen, lab pH, alkalinity, estimated land area for use in remediation, head drop, aluminum, ferrous iron, and ferric iron. Where possible, options of units have been given—the conversions are computed internally.
By clicking the “Submit Current Values” button, a new window (Figure 2) will come up giving rating of each of seven different remediation methods. These methods are aerobic wetland, compost wetland, anoxic limestone drain, diversion well, open limestone channel, RAPS, and instream dosing. In this second window, each of these methods is given a rating on a scale of zero to one. This rating is generated by giving a site a rating on the same scale for each limitation of each method of remediation. These ratings are then multiplied together to give a final rating for each method. This process of generating the scores will not give a site a non-zero score if one of the characteristics does not match at all and will give a perfect one to a site where all of the characteristics match exactly. If a method has conditions that would be ideal, but still others that would still allow the method to be effective, just less so, the ideal conditions receive a one, and the functional conditions receive a score on a linear scale decreasing as they deviate from the ideal, until at last they are out of range and receive a zero.
After receiving the ratings for each method, the user has a chance to receive a more detailed report of the ratings. This report shows the ratings for each characteristic and the ideal conditions for a method; it is retrieved by clicking the “Details…” button next to the method’s score.

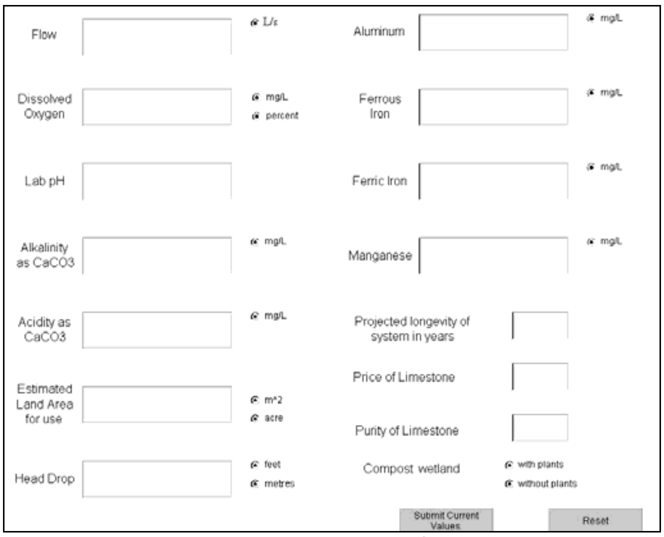

**Figure 1: User Interface**

***Model Results***

AMDSelect produces projected efficacy ratings for each of the included remediation methods on a scale of zero to one. The ratings are calculated by comparing the ideal conditions for a remediation method to the actual site value for each included variable. Many methods merely have a cut-off value where the system will no longer be effective, while others have a so called “grey area” in which effectiveness is limited, but not significantly reduced. If the site characteristics meet the ideal conditions, that characteristic is given a score of one, if it doesn’t meet the effective conditions; the characteristic is given a score of zero, and if the site value is in the “grey area,” a linear regression is used to determine a score between one and zero. To develop the total score, the product of the individual characteristic scores for a remediation method is taken, giving a value between zero and one—one being effective and zero being ineffective.

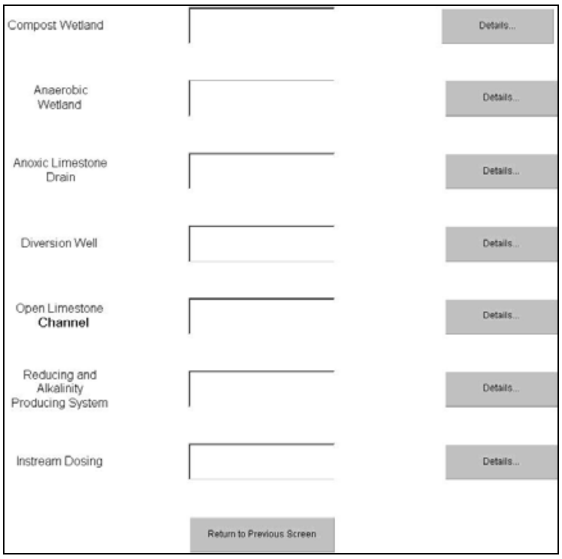


**Figure 2: Results Page**

A further level of the program may then be reached in which a preliminary cost estimate per year and over the life of the project will be calculated for each method earning a score above 0.5.

**Decision-Making Modules**

***Aerobic Wetland***

First, the existence of at least one of the variables needed is checked; if they are all blank, instead of a rating, AMDSelect returns “Not Applicable.” The variables used by AMDSelect to decide the effectiveness of an aerobic wetland are alkalinity, acidity, pH, flow, ferric and ferrous iron, manganese, and land area available.

Various decisions go into deciding the effectiveness of an aerobic wetland. AMDSelect begins by checking whether the water is net alkaline or net acid—net alkaline returns a rating of one and net acid returns a rating of zero. AMDSelect then checks the pH value—to receive a one, the value must be above 5.5; a zero is given below 4; and between 4 and 5.5, ratings are assigned on a linear scale from zero to one. Then, using iron, manganese and acidity loading values, the minimum size for the wetland is calculated and this number is compared to the amount of land the user indicated was available. Ferric iron loading per area is then calculated; a value below ten g/m$^2$/day will be assigned a rating of one, a value above twenty g/m$^2$/day will be assigned a zero, and all the values between the two will be assigned ratings based on a linear scale between one and zero. Finally, ferrous iron concentration below 70 mg/l will be assigned a one and a concentration above 70 mg/l will be assigned a zero. A price estimate will be provided based on the amount of land need for the wetland based on acid, iron, and magnesium loadings. The accepted value for a excavation and some soil for an aerobic wetland is \$54 per square metre (\$6.00 per square foot) of wetland area (Skousen 2001).

***Compost Wetland***

AMDSelect begins by verifying that at least one of the values needed is present. These include acidity, alkalinity, pH, flow, ferric iron, dissolved oxygen, aluminium, and land area. If one is missing, a value of “Not Applicable” is returned.

The water must be net acidic and have an acidity load per area of less than 3.5 g/m$^2$/day to receive a rating of one. If water has an acidity load per area of greater than 7 g/m$^2$/day or is net alkaline, it receives a zero. Water with an acid load per area between 3.5 g/m$^2$/day and 7 g/m$^2$/day is assigned a rating scaled between zero and one linearly. Dissolved oxygen above 2 mg/L receives a one, below 1 mg/L receives a zero and between the two is scaled. To receive a rating of one, the pH must be above 3. If land area is larger than a computed minimum wetland size, then it receives a zero. Finally, both ferric iron and aluminium concentrations must be above 1 mg/L for a rating of one. The price estimate for this method is determined with Skousen’s figure (2001) that an anaerobic wetland without plants will cost $54 per square metre ($6 per square foot) and one with plants will cost $162 per square metre ($18 per square foot).

***Anoxic Limestone Drain (ALD)***

AMDSelect begins by verifying that at least one of the variable that affects the effectiveness of an ALD has been entered; if they haven't, AMDSelect returns "Not Applicable" in lieu of a numerical rating. Acidity, alkalinity, dissolved oxygen, pH, flow, ferric iron and land area are evaluated.

After this, AMDSelect evaluates alkalinity and acidity—to receive a rating of one, the water must be net acid and the acid concentration must be below 300 mg/L. Dissolved oxygen is the next value checked; a zero is given for a value above two mg/L, a one is given to a value below one mg/L, and ratings on a linear scale are given for values between one and two. For a rating of one, the flow must be below 0.014 L/s, a zero is given to flow above 0.07 L/s, and ratings between zero and one are assigned linearly to the values between. Ideal pH (a rating of one) for the use of an ALD is between 4 and 5; all other values are assigned a zero. Ferric iron and aluminium concentrations are both rated in the same fashion; a rating of one is assigned if the values are below 1 mg/l, a zero is assigned for values above 25 mg/L, and the values between them are given ratings between one and zero. A price estimate will be provided for limestone, excavation, liners, pipes, etc, based on tons of limestone needed. 455 tonnes of limestone are needed for each litre of water per second. The price of an ALD is about $45 per tonne of limestone needed (Skousen 2001).

***Diversion Well***

The existence of at least one of the variables needed for evaluation of effectiveness is checked. These variables are acidity, alkalinity, pH, flow and hydraulic head drop. Otherwise, a value of "Not Applicable" is revealed.

The first rating is given depending on alkalinity/acidity. To receive a one, the water must be net acidic. Flow between .2 L/s and 255 L/s receives a one, otherwise a zero is awarded. pH above 4 is given a one; otherwise, a zero is assigned. Finally, if hydraulic head drop is above 3.1 metres, a one is awarded, a zero is given for head drop below 2.4 metres, and results are on a linear scale between one and zero for all values between 2.4 and 3.1. A price estimate is based on $10,000 for initial site preparation plus enough limestone to reduce the acid load based on acid concentration and flow and $1000 a year of parts and maintenance (Stoertz 1999).

***Open Limestone Channel (OLC)***

AMDSelect begins by assuring at least one of the following variables is entered: acidity, alkalinity, dissolved oxygen, ferric iron, and aluminium. Otherwise, a value of "Not Applicable" is returned.

To receive a one, the water must be net acid and the acidity must be below 80 mg/L. Since the system attenuate metals through iron armouring and aluminium floc, oxygen, iron and aluminium concentrations above one mg/L are given a one and ones below receive a zero. The price estimate is based on the amount of limestone needed to neutralize the acid load based on flow and acid concentration.

***Reducing and Alkalinity Producing Systems (a.k.a. Successive Alkalinity Producing Systems (SAPS))***

AMDSelect begins by assuring that at least one of the following variables is present: acidity, alkalinity, pH, flow, ferric iron, dissolved oxygen, manganese concentration, and land area. Otherwise, a value of "Not Applicable" is returned.

The first rating will be a one if the water is net acid and the acid load per area is less than 30 g/m$^2$/day, a zero if either the water is net alkaline or if the water has an acid load per area of more than 50 g/m$^2$/day; if the acid load per area is between 30 g/m$^2$/day and 50 g/m$^2$/day the rating is based on a linear scale from one to zero. Since oxygen is easily removed from the system, oxygen is a one above 2 mg/L and zero below 1 mg/L, between these the rating is scaled linearly from one to zero. Both ferric iron and manganese concentrations receive a one if they are above 1 mg/L and a zero if they are below. The price estimate is based on Skousen's estimate (2001) that a SAPS system will cost about $165 per square metre ($15 per square foot).

***Instream Dosing***

AMDSelect begins by verifying that at least one of the following values has been entered: acidity, alkalinity, flow, and ferrous iron concentration. Otherwise, a value of "Not Applicable" is returned.

A one is given to water that is net acid; otherwise, a zero is given. Flow above 114 L/s receive a rating of one, below that, it receives a rating of zero. Ferrous iron concentration below 50 mg/L receive a rating of one, above 100 mg/L receive a rating of zero, and ratings for values between the two are scaled between zero and one. A price estimate is based on limestone needed to neutralize the acid present plus yearly maintenance and miscellaneous costs, as well as about $5,000 of site preparation.

**RESULTS**

AMDSelect has been applied to several test sites in both the Appalachian Coalfields in the United States and the Durham and North Yorkshire Coalfields and Cornwall metal mining district of England. Three case studies are presented here in which the sites in question have been successfully remediated—Essex Mine Discharge and Majestic Mine Adit in the Monday Creek Watershed in Southeastern Ohio and Morrison Busty Spoil Heap in County Durham. These provide valuable insight into the practical application of AMDSelect to potential cleanup programs.

Tables 1, 2, and 3 show the water chemistry values for the three sites. AMDSelect has been applied to each of these sites and the theoretically most effective system(s) for each of the three sites is included in these tables. The similarity between the results given by AMDSelect and the decisions made by experienced environmental engineers shows the effectiveness of the decision-making software.
This software is currently in use in the Monday, Sunday, and Raccoon Creek Watersheds of Ohio and may soon be adopted by watershed groups in West Virginia and Western Maryland. It is expanding chances for grassroots organizations to choose a remediation system that will be both effective and economically viable.

| | | |
|---|---|---|
| Flow | 1.5 | L/s |
| pH | 6.06 | |
| D.O. | 10 | mg/L |
| Alkalinity | 51.8 | mg/L as CaCO3 |
| Acidity | 49.2 | mg/L as CaCO4 |
| Land Area | 500 | square metres |
| Head | 1 | metres |
| Total Fe | 5.35 | mg/L |
| Al | 5.32 | mg/L |
| Mn | 3.78 | mg/L |
| Suggested System | | Anaerobic Wetland |
| Actual System | | Anaerobic Wetland |

**Table 1. Site Data for Morrison Busty Spoil Heap Effluent**

| | | |
|---|---|---|
| Flow | 0.059 | L/s |
| pH | 5 | |
| D.O. | 6.9 | mg/L |
| Alkalinity | 0 | mg/L as CaCO3 |
| Acidity | 51.3 | mg/L as CaCO4 |
| Land Area | 15000 | square metres |
| Head | 1 | metres |
| Fe(II) | 0.14 | mg/L |
| Fe(III) | 21.21 | mg/L |
| Al | 1.33 | mg/L |
| Mn | 2.1 | mg/L |
| Suggested System | | RAPS |
| Actual System | | RAPS |

**Table 2. Site Data for Majestic Mine Adit**

| | | |
|---|---|---|
| Flow | 12.7 | L/s |
| pH | 4.97 | |
| D.O. | 7.1 | mg/L |
| Alkalinity | 0 | mg/L as CaCO3 |
| Acidity | 85.5 | mg/L as CaCO4 |
| Land Area | 500 | square metres |
| Head | 10 | metres |
| Fe(II) | 1.13 | mg/L |
| Fe(III) | 16.3 | mg/L |
| Al | 5.63 | mg/L |
| Mn | 2.6 | mg/L |
| Suggested System | | Diversion Well or RAPS |
| Actual System | | Diversion Well |

**Table 3. Site Data for Essex Mine Opening**

## CONCLUSIONS

Since it is based on the available data concerning effectiveness of various acid mine drainage remediation methods, the AMDSelect decision-making system is as accurate as the information it is based on. As technology evolves, so must the decision-making methods; therefore, the limits used in this software version will likely change over time and AMDSelect is set up to allow for simple changes in the constraints. The model results have also been generally consistent with decisions made based on engineers' experience, giving a certain level of confidence to the results given by AMDSelect.

## REFERENCES

Baker, M. J. 1999. Parameter Limitations of Mitigation Technologies. Michael Baker Jr., Inc.

Batty, L. C., and P. L. Younger. 2002. Critical role of macrophytes in achieving low iron concentrations in mine water treatment wetlands. Environmental Science & Technology **36**:3997-4002.

Kepler, D. A., and E. C. McCleary. 1994. Successive alkalinity-producing systems (SAPS) for the treatment of acidic mine drainage. Pages 195-204 *in* International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA.

Singer, P. C., and W. Stumm. 1970. Acid Mine Drainage: The Rate-Determining Step. Science **167**:1121-1123.

Skousen, J. G. 2001. Treatment Estimates for Truetown. Pages E-mail *in* N. A. Kruse, editor., Morgantown, West Virginia.

Skousen, J. G., A. Sexstone, K. Garbutt, and J. Sencindiver. 1996. Wetlands for Treating Acid Mine Drainage. *in* J. G. Skousen and P. F. Ziemkiewicz, editors. Acid Mine Drainage Control and Treatment. West Virginia University, Morgantown, West Virginia.

Skousen, J. G., and P. F. Ziemkiewicz. 1996. Acid Mine Drainage Control and Treatment, Second edition. West Virginia University, Morgantown, West Virginia.

Stoertz, M. W. 1999. Specifications for Diversion Well (Essex Mine). Ohio University, Athens, Ohio.

Watzlaf, G. R., and D. M. Hyman. 1995. Limitaitons of Passive Systems for the Treatment of Mine Drainage. U.S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, Pennsylvania.

Younger, P. L., S. Banwart, and R. S. Hedin. 2002. Mine Water: Hydrology, Pollution, Remediation. Kluwer Academic Publishers, London.

Younger, P. L., and D. J. Sapsford. 2004. Evaluating the potential impact of opencast coal mining on water quality (Groundwater Regulations 1998): An assessment framework for Scotland. Scottish Environmental Protection Agency.

Ziemkiewicz, P. F., J. G. Skousen, and R. Lovett. 1996. Open Limestone Channels for Treating Acid Mine Drainage: A New Look at an Old Idea. *in* J. G. Skousen and P. F. Ziemkiewicz, editors. Acid Mine Drainage Control and Treatment. West Virginia University, Morgantown, West Virginia.