III. ABATEMENT CRITERIA DEVELOPMENT

METHODOLOGY

Approach and Water Quality Criteria: An abatement plan was derived from an analysis of the average water quality of the various stream reaches within the Raccoon Creek study area. If the water quality data indicated AND pollution within a particular stream reach, then an investigation, utilizing field reconnaissance and office engineering data gathered during the course of the study, was performed to identify the contributing factors of the pollution. Once the pollution causes were isolated, a proposed abatement plan was analyzed and developed to fulfill two criteria:

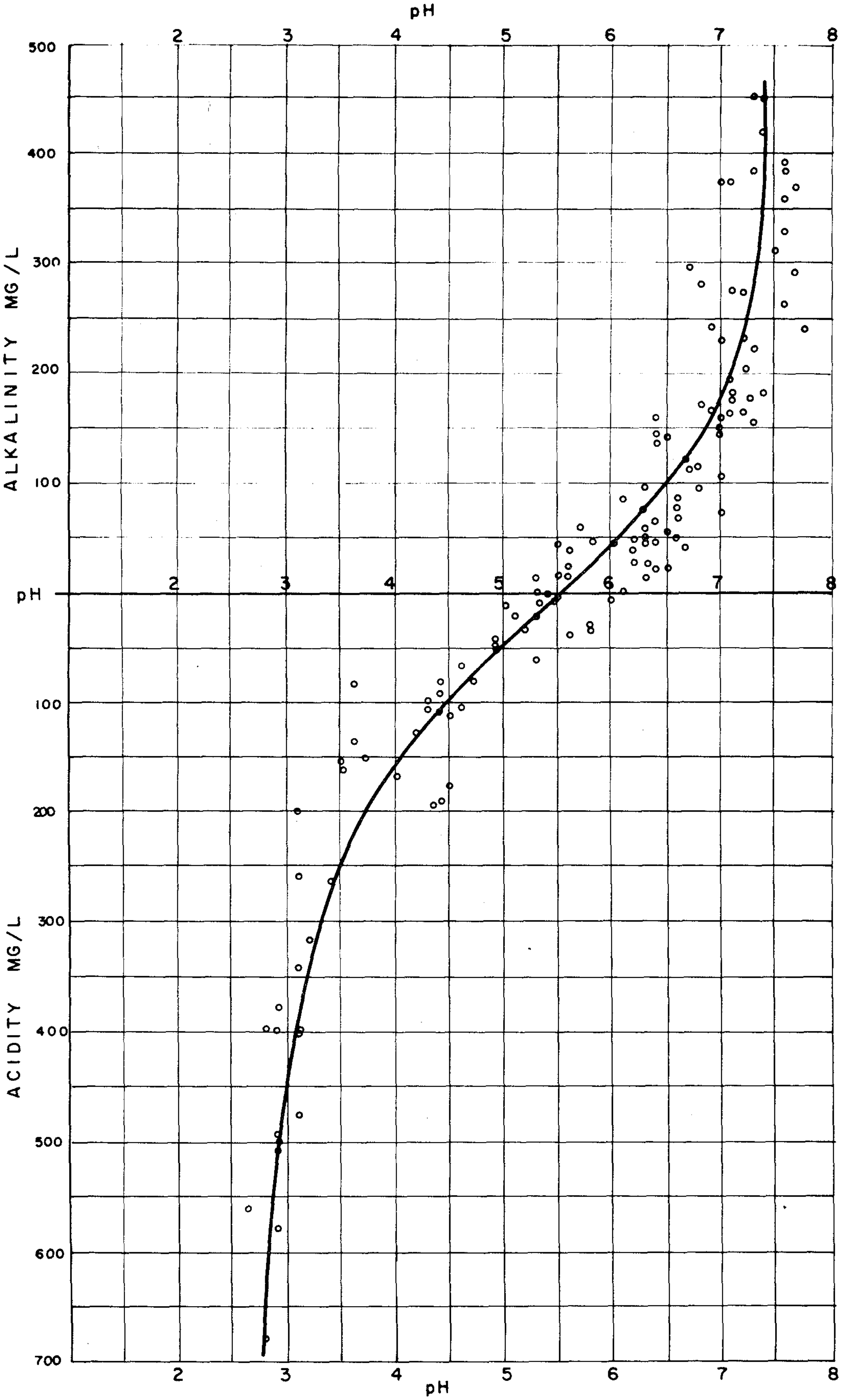
> The abatement plan should improve the stream quality to the minimum clean streams standards set by the Commonwealth of Pennsylvania for pH, acidity and alkalinity.
>
> The abatement plan should consider technically practical methods most economical to achieve the objectives of the desired standards.

The water quality criteria for Raccoon Creek, according to Chapter 23, under Title 25, Rules and Regulations, Department of Environmental Resources as amended is as follows:

pH:	Not less than 6.0 and not more than 8.5
Alkalinity:	Not less than 20 mg/l
Total Iron:	Not more than 1.5 mg/l
Sulfate:	Not more than 250 mg/l or natural levels, whichever is greater

Water Quality Parameters: The results of the analysis of stream samples obtained from the Raccoon Creek study area were tabulated, plotted and studied. On the basis of this study the average acidity and alkalinity concentrations were selected as the main design parameters to meet these clean streams standards because they were analyzed on all samples and because they provide stochiometrically equivalent values. Stochiometrically equivalent values for acidity and alkalinity means they can be numerically compared.

An effort was also made to empirically correlate the net alkalinity concentrations (alkalinity minus acidity) with the other water quality parameters of pH, total iron, and sulfates. The data used to obtain these correlations were from actual analysis results of stream samples obtained from the Raccoon Creek study area. When graphs were prepared plotting net alkalinity versus either pH, total iron, or sulfates, only the net alkalinity vs. p1-I graph yielded a smooth curve as shown on Plate No. 12. This result is theoretically predictable because pH is the concentration of the hydronium ion, whereas, acidity is the total ability of the sample to donate the hydronium ion; and alkalinity is the total ability to absorb the hydronium ion. Total iron and sulfate concentrations do not yield any similar correlation with pH either in theory or in the actual samples analyzed from Raccoon Creek. The coordinates depicting net alkalinity versus both iron and sulfates were too scattered to fulfill any meaningful correlation.



pH versus NET ALKALINITY/ACIDITY FOR SEVERAL SAMPLES FROM RACCOON CREEK & ITS TRIBUTARIES

Source Of Data : State Designated Testing Laboratory

Plate 12

Abatement Effects: Not only are acidity and alkalinity convenient parameters for predicting abatement effects in this study area because they provide a stochiometrically predictable relationship, but they also correlate well with pH. According to the graph of net alkalinity concentration versus pH shown on Plate No. 12, an abatement plan designed to yield an average net alkalinity concentration of about 50 mg/l should produce a corresponding improvement in pH to about 6.0. Moreoever, no similar correlation between net alkalinity with either iron or sulfates can be predicted. Thus, the recommended abatement plans are designed to yield a net alkalinity concentration in the receiving streams of at least 50 mg/l. This method should, on the average, fulfill the water quality criteria of pH greater than 6.0 and net alkalinity greater than 20 mg/l. However, no prediction of the resultant iron and sulfate concentrations can be made except the assumption that ferric iron should decrease somewhat due to its lower solubility as the pH is raised.

The fundamental assumption of the abatement plan is that one pound of alkalinity will neutralize one pound of acidity. The theory of this hypothesis is derived from, "Standard Methods for the Examination of Water and Waste Water," 13th Edition, 1971, Section 201. See the Technical Appendix for further discussion.

Recommended Plan: The basis of the abatement plan was to ascertain which stream reaches of the study area were polluted by AAA) as defined by an average net alkalinity of less than 50 mg/l. An abatement plan was then developed for monitoring stations located within these polluted streams to improve the water quality so that an average net alkalinity of 50 mg/l could be fulfilled.
If more than one abatement plan was developed to improve the water quality to the desired criteria, then the most efficient of the two plans was chosen. The recommended plan was also dependent upon the ratio of cost to pounds per day of reduced acid load.

PRIORITY PLAN DEVELOPMENT

Pollution Index: A pollution index to reflect the severity of stream degradation was devised based upon the characteristics of a particular stream reach. This pollution index was developed to consider the acid load entering a stream, the miles of stream affected by the acid loads and the frequency of AM pollution. The pollution indexes are tabulated on Table 3.

Stream Reach: The first step in calculating the pollution index was to delineate the Raccoon Creek study area into stream reaches defined by stream monitoring stations (numbers denoted by prefix SR-). The definition of a stream reach for the main stem of Raccoon Creek and any of its tributaries with more than one stream monitoring station is a length of stream lying between two consecutive stream monitoring stations with the pollution index assigned to the stream monitoring station farthest downstream. Thus, every stream reach that could be defined by a downstream monitoring station was given a pollution index.

Acid Load: The amount of pollution entering a stream reach was defined by the total calculated average net acid load of all AMD sources which entered that stream reach.

TABLE 3

POLLUTION INDEXES

Rank	Monitoring Station	Average Net Acid Load (lbs/day)	Distance From SR-67 (miles)	Ratio of Samples With pH Less Than 6.0	Pollution Index
1	SR-21	14,570	12.6	13/13	183.6
2	SR-34	9,410	6.6	11/11	62.1
3	SR-12	3,590	13.8	13/13	49.5
4	SR-54	2,880	6.5	13/13	18.7
5	SR-8	4,220	15.1	3/13	14.7
6	SR-28	1,100	12.6	12/13	12.8
7	SR-16	2,400	13.2	5/13	12.2
8	SR-42	900	10.7	11/12	8.8
9	SR-13	500	14.6	13/13	7.3
10	SR-65	1,140	6.1	13/13	7.0
11	SR-27	490	12.8	13/13	6.3
12	SR-15	500	13.4	12/13	6.2
13	SR-26	450	13.5	11/13	5.1
14	SR-55	870	5.8	13/13	5.0
15	SR-45	600	9.8	11/13	5.0
16	SR-14	370	13.6	11/12	4.6
17	SR-66	1,020	3.5	12/12	3.6
18	SR-33	340	10.5	9/13	2.5
19	SR-51	410	4.9	13/13	2.0
20	SR-57	455	4.8	11/12	2.0
21	SR-36*	210	9.7	12/13	1.9
22	SR-20	590	8.6	4/12	1.7
23	SR-17	140	11.7	11/13	1.4
24	SR-19	120	9.8	13/13	1.2
25	SR-43	120	10.8	9/12	1.0
26	SR-58	200	4.5	9/13	0.6
27	SR-49	130	4.9	11/12	0.6
28	SR-41	70	11.3	2/12	0.1
29	SR-56	140	5.2	2/12	0.1
30	SR-47	20	9.5	8/13	0.1
31	SR-48	60	5.8	2/13	0.1
32	SR-30	70	11.3	0/13	0
33	SR-52	10	4.2	0/13	0

*Average net acid load for SR-36 was derived from SL 130-1, Preliminary Report

Affected Miles: To assess the miles of polluted stream resulting from AMD discharges is virtually impossible due to the difficulty in calculating background flows and concentrations from natural and undetected sources. To approximate this figure, the miles downstream from each monitoring station to SR-67 were measured. SR-67 is the farthest downstream monitoring station of the Raccoon Creek study area. The basis for this consideration is that the farther upstream a discharge, the greater the potential downstream pollution. By incorporating the miles of stream from SR-67 to the monitoring station being assigned a pollution index, the pollution index will weigh in favor of the uppermost reaches, thus producing a greater benefit if the abatement plans are implemented in order of decreasing pollution indices.

Frequency of Pollution: The final parameter used in the evaluation of the pollution index formula was the frequency of pollution. Many streams are only polluted at certain times of the year (usually periods of low flow) and therefore, those streams having marginal pollution should rank lower on the abatement priority list than streams which are degraded by AMD all year. The frequency of pollution was arbitrarily defined as the ratio of samples with pH less than 6.0 to the number of samples analyzed.

Pollution Index EQUALS
Calculated Average Net Acid Load* Directly Entering A Stream Reach From AMD Discharges
TIMES
Distance In Stream Miles From SR-67 To The Monitoring Station Defining The Stream Reach
TIMES
Ratio of Samples With pH Less Than 6.0 To The Number Of Samples Analyzed
DIVIDED BY
1000

Example: The stream reach of the unnamed tributary of Little Raccoon Run at SR-26 receives 450 lbs/day of net acidity from AND discharges. Monitoring station SR-26 is 13.5 miles upstream of SR-67 and the pH value of samples from SR-26 was less than 6.0 for 11 out of 13 samples. The pollution index is then:

$$\frac{450 \times 13.5 \times (11/13)}{1000} = 5.1$$

*To calculate the average net acid load, multiply average flow by average net acidity concentration presented on the water quality data sheets by the appropriate conversion factor.

Priority Ranking: Thirty-one stream reaches out of 71 stream readings had a positive pollution index. However, some of these stream reaches were combined if the recommended abatement could be more efficiently applied to more than one stream reach. If the abatement plans for two stream reaches were combined to yield a more efficient plan, then the pollution indices were also combined to obtain the new pollution index. The final pollution indices were then ranked in descending order, from the highest to the lowest, and given a priority number beginning with l. This ranking forms the recommended sequence for proceeding with a comprehensive solution to the MID pollution in the Raccoon Creek study area.

ABATEMENT METHODS AND EVALUATION

Abatement Techniques: One or a combination of the following techniques were considered applicable for abatement of AND pollution in the polluted stream reaches within the Raccoon Creek Watershed study area:

Surface Reclamation

Deep Mine Sealing

Daylighting Fly Ash

Injection Treatment

Surface Reclamation: Surface reclamation is the general term defined as any combination of regrading, channelization, backfilling of subsidence areas and mine openings, eliminating ponding, minimizing stream infiltration into deep mines, strip mine spoils and coal refuse banks, and revegetation of the strip mine areas and coal refuse banks.

The purpose of surface reclamation is to reduce surface water infiltration feeding an AMD discharge and to augment surface runoff by the restoration of natural drainage characteristics. Since these improvements are dependent upon precipitation, soil and rock permeability, slope characteristics, and vegetation, the effects of surface reclamation were calculated by incorporating the inherent hydrologic and physical characteristics of Raccoon Creek. These factors were incorporated into two general formulas, which were developed to predict the results of most of the proposed surface reclamation projects. One formula was derived to predict the amount of reduced infiltration to a strip mine, deep mine or refuse pile source, while the other enables a prediction of the average restored or augmented runoff to a stream reach. The derivation of these two general formulas are discussed in the Technical Appendix. Limitations which must be considered where surface reclamation is recommended in this report are as follows:

Additional cost required to reduce sedimentation and erosion from the various abatement work areas.

Additional costs to rehabilitate existing stream channels or structures downstream of the work areas.

Ability of the Commonwealth to obtain property easements necessary to perform the abatement work.

Deep Mine Sealing : Deep mine sealing discussed in this report considers the construction of bulkhead seals and the installation of an impervious barrier along the outcrop between the seals, capable of preventing excessive seepage along the outcrop, thus, inundating the abandoned mine. Deep mine sealing is to improve the water quality of mine discharges at the updip side of the mine through the reduction of oxygen necessary for pyritic oxidation.

However, there are several limitations which must be considered where mine seals are recommended in this report:

> The available mine maps are often inaccurate, therefore, the actual location of mine workings must be estimated. The design of a mine sealing project requires the acquisition of an accurately surveyed mine map and/or test boring data.
>
> Actual mine conditions are unknown in reference to water levels, open voids and collapsed areas.
>
> Unknown weak areas may be present in the mine seal, grout curtain, or the existing coal outcrop and thus cause leakage.
>
> The mine pool will require lowering to permit construction of seals where the mine is completely flooded and is discharging by artesian flow.
>
> The effects of significantly raising the water table may provide problems to structure owners, land owners and mineral owners, as well as water supplies or aquifers.
>
> The hydrologic characteristics of mine areas is complex and varies from mine to mine, therefore, estimated hydrologic heads could be in error.

The predicted abatement results of a mine seal are assumed in this report to occur after the inflow and outflow of a mine have reached equilibrium. A hydrostatic seal, therefore, should reduce a downdip mine discharge temporarily, but once equilibrium is reached, the total outflow of the mine should be equal to the total inflow.

With this assumption, a mine seal will not reduce the flow, although eventually some or all of the outflow may occur in a different sub-watershed than the original deep mine discharges. The basis of all mine seals recommended throughout this report is to improve the net alkalinity concentration of the eventual outflow through inundation of the mine complex.

For the purpose of determining the effect of mine seal abatement plans, it was assumed that the net alkalinity of the outflow would be improved on the average by 70% over the original average concentration of the deep mine discharges. It has been reported in literature that the water in a totally inundated mine is alkaline. However, in partially flooded mines, there is either acid water or both acid and alkaline waters.

Daylighting: Daylighting as used in this report is generally defined as the technique whereby stripping of the overburden is initiated to remove the remaining coal reserves in abandoned deep mines. Daylighting is recommended wherever it is economically possible to reduce AMD discharges by eliminating or burying the majority of pyritic material associated with an abandoned deep mine. Daylighting essentially removes an area that is contributing surface infiltration to a deep mine. Moreover, daylighting with proper surface reclamation may restore unpolluted runoff, especially if the surface over the deep mine is a subsidence prone area. Since one or both of these improvements usually result from daylighting, the formulas noted in the Technical Appendix as developed for surface reclamation were used to predict the results of daylighting. The limitations considered for surface reclamation generally apply to areas which were considered for daylighting. The sale of the coal, mineral ownership, and land use will essentially determine the feasibility of a daylighting project.

Fly Ash Injection: Fly ash injection into a deep mine is a proven technique for reducing the risk of mine subsidence. This method of fly ash injection into a deep mine, in order to prevent extensive mine subsidence, is the same method referred to in this report and recommended as a mine drainage abatement technique. While there has been no literature indicating the results of utilizing fly ash for AMD abatement, fly ash injection provides some advantages over sealing and thus should be worthy of consideration. Some of the advantages of fly ash injection over deep mine sealing are:

The reduced risk of hydrostatic pressure against a bulkhead seal.

Reduction in risk of subsidence which eventually causes loss of surface water into a mine complex.

Fly ash is often highly alkaline.

The beneficial use of a solid waste material.

Limitations of the procedures as recommended are:

Siltation to the stream from mine drainage discharges carrying fly ash in suspension.

Close spacing of injection holes over large areas will require property easements and could result in some property damage claims.

The effects of a fly ash injection abatement plan were predicted to be the same as those of a properly installed mine seal, namely, no flow reduction after inflow-outflow equilibrium is achieved. A 70% improvement in the net alkalinity concentration of the effluent is reported in the literature for deep mine sealing, and thus is estimated for fly ash injection.

Treatment: Treatment as used in this report considers the construction of a specific type of plant along a stream reach and treatment of all water which flows past that point for the neutralization of acid mine drainage. Any recommended treatment facility is assumed to treat maximum flow entering the plant and to discharge an effluent meeting the minimum Pennsylvania Clean Streams criteria for pH, acidity and iron. The effect of treatment upon a downstream monitoring station assumed the average flow unchanged and the treated effluent to have a net alkalinity concentration of 50 mg/l.

The limitation that must be considered where treatment is recommended in this report are:

> The treatment of AMD is considered to be a temporary solution. Treatment does not correct the problem at the sources. Yearly expenditures of funds are required for operation and maintenance.

Evaluation: One or more, or a combination of the five abatement techniques were applied to each polluted stream reach and evaluated. The evaluation consisted of estimating the net flow and net alkalinity concentration following the abatement plan and substituting the new flow and concentration figures into the following formula:

$$C_s = (A (F_iC_i) + F_bC_b) / (F_i + F_b)$$

Where:

C_s = Resultant concentration at the stream monitorimg station.

F_i = Predicted flow resulting from the abatement plan.
C_i = Predicted net alkalinity resulting from the abatement plan.
F_b = Calculated average base flow at the stream monitoring station.
C_b = Calculated average base net alkalinity at the monitoring station.

Base flow and concentrations of net alkalinity were calculated from the available data obtained at the stream monitoring station during the sampling phase of the study. The results of the formula represent the flow and concentrations of all water entering a stream upstream of a stream monitoring station, including some upstream sources and tributaries which may not have been sampled.

If an initial abatement plan calculation predicted a net alkalinity concentration at the stream monitoring station (Cs) of less than 50 mg/l, then additional abatement measures were proposed until the value of C_s was at least 50 mg/l. The combination of the abatement plans which yielded at least 50 mg/l for Cs then became the recommended abatement plan for that particular stream reach.

In some cases an alternative combination of individual abatement plans would yield a greater concentration of net alkalinity than the first combination, but usually at a greater cost. When this occurred, the two or more combinations of abatement plans were estimated to be technically feasible to raise the net alkalinity to 50 mg/l, but the single plan which was eventually recommended was that plan with the lowest ratio of cost to pounds per day of reduced acid load.

Other abatement considerations were included with each priority plan where such work would reduce the acid load from a documented source within the particular stream reach even though such work is not required or is insufficient by itself to raise the net alkalinity of the stream reach to clean stream standards.

ESTIMATING THE COSTS OF ABATEMENT METHODS

The following cost ranges used in this report as listed below for the various abatement techniques were gathered from suppliers, contractors and state agencies during late 1974 and early 1975.

Surface Reclamation: The following range of costs were considered where surface reclamation was recommended.

Clearing and Grubbing:	$50.00 - $ 300.00/Acre
Channels With Intermittent Flow	
Earth Channel	$3.00 - $5.00/Lin. Ft.
Clay Lined Channels	$5.00 - $10.00/Lin.Ft.
Bentonite-Clay Lined Channels	$20.00 - $30.00/Lin.Ft.
Bituminous Flumes	$15.00 - $20.00/Lin.Ft.
Concrete Flumes	$30.00 - $50.00/Lin.Ft.
Channels Flowing Full	
Grouted Stream Channel	$50.00 - $200.00/Lin. Ft.
Concrete Lined Channel	$50.00 - $200.00/Lin. Ft.
Combination Clay-PVC Rock Lined Channel	Detailed Investigation Required
Diversion Ditches	$1.00/Lin. Ft.
Regrading	$ 1,000.00 - $5,000.00/Acre
Soil Treatment and Seeding	$ 350.00/Acre
Structures (Headwalls)	$2,000.00
Localized Subsidence Depressions	$ 500.00 - $5,000.00/Each
Pipes or Culverts	$ 50.00/Lin. Ft.
Riprap Slope Protection	$ 30.00/Lin. Ft.

Deep Mine Sealing: The estimated cost of mine sealing was based on utilizing the following unit prices:

Mobilization of Drill Rigs		$50.00/Rig
Mobilization of Grout Plant		$10,000
Drilling Relief Wells		$10.00/Lin. Ft
Drilling Bulkheads and Grouting		$5.00/Lin. Ft
Casing Relief Wells		$3.00/Lin. Ft.
Materials:	Concrete	$50.00/cu.yd.
	Gravel	$50.00/ton
	Cement	$1.65/cu. Ft.
	Fly Ash	$0.20/cu. Ft.
Pumping		$3.00/cu. Ft.

Daylighting: Daylighting costs were divided into two components, actual construction costs for the removal of overburden and sequential backfilling and the income from the sale of recoverable coal. Overburden handling is estimated at $0.60 to $0.80 per cu. yd., depending on the depth of overburden and rock characteristics and includes reclamation. Credit for the sale of recoverable coal is $18.00 per ton to offset overburden handling and reclamation costs. If the overburden handling and regrading costs were greater than an equivalent of $18.00 per ton of coal mined, the excess was the estimated cost to the Commonwealth. It may be of benefit for the Commonwealth to consider this work based on the possibility of recovering 3,000 tons of coal per acre (20% of 15,000 tons/acre Pittsburgh Coal seam including roof coals). With the current market value of coal averaging $25.00 per ton, the sale of recoverable coal could be used to offset the costs of the proposed abatement plan.

Fly Ash Injection: The cost of fly ash injection is based on current prices for drilling, pumping, and transportation of fly ash. A deep mine was assumed to contain 50% void space, which includes sections of main haulage ways, butt entries, and rooms which are uncollapsed. In the large void areas, the fly ash was estimated to be pumped dry, whereas in subsided areas, the fly ash was estimated to be pumped underground in a slurry. The prices used for estimating fly ash injection are:

Drilling	$ 5.00/Lin. Ft.
Casing	$ 3.00/Lin. Ft.
Injection of Dry Fly Ash	$ 5.00/Ton
Injection of Fly Ash Slurry	$15.00/Ton

Treatment: Cost ranges for treatment were determined from "Processes, Procedures and Methods to Control Pollution From Mining Activities," United States Environmental Protection Agency, 1973. Using this EPA data, which was obtained from several existing lime neutralization plants, graphs of capital and operating costs versus plant capacity were plotted. From these graphs estimated capital and operating costs were extrapolated for a lime neutralization facility having the capacity to effectively treat water of a given volume and acidity concentration.