SECTION IX

ABATEMENT METHODS

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To counteract the conditions described in Section VI a number of techniques are available which will either terminate these discharges or neutralize their effects.

Abatement methods might be arbitrarily grouped into two categories, those which terminate and those which treat. Abatement by termination is a preferred technique, once applied it need not be repeated. Abatement by treatment has the disadvantage of requiring continuous operation to maintain its ef fectiveness. The use of treatment rather than termination may be justified only when termination is impossible or its cost becomes so great as to exceed the capitalized cost of continuous treatment.

ABATEMENT BY TERMINATION

Abatement by termination is brought about by following one or both of these physical principles:

1. By eliminating all opportunities for contact between pyritic materials and oxygen or moisture, the chemical reactions which generate acid mine drainage are halted.
2. By eliminating all opportunities for the transport of mine acid from the reaction site, the discharge of acid mine drainage is halted.

The most effective methods of creating those conditions which will terminate acid mine drainage according to the above principles are flooding and surface sealing. To accomplish these aims, the following techniques are available:

1. Mine Sealing and Backfilling
2. Remedial Subsurface Grouting
3. Surface Treatment
   a. Regrading
   b. Impermeable Sealing
   c. Revegetation
   d. Burial

Each method and its applicability to the Loyalhanna Watershed are discussed in this section.

<u>MINE SEALING</u>

The most widely utilized and most direct approach to the elimination of a polluted discharge source is to apply a seal to the point of discharge. The sealing of mines has been employed with varying degrees of success. The function of the seal is either to retain water within the mine so as to stop the flow and eventually achieve complete flooding or to keep water out of a mine to prevent the transport of already formed acid. A variant on the usual dry seal is the wet seal. The wet seal is a seal with an air trap which allows water to flow into or out of a mine but attempts to exclude the flow of air.

The least difficult mine to seal is a mine that is still active but about to be abandoned. More difficult but still feasible is a dry and accessible abandoned mine. In either case sealing is accomplished by the construction of a set of dry wall retainers or bulkheads and the filling of the void between them with cement or grout. More sophisticated techniques have been developed to seal mines remotely through boreholes by pumping grout into the abandoned passageways. The most difficult mines to seal are those which are flooded or high flowing.

The Halliburton Company, a major subsurface construction contractor, has compiled for the Federal Water Pollution Control Administration a thorough state of the art review of mine sealing techniques now published in a report entitled "New Mine Sealing Techniques for Water Pollution Abatement".

The Halliburton report commenting upon field testing of various seals concludes in part;

1. A mine seal, composed of rear and front bulkheads of a quick setting slurry with expansive type cement filler between would be satisfactory to seal a mine drift to hold a required head of impounded mine water.

2. Based upon findings from field tests conducted to determine the feasibility of placing a mine seal in a high flow mine, it was concluded that a mine seal can be constructed in a high flow mine using techniques developed under this contract. (See definition of high flow next page).

3. Remedial grouting with cementitious material was unsuccessful on a previously placed aggregate seal. It was apparent that it is very

difficult to consolidate aggregate in place and obtain a satisfactory seal due to the necessity of containing the grout within the aggregate. Although many of the fluid channels were apparently closed during the remedial grouting, enough additional channels remained open to permit the flow to continue unabated.

4. The injection of jelled fluid into a previously sealed mine was not successful in reducing leakage.

The cost of the various sealing processes discussed in this report was in the range of $8,000 to $10,000 per seal. This price included materials and labor.[20]

The most promising aspect of this study appeared to be the successful sealing of a high flow mine. However, a review. of the specific project revealed that the seal was placed after diverting the flow from the site of the seal and also required access to the site. The flow diverted was later estimated to be in the range of 60 gallons per minute.[21] (Since the publication of the Halliburton Report other mines, flowing at rates as high as 200 gpm have been sealed). While not stated in the report, no mine flowing at a rate, of more than 30 gallons per minute has been sealed successfully by remote means. The difficulties encountered in remote sealing were site preparation and loss of grout due to continuous flow of water through the mines. There are potential techniques for the remote sealing of high flow mines currently in the research and, development stage, but they have not been successfully tested.[23] To our knowledge, no mines flowing at the rate of 2, 000 gpm have been successfully sealed by remote means.

A possible technique for accomplishing the sealing of a high flowing mine under unflooded conditions was the utilization of an inflatable rubber plug similar to that used to temporarily dewater large diameter sewers. However a discussion with a representative of a potential supplier of these plugs indicated that these plugs were limited to low head installations and had never been used in mines.

Applicability - Major Discharges

The sealing of the three major watershed discharges would require remote insertion of a seal into a flow of 2, 000 to 5, 000 gallons per minute, which is beyond the limits of existing remote sealing technology. To explore the shaft discharges at sites #5177 or #5364 prior to seal installation would require the dewatering of large areas of underground workings and continuous pumping to maintain a dewatered condition. If accurate mapping were available, it might be possible to intersect the drifts leading to these discharges from surface boreholes. However, accurate mapping is not readily available and exploratory boreholes would be necessary.

To seal discharge #5364, extensive sealing would be required because there is no shaft or drift but only a discharge pipe rising from the mines. It would be necessary to isolate the whole area of subsurface leakage.

The consequences of mine seals at these three points are uncertain. The immediate result would be the cessation of flow and the raising of the mine water level. The average flow into these mines is between 5 and 10 inches of water per year. If the overlying rock were 100% void space, the rise in water level would be limited to this less than one foot per year. However, the voids being only about 25% of the total rock volume, the rise in water level would be several times the annual seepage rate or about 3 feet per year.

If it were possible to achieve complete innundation of the mine workings in the Latrobe and Greensburg coal fields, the artesian leaks located at low points and along the valleys would be of extremely low acidity and could be. tolerated. However, it is questionable whether flows could be contained within the mines until complete flooding was achieved, or if the resulting creation of high hydrostatic pressure within the mines could be contained to make complete flooding of the upper mines possible.

One indication of the difficulties to be encountered in sealing mines of the Latrobe Syncline are the presence of associated upland discharges. These discharges flow in response to changes of the flood levels in the mine. Associated with Latrobe North major discharge #5177 (elevation 990) are discharges #5302 (elevation 1020±) and #6151 (elevation 1020±). These discharges are seasonal and occur under the conditions of elevated water tables. Most of these discharges are located at mine mouths but several have also been classified as refuse pile seeps. Associated with Latrobe South major discharge #5364 (elevation 990) is the swamp area near St. Vincent's Lake (discharges #5361 and #5362). The discharge at Crabtree (#5356 does not have any seeps associated with it, but discharge #5354 is a potential upland discharge.

If it were possible to seal discharge #5177, all other associated discharge points would also require sealing and the water level would have to rise to elevation 1207 in the Superior #2 mine to achieve innundation. This would subject the areas near Superior and Loyalhanna to Artesian heads of up to 200 feet. The resulting pressure may be sufficient to create new acid discharges in areas of weakened and fractured rock.

If discharge #5364 were sealed, it would be necessary to raise the water level to elevation 1200 to achieve innundation. This would also subject existing seepage points to an artesian head of 200 feet±.

In earlier sections it was noted that because of cave-ins and roof falls, water leaked from the Pittsburgh sandstone acquifer into the Pittsburgh seam mines. It is also equally possible for flow to move back into this formation where the sandstone is below the hydrostatic head elevation of the Pittsburgh coal seam. Acidic flow once in the Pittsburgh sandstone aquifer could follow the sandstone formation to a point of surface discharge. It is therefore felt that any attempt to achieve full innundation of the mines will not be successful as long as there is free passage of water between the

Pittsburgh coal and sandstone formations. The means and costs of eliminating this passage are discussed under the topic of Grouting.

While the nature of potential artesian discharges is not as well documented in the Greensburg coal area, it is felt that similar hydrologic conditions exist.

To summarize the applicability of seals to the three major discharges:

1. These discharges would be extremely difficult to seal, requiring extensive dewatering during the construction phase.

2. No discharges of these magnitudes have ever been sealed by remote means using existing technology.

3. For sealing to be effective, total innundation of all interconnected mines must be achieved or acid flow will resume at higher elevations.

4. It is doubtful if the artesian discharge heads developed by complete flooding could be contained by the fractured overburden at low points in the valleys. This is especially doubtful since at least one discharge (#5364) was installed precisely to relieve existing artesian discharges.

Applicability - Minor Discharges

In the upper level drift entries of the major coal fields and in the less extensively mined Freeport seam exist several sites suitable for conventional seals. In the Chestnut Ridge anticline mines of the Freeport formation, particularly in the vicinity of Miller Run, several discharging mines should be capable of sealing or resealing. Discharge #5073 is down-dip from the existing seal and could easily be maintained in a flooded condition. Discharges #5074 and #5075 will require seals to withstand 200 feet of head but the existing overburden may be sufficient. Other applications are discussed at the proposed placement sites.

GROUTING

A second method of artificially altering subsurface conditions to eliminate or reduce the flow of Acid Mine Drainage is through the use of grout as a. filler material. This is a method similar to sealing except that the scale of application is much greater.

Two methods of application were considered. One method would utilize an area grout in order to decrease the permeability of the aquifers above the coal seam so as to prevent the passage of flow into or out of the seam through the overlying sandstone. A second application would utilize a grout curtain to create or repair barrier pillars isolating potential discharges from their upland recharge sources.

A soil treatment contractor, specializing in subsurface grout applications was questioned as to the cost, feasibility, applicability and longevity of grout as a remedial method of AMD abatement. Based upon his reply the following grout application was investigated.[23]

Area Grouting

It would be possible, though unusual, to apply grout to a subsurface acquifer.

If it were done, a reconstructed permeability coefficient of 10^{-8} cm/sec could be achieved. A permeability coefficient of 10^{-8} cm/sec would have the following effect: If one square mile of sandstone were grouted to a depth of 5 feet and were subjected to an artesian head of 100 feet, flow through the acquifer would be reduced to 82 gallons per minute per square mile. This is based upon the following relationship –

$$Q = \frac{(K)(A)(h)(t)}{L} \quad \text{where} \quad \begin{aligned} K &= 10^{-8} \text{ cm/sec} = 0.328 \times 10^{-9} \text{ ft/sec} \\ A &= 1 \text{ mile}^2 = (5.28 \times 10^3)^2 \text{ ft.}^2 \\ h &= 100 \text{ or } 10^2 \text{ ft (hydrostatic head)} \\ L &= 5 \text{ ft. (thickness of formation)} \end{aligned}$$

$$Q - 0.328 \times 10^{-9} \text{ ft./sec.} \quad \times \frac{10^6 \times 5.28^2 \text{ ft.}^2 \times 10^2 \text{ ft.}^2 \times 1 \text{ sec.}}{5 \text{ ft.}}$$

$$Q = 0.183 \text{ ft}^3\text{/sec or 82 gallons/minute per square mile}$$

(This is equal to 1/25" of an inch per year)

This low rate of permeability would allow the complete innundation of the coal seam and achieve total flooding.

The cost of such a project was estimated based upon the contractor's suggested unit prices as $16 per square foot of surface area. This cost was calculated as follows:

Method of placement - Grout pipes 101 on center to a depth of 50' @ $5/l. f.

Number of grout pipes per square mile = $\frac{(5280)^2}{(10)}$ = 280,000 grout pipes

Length of pipe = 50’ total length - 14, 000, 000’

Total cost @ $5/linear foot = $70, 000, 000 per square mile

Cost of grout = $1.50 per gallon or $11.00 per ft.^{3}

Volume to be grouted = 5, 280 x 5, 280 x 5 ft.^{3} estimated take (voids) = 25%

Volume = 35, 000, 000 ft.^{3} = $370,000,000

Cost of Materials = $370, 000, 000

Total project cost per square mile $440, 000, 000

Cost per ft.^{2} $16.00

In the vicinity of discharge #5364 and St. Vincents Lake (at Latrobe) approximately 0.9 of a square mile of the Pittsburgh Coal seam is overlain by land with a surface elevation of 1000 or less. Assuming that localized grouting would contain the artesian discharges, an approximate remedial construction expenditure of $400, 000, 000 would be required to achieve sealing and subsequent flooding of the Latrobe South coal field.

Costs of a similar magnitude are associated with sealing and grouting at discharges #5177 and #5356.

Cut Off Wall Construction

To construct an underground barrier wall, a similar method of grout application could be utilized. In this case, three rows of grout pipes were recommended with pipes on five foot centers at a cost of $12, 000, 000 per mile of length. Pipes per mile of barrier = $3\frac{(5280)}{(5)}$ = 3500 pipes.

The construction of a transverse cut off wall would necessitate a deeper depth of application. A total of 3500 pipe lengths pipe lengths of 100' are assumed. Total length of pipe = 350,000'/mile of barrier. Cost/mile is $4, 750, 000 at $5.00 per lineal foot of pipe.

Cost of grout = $11.00 per cubic foot of take. Assume that a barrier would require 40 feet of height to seat completely grout = 5280' x 20' width x 40' height x 25% take = 1,050,000 $ft.^3$ of grout or $10,000,000 per mile.

Total cost per mile = $12, 000, 000

To attempt to isolate discharges #5177 or #5364 with associated -swamps would require about 2-1 /2 miles of barrier wall at a total cost of $30, 000, 000. This cost is substantially less than the cost of sub-surface sealing, and for areas as large as those under consideration, would be preferred. If an infinite life is assumed for each barrier, the annual cost of each installation at 6% annual interest cost is approximately $1, 800, 000. For this sum complete abatement would not be achieved, but the flow and strength would be substantially reduced. The equivalent annual cost of acquifer sealing would be approximately $24, 000, 000.

As applicable to the discharge points of major seams with a large number of unknown interconnections and roof falls, grouting is a relatively expensive method of abatement. If applied to mines with well located breaks and falls, selective grouting could be highly effective at a low cost.

Because of the high cost, unknown effectiveness, and availability of other methods at a lower annual cost, massive grouting is not recommended.

SURFACE TREATMENT

Surface treatment to prevent the formation and transport of acid mine drainage from refuse piles and other surface features consists of the application of one or more of the following engineering techniques.

1. Earth moving
2. Impervious Surface Sealing
3. Revegetation A wide choice of materials for backfilling or sealing and the several types of vegetation are available. The desired results to be obtained through the application of surface treatment measures are:

1. A reduction in acid generation through decreased oxygen contact with pyritic surfaces.
2. A reduction in acid flows through the diversion of runoff from acid generating surfaces.
3. A reduction in acid intensity by on-site neutralization through direct contact with alkaline materials.
4. A reduction in refuse pile erosion and the exposure of buried pyrites through the use of vegetative cover and regrading measures.
5. An improvement in refuse pile appearance as a byproduct of regrading and revegetation.

These measures can be applied in varying degrees and combinations as determined by the site of application.

The major surface related problems in the Loyalhanna watershed are generated by surface refuse (or gob) piles. These problems are:

1. Acid runoff from the major piles and
2. Discharges from mines flowing through associated refuse areas.

A third but minor problem is the acid pollution seepage from strip mine cuts.

Each of the four major refuse piles of the watershed cover 50 or more acres and are 50 or more feet in-height. They consist of between 2,000 and 4,000 acre feet or 3,000,000 to 6,000,000 cubic yards of potentially acid generating materials. The sequence of operations required for the reclamation of refuse piles is proposed as:

1. Regrading
2. Sealing
3. Planting

<u>Regrading</u>

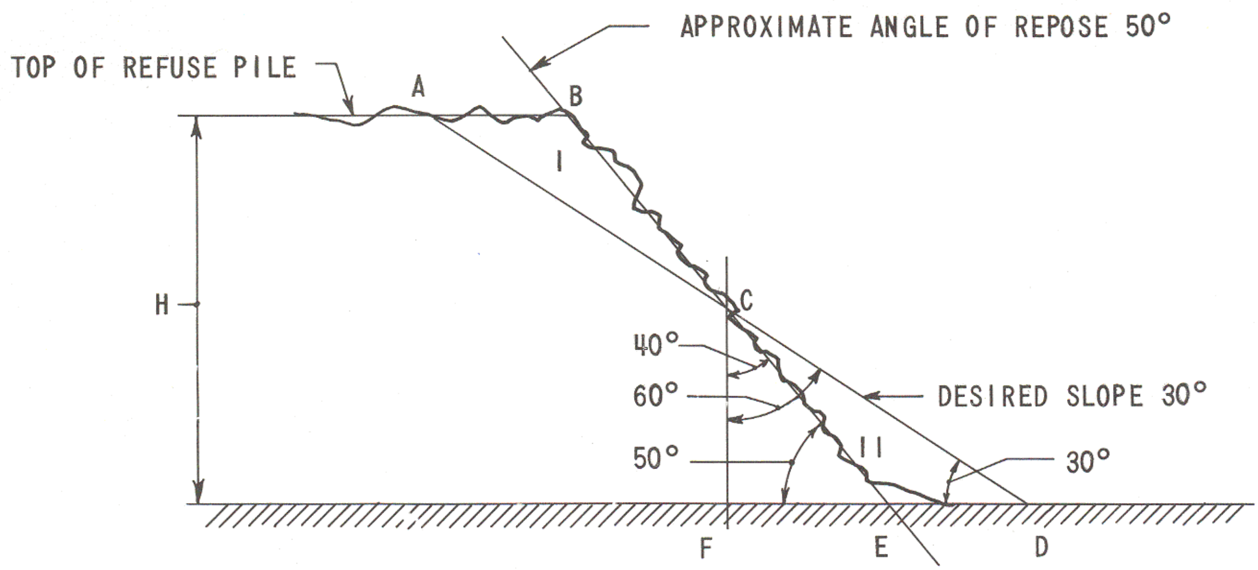
Regrading is necessary to:

1. Reduce the steepness of slopes to permit the operation of construction and agricultural equipment on the site and

2. To prevent the erosion of the surface treatment material.

The cost of regrading the perimeters of these refuse piles is estimated at 83 cents times the pile height squared per 100 linear feet. To regrade a 1,000

foot length of 40' slope would cost an estimated \$13, 200 or $\frac{1000}{100}$x40x40x83c.



The regrading of refuse pile slope BCE to a workable, non-erodable slope ACD consists of moving the material in cross sectional area I (ABC) to space II (DEC) at the toe of the slope.

When point C, common to both slopes is fixed at $\frac{1}{2}$ the refuse pile height, area I is equal to space II.

Space II is equal to $\frac{1}{2}$ (base) x (height) or $\frac{1}{2}$ (h/2) (DE).

DE is equal to FD-EF.

Since FD = CF (Tan. DCF) = CF (Tan.60°)
and EF = CF (Tan. ECF) = CF (Tan.40°)
then DE is equal to CF (Tan.60°) - Tan.40°) or .893 CF

Area II is equal to $\frac{1}{2}\left(\frac{h}{2}\right)$ .893 $\left(\frac{h}{2}\right)$ or $.11h^2$.

For 100' of slope, Volume I = $11h^2$ $feet^3$ or $.413h^2$ cu.yds.

At $2.00 per cu.yd. - altering slope BE will cost $.83 $(\text{height of pile in feet})^2$ per 100' of length.

DERIVATION OF SLOPE REGRADING COST	MINE DRAINAGE POLLUTION ABATEMENT MEASURES FOR THE LOYALHANNA WATERSHED	PLATE
BUCHART-HORN CONSULTING ENGINEERS & PLANNERS		IX-1

This cost was derived by the following method:

The typical angle of repose of unconsolidated gob has been observed to be as steep as 50° (or 1.2 to 1.0) however, these slopes are extremely unstable and unworkable. A more desirable slope for working purposes and erosion prevention is 30° (or approximately 1.0 to 3.0). The volume of material to be moved per 100' to reduce slopes from 50° to 30° is equal to: .415- $(\text{height in feet})^2$ cubic yards per 100' linear feet or,

$$V = 1/2 \times 100 \times \frac{(\text{height})^2}{2} \times (\tan 60^{\circ} - \tan 40^{\circ}) \text{ or } 50 \times \frac{h^2}{4} \times (.90)$$

or $11.25\ h^2$

(if h = 50 feet, $v = 28,125\ ft.^2 = 1,050\ yd.^3$)

if height is expressed in feet and V is in cubic yards

$$V = .415\ (h^2) \text{ per } 100'$$

At an estimated cost of \$2.00 per cubic yard for earthmoving with bulldozer or dragline (no haul) the cost per 100 lineal feet of 50° slope regraded to 30° slope is equal to: $\$.83 \times h^2$ (h is in feet).

The largest surface gob pile in the watershed is located at Hannastown. Average pile height is approximately 70' and pile perimeter is about 7,000'. To regrade the slopes to less than 1:3 would require the movement of approximately:

$\left(\frac{7,000}{100} \times 70^2 \times .415\right) yd.^3$ or $137,500\ yd.^3$ at an approximate cost of \$275,000.

Sealing

Sealing as a surface treatment is utilized to eliminate runoff from the pile mantles and curtail the flow of air into the piles. A group of potential sealing materials have been evaluated by the MSA Research Corp. of Evans City, Pa. in a report to the Commonwealth of Pennsylvania dated March 24, 1971. In this report the water retardant characteristics of these materials were evaluated. The materials were tested on-site and the materials used and the installed cost per square foot and per acre are given in the following table.

Material	Cost/ft.^{2}	Cost /acre
Urethane foam	23 c	$10,000.00
Polyethelene Film	10 c	4,356.00
Linseed Oil	15c	6,500.00
Fly Ash	5c	2,200.00
PVC Cocooning	19c	8,300.00

*materials at no cost., on-site labor only.[24] The performance of these materials as seals was evaluated in regard to the following criteria.

1 . Imperviousness

2. Elasticity

3. Resistance to weather and foot traffic

4. Ease of maintenance and repair

5. Degree of site preparation required

6. Initial cost

The test results indicated the following:

1. Polyurethane Foam, effective over the 15 month test period, unaffected by wind, less prone to rupture, will support foot traffic.
2. Fly Ash, wetted and compacted formed an effective water barrier, but eroded badly. Stabilization with sodium silicate or portland cement was also studied. Sodium silicate subject to cracks. Fly ash cement testing inconclusive.
3. PVC Cocooning, permeable to water and failed to resist weather conditions.
4. Linseed Oil , permeable to water.
5. Polyethylene Sheeting, effective but required an anchoring method consisting of wire mesh or soil cover.

Of those materials tested, polyurethane foam at $10, 000 per acre performed best under test conditions. However, in the accompanying literature review, several unfavorable characteristics of urethane foam systems which were not evident in the test plots were noted. These characteristics included:

1. Foams, while sufficiently elastic to resist small movements within the pile will crack when larger movements occur.
2. Urethanes will ignite on a burning gob pile.
3. Steam generated in a gob pile will cause foam deterioration.
4. Coating the side of a pile may involve more labor depending upon the angle of repose.[25]

It might be concluded that while urethane foam may be of use in the treatment of smaller refuse piles, its cost, limited flexibility and vulnerability to steam and fire make its application questionable in the surface treatment of major refuse piles.

Of the remaining surface coating materials, other defects were evident. Polyethelene film required a soil or wire mesh covering and care in jointing which also raised questions about its practicality for large surface area. Fly ash was considered suitable because of its low cost and impermeability but required protection from erosion. If, however, suitable protection from runoff could be provided, fly ash could be an ideal sealant.

Coincident with the MSA investigation of refuse pile covering materials, the Bureau of Mines was conducting an investigation into the "Reclamation of Acidic Coal Mine Spoil with Fly Ash. " The Bureau of Mine's investigation was not concerned with the use of fly ash as a surface coating but with its use as a means of raising the pH of acidic spoil piles to non-toxic levels and as a soil conditioner. The combined results of these two investigations suggest that fly ash might serve as a sealant and neutralizer for acidic gob piles and support its, own erosion resisting vegetative cover. Because fly ash consists predominantly of fines, the soil element usually missing in refuse piles, it has a potential use as a conditioner of refuse pile soil texture, adding density and alkalinity to the resulting soil. The texture of mine dump soil is generally classified as a sandy clay loam because of its high sand and low silt content. By the experimental addition of fly ash, the mine dump soil texture characteristics were altered to those of a silt loam. A silt loam is a denser soil with lesser permeability and greater water holding capacity. Evidence of the improvement of the microbiological environment was also noted.[26]

The Bureau of Mines study concluded:

> "The experiment demonstrated the feasibility of disposing of large quantities of fly ash on surface mine spoil to reclaim these areas . . . Certain species of grasses and legumes such as Kentucky 31, fescue orchard grass, rye grass, red top grass thrived on fly ash reclaimed spoil. "

The rate of application was 600 tons per acre (100 tons per acre = 1 acre inch of fly ash, 600 ton/acre = 6" of fly ash applied) which was mixed with the spoil to a depth of one foot. The test plots were also treated with 1000 lbs. per acre of 10/10/10 analysis fertilizer at the time of seeding. No indication of cost was given as this was a pilot scale application.

Related cost data was obtainable from the Appalachian Regional Commission Study of Acid Mine Drainage Control. The ARC study reported a cost of soil preparation from $8.00 to $15.00 per acre.[27] The cost of grass seed was reported as $6.00 to $12.00 per acre. MSA reports a cost of 5 c /ft.^{2} or $2,200 per acre when applying a two foot layer of fly ash. A 600 ton/acre application is equal to 6" of fly ash, therefore, the two foot application should be sufficient. The cost of transportation of fly ash to the site is not included.

The cost of fly ash, sealing, neutralization and vegetation is therefore estimated at $2, 250 per acre.

REFORESTATION

The Pennsylvania State University in Special Research Report #71 entitled "The Revegetation of Highly Acid Spoil Bank in the Bituminous Coal Region of Pennsylvania" investigated the survival of trees and shrubs in highly acidic spoil banks. They concluded in part; "…spoils with a pH even as low as 4.0 can be revegetated using various species which have shown some tolerance to acidity... The importance of high soil moisture must be emphasized. Apparently high moisture content has a dilution and leaching effect on acidity".[28] If high soil moisture content is critical, the use of fly ash as soil conditioner which raises the soil moisture content, would have a beneficial effect on tree growth.

The species observed with the greatest survival potential were red pine and European white birch.[29] The Pa. Dept. of Mines and Mineral Industries has compiled a list of the tree species to be used on spoils with a pH of below 3.5. This list includes European Adler, Red Pine, Pitch Pine, Scotch Pine, Austrian Pine and Birches. The cost of tree planting is reported as 4c per seedling and 3c labor. Normally 900-1200 trees are planted per acre. Cost $70/acre.[30]

STRIP MINE RECLAMATION

As previously noted, the presence of unreclaimed strip mine

pits may affect the water quality of the watershed by two mechanisms.

1. The production of acid in the exposed pyritic materials.
2. The entry of flow into the coal seam through strip pits.

As previously noted, because of the age and relatively small scale of the strip openings in the watershed, no strip mine spoil banks have been identified as major surface acid load contributors.

A review of the subsurface hydrology of the region has indicated that ground water percolation through faults and roof falls above the Pittsburgh coal seam is the predominant, recharge source feeding the major discharges. The direct contribution of the strip mined areas to acidity or flow is believed to be minor.

The desired objective of decreasing exposure to the ambient atmosphere of pyritic materials and the restoration of natural drainage is best accomplished by reburying the pyritic material in the strip cut and covering with non-reactive material until a drainage pattern away from the highwall is re-established.

The typical strip mine cut occuring at the outcrop of the Pittsburgh seam slopes downward towards the highwall. The seam is sloping at the point towards the axis of the syncline. The overburden is rising towards the synclinal axis and stripping was practiced until the highwall reached a height of about 30' to 40'. The cost of regrading those abandoned strip mines is estimated at 25c times the width of the strip, squared per 100 lineal feet. This cost was determined as follows:

The average slope of the coal seam is about 1:20 down from the outcrop. The average slope of the undisturbed overburden is 4:20 upward from the outcrop. The increase in highwall height as excavation proceeds from the outcrop line into the hillside is 5:20 or 1 foot of highwall per 4 feet of excavation up the hillside. The height of 40' is reached 160' from the outcrop line which corresponds to the average width of strip mine pit. To re-establish drainage without returning to the original contour, a surface slope of 1:50 is desirable. To achieve a 1:50 slope against a drop of 2.5:50, a cross sectional area of fill of $(w) \times \frac{(w)}{2} \frac{(3\text{-}1/2)}{(50)}$ or

$0.035w^2$, (w = width of pit in feet). is required. The required Volume per 100' is equal to $3.5w^2$ cubic feet or $0.013w^2$ cubic yards. At \$2.00 per cubic yard, the cost of regrading to minimum slope is equal to $\$0.25w^2$

If the cut width is equal to 150'. cost per 100 lineal feet of strip mine regrading is equal to \$560.00.

The Appalachian Regional Commission also estimates the cost per acre of strip mine reclamation as follows.[32]

For a 10 acre site, ARC's estimated cost is $45 per foot of highwall per acre. A site 100 feet long, 150 feet wide with a 40 foot highwall would cost:

40 x $45 or $1,800 acre,

The cost per 100' = $\frac{15,000}{43,560}$ x $1, 800 = $620.00

Cost of minimal rehabilitation = $600 per 100'.

This cost does not include soil conditioning or revegetation. However, Pittsburgh seam strip mine spoil banks have a relatively high pH and may not require extensive soil conditioning.

SEALING OF DRIFT MINES IN STRIP PITS

The collapse of high wall overburden has obscured the presence of drifts intercepted by the strip excavation. If these openings are encountered during backfilling operations, they should be sealed to reduce direct inflow into acid producing areas.

SUMMARY OF ABATEMENT METHOD INVESTIGATION

Abatement by termination may be successfully applied when the acidity generating reaction sites are susceptible to abatement caused by the exclusion of air. This is generally accomplished by flooding. If the formation of acid cannot be halted, the acid products will continue to accumulate in a soluble form awaiting the presence of sufficient moisture to remove them. In such situations, temporary abatement may be achieved by sealing, but the beneficial effects achieved by this form of abatement are endangered by the potential release of a pool of accumulated contaminants any time in the future.

In the case of the three major subsurface discharges, #5177, #5356 and #5364, the unlikelihood of obtaining complete flooding or complete dewatering to prevent the movement of acidic materials has been established. In lieu of termination, treatment will be proposed.

The surface sources of acidic drainage appear to be more amenable to abatement and appropriate termination measures will be recommended.

ACID MINE DRAINAGE TREATMENT METHODS

The disadvantages of treating acid mine drainage are several. Treatment does not eliminate the conditions which are causing the generation of acidic flows. The beneficial effects of treatment cease when the treatment is discontinued or interrupted. The funds spent for treatment are non-recoverable. The decision to treat rather than abate commits the owner or operator to the continuous expenditure of future funds for salaries, maintenance, power and chemicals.

The sole advantage of treatment is that it can improve water quality when all abatement methods are impractical or unsuccessful. Treatment may be considered as a last resort to be utilized when the disadvantages of not treating the mine discharges outweigh the disadvantages of treatment.

Treatment methods may be divided in two groups reflecting the process used to improve water quality. One group of processes may be described as the neutralization - reaction type, while the other group may be described as the removal type. The basic difference between method types is that one permits stabilizing reactions to operate on the unstable substances under controlled conditions while the other removes the unstable matter by physical- chemical means.

The environmentally harmful characteristics of acid mine drainage are caused by its chemically unstable nature. Acid drainage as all other substances, seeks neutralization and complete oxidation as an end product. Mine drainage is acidic and incompletely oxidized. Its ability to react with any available source of alkalinity with which it comes in contact, resuits in the disruption of aquatic life and human discomfort. The accompanying tendency for instream oxidation of ferrous iron to take place with the resulting formation and deposition of insoluble ferric iron precipitates is a second disruption of aquatic equilibria. An oxidation- neutralization treatment process supplies the necessary alkalinity and oxygen and allows the insoluble precipitates to settle out under controlled conditions. The resulting effluent is normally unreactable. A removal process however, removes rather than stabilizes the unstable reactants and produces a purified rather than unreactant effluent.

Neutralization and removal processes and their associated costs are

listed below.

Method	Cost/l,000 gallons
Neutralization -Oxidation	\$0.19 to \$0.28
Reverse Osmosis	\$0.19 to \$0.50
Ion Exchange	\$0.61 to \$2.53
Electrodialysis	\$0.58 to \$2.52
Evaporation (Distillation)	\$0.35 to \$3.00[33]

The processes noted above and others referred to are discussed fully in Appendix B, "Economic Study of Mine Drainage Control Techniques" of the Appalachian Regional Commission Report of Acid Mine Drainage in Appalachia.

The extreme range of costs per 1,000 gallons treated by a purification process is due to the range of plant sizes and capacities. In purification process plants the cost per 1,000 gallons treated which increases as plant size decreases, is a reflection of the high capital costs. To illustrate the range of estimated costs for neutralization and purification plants, the capital cost for a plant sized to treat a flow similar to discharge #5356 is given. The flow characteristics of discharge #5356 are, rate of flow 5,000 gpm or 7.2 MGD, acidity is equal to 250 mg/L, iron (ferrous) is equal to 121 mg/L.

Capital costs and operating costs/l,000 gallons as derived from ARC study are:

	Capital Costs	Operating Cost/1000g
1. Distillation	$10,000,000	50c
2. Ion exchange	$ 7,000,000	75c
3. Electrodialysis	$ 6,500,000	70c
4. Reverse Osmosis	$ 7,000,000	35c
5. Lime Neutralization	$ 800,000	19c

The capital costs cited above are for estimating use only and do not reflect design refinements based upon detailed process design. However, as an order of magnitude comparison, the capital costs of purification methods, which produce a purified rather than deactivated effluent are about ten times greater than capital costs for neutralization. On a daily operating basis, even with the cost of reagents included, neutralization is still the most economical alternative. The operating costs above are calculated on a 365 day operational basis. If the plants were run only at those times during which acidity exceeded a predetermined level, less than 365 days operation could be expected. If the facility is not operated on a 365 day a year basis, the allocated ammortization and salary costs. for the facility per 1,000 gallons will increase while the cost of materials and energy will remain constant. In the Loyalhanna watershed where acid reduction is not required 365 days per year, the operating cost increase per gallon for parttime operations will reflect the capital cost of the facility. On this basis, even with the cost of alkali materials included, the operating cost per 1,000 gallons treated of a neutralization plant will compare even more favorably with purification plant cost per 1,000 gallons.

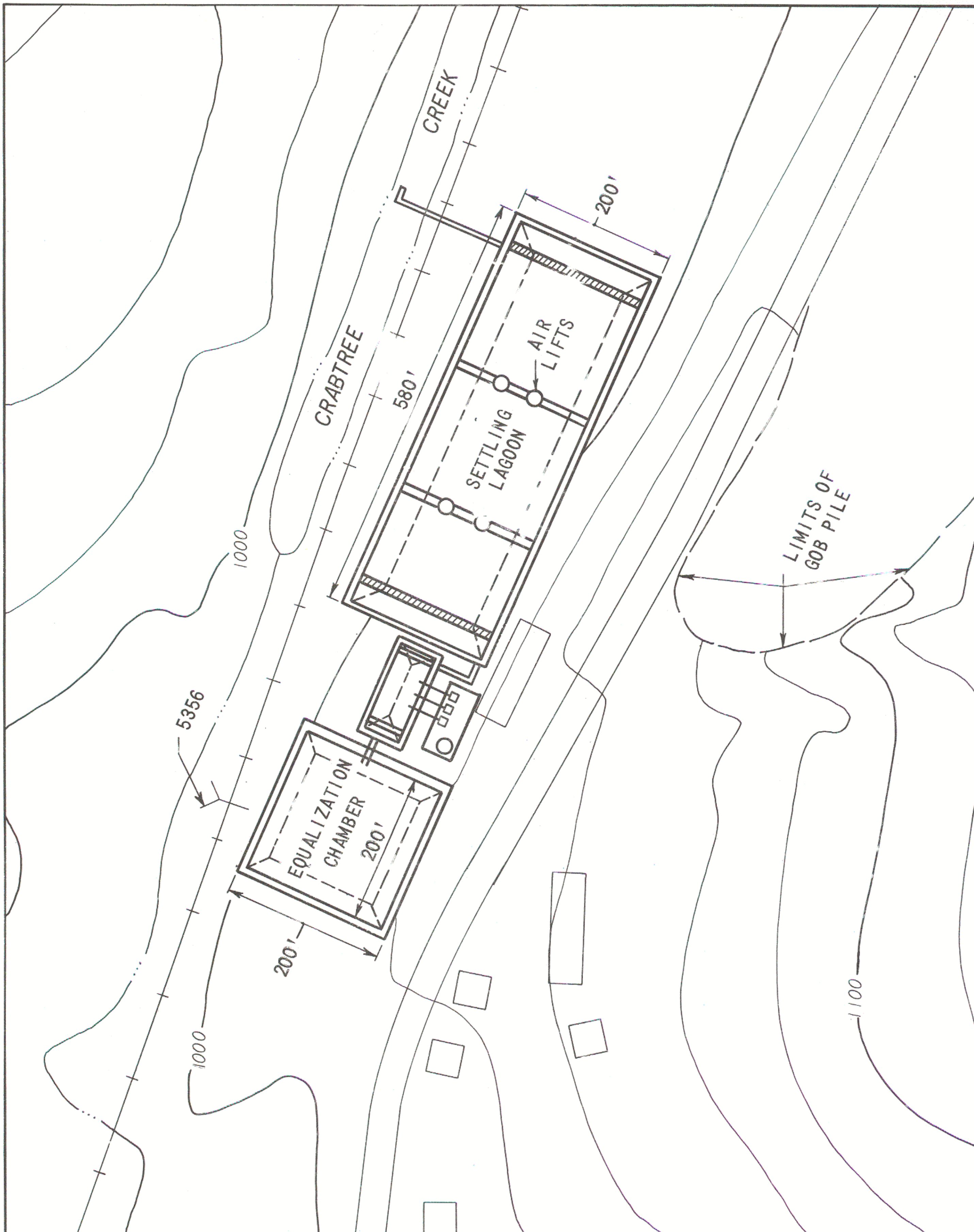
The disadvantage of an oxidation- neutralization type process is the carry over of a high dissolved solids concentration. However, the criteria for acid mine drainage pollution based upon water use indicates that high dissolved solids are most critical to consumptive water users only and that recreation uses are less sensitive to a high dissolved solids content.

NEUTRALIZATION PROCESSES

The most commonly employed neutralization- oxidation systems are the lime neutralization oxidation, limestone neutralization- oxidation and the combined lime- limestone neutralization methods.

The applicability of each method is dependent upon the state of the. iron present. Acid drainage with iron present in the ferrous state will require neutralization with oxidation to the ferric state with the resultant production of additional acidity. Drainage with iron previously oxidized to the ferric state will require only neutralization. The three major discharges of the Loyalhanna watershed contain iron almost exclusively in. the ferrous state and will require oxidation in addition to neutralization.

The applicability of a Limestone neutralization process to an acid discharge containing ferrous iron was commented upon by investigators at the University of West Virginia, "He who tries to treat large quantities of acid mine water containing high proportions of ferrous iron with a straight calcium carbonate (limestone) neutralizer is likely to be in for some real interesting and expensive experiences".[34]



PROTOTYPE OXIDATION NEUTRALIZATION PLANT	MINE DRAINAGE POLLUTION ABATEMENT MEASURES FOR THE LOYALHANNA WATERSHED	PLATE IX-2
BUCHART-HORN CONSULTING ENGINEERS & PLANNERS		

The interesting experiences alluded to concern the effects of ferrous iron on the calcium carbonate used as a source of alkalinity in the limestone neutralization process. About their experiences the authors comment, "it is not surprising that as free acid generated by the partial hydrolysis of ferrous iron is used by the $CaCO_3$ (limestone) to form lime, the pH rises above pH 7, stops the reaction of $CaCO_3$ to form lime. If lime instead of CaC03 is used then the pH will rise to around pH 10 and all the iron should be precipitated... The above chemistry also indicates that the ferrous chemistry also indicates that the ferrous iron must be oxidized to ferric iron with the formation of free acid before the calcium carbonate can react with it".[35]

The oxidation of all ferrous iron to ferric iron is a necessary step in the neutralization process. With limestone reagents, this step must precede neutralization and occur at pH 7 or less. With lime as the reagent, this step may occur after lime addition and occur at a pH above 7. 0. The effect of pH upon the rate of oxidation has been investigated and the following concluded: The rate of ferrous iron oxidation is strongly pH dependent...

From the rate equation we see that the rate of ferrous iron oxidation is first order dependent on the ferrous iron concentration and oxygen pressure, and directly proportional to the second power of the hydroxide ion concentration. Previous investigations and subsequent work confirm the first order kinetics for ferrous iron and oxygen concentrations, but find the second power dependence on hydroxide concentration to hold only for pH values above approximately 4.5. As the pH is decreased, the dependence on the power of the hydroxide ion concentration becomes less and at pH 3 it will be independent of it.

By the formula $1/2 \text{ time} = \frac{2}{\log K}$ we can calculate. the time required to oxidize 1/2 of the ferrous iron concentration...using the rate constants we will find that at pH 5, 6, 7 and 8 the half times become 150 minutes, 1/2 minutes, and 9 seconds respectively. ..these calculations are based on the assumption that the water remains saturated with respect to oxygen during the period of oxidation and that the pH remains the same."

To oxidize drainage containing 500 mg/l ferrous iron at pH 7 requires a detention time of 110 minutes To oxidize this same concentration of ferrous iron at pH 8. 0 requires only 1 minute, six seconds. In both cases, the end point ferrous concentration is 2 mg/l.[36]

In terms of process applicability, the high ferrous iron concentration of the mine drainage indicates the use of lime rather than limestone for neutralization in the Loyalhanna Watershed. The reagent costs of these two processes are about equal. The following table indicated the theoretical cost per ton of materials required to neutralize one ton Of H_2S0_4.[37]

Material	Cost/Ton/Material	Cost/Ton/H_2SO_4 Neutralized
Limestone		
Lump	$ 1.60	$ 1.64
Pulverized	$ 3.50	$ 3.57
Airfloated	$13.50	$13.77
Lime (Hydrated)	$19.25	$14.47
Soda Ash	$32.00	$34.97
Ammonia	$92.00	$31.94

While lump or pulverized limestone appear to be the least cost reagents on a theoretical basis, calcium carbonate tends to become coated with the insoluble products of the neutralization reaction and thus requires over neutralization. To compensate for this surface effect, a decrease in particle size to a 400 mesh size (0.037 mm. or 0.0014 inches in diameter) is necessary. This increases the equivalent cost to $13.77 per ton of H_2S0_4 neutralized.

While a final choice of neutralization methods should be based upon a detailed feasibility investigation of all alternative process, the use of the lime-aeration system appears best suited for the discharges of the Loyalhanna watershed. The lime aeration method shall be used as an estimating basis to determine the cost of- neutralization.

PROPOSED TREATMENT PROCESS

It is proposed that a lime neutralization- aeration process consisting of equalization, aeration-neutralization, and sedimentation stages be employed to treat effluents from major discharges #5356, #5364 and #5177.

Process Design Criteria:

1. Design Flow, 150% of average daily discharge.
2. Equalization Lagoon Capacity, 25% of daily average flow or 4 hours detention at peak flow.
3. Aeration- Neutralization Lagoon Detention, time, 20 minutes. Aeration rate (for mixing and suspension) 1 cubic foot of air per minute per square foot of surface area.
4. Settling Lagoon detention time 12 hours.

Process Description

Effluent from mine discharge enters equalization lagoon. After approximately four hours detention, effluent overflows into aeration lagoon. In the aeration lagoon, the mine discharge is mixed with a lime slurry and agitated by the action of a diffused air system. At the elevated pH, oxidation of ferrous iron to ferric iron is almost instantaneous. After 20 minutes detention, effluent is then dosed with a polyelectrolite and discharged to the Settling lagoon. Detention time in the settling lagoon is 12 hours to allow for the precipitation of ferric hydroxide under controlled conditions. Overflow is discharged to stream.

FACILITIES COST

The estimated construction cost for these facilities is as follows:

Discharge#	Average Flow Rate	Plant Construction Cost
#5364	2.86 MGD	$187,000
#5177	3.28 MGD	$192,000
#5356	7.34 MGD	$261,000

These estimated costs are substantially lower than costs reported for other neutralization facilities and represent a bare minimum construction cost. A number of economies such as the use of clay lined lagoons and minimal sludge handling facilities have been included in these designs.

The effects of capital cost on total annual cost for a neutralization plant is moderate. If a useful life of 20 years is anticipated for these facilities, the annual capital recovery charge for each facility is $16,000; $17,500 and $23,000. In contrast, operating costs (excluding capital recovery) are estimated to be between $80,000 and $105,000 annually. Therefore, the effect upon annual costs du to the upgrading of the neutralization facility construction methods and materials if desired, producing 400% construction cost increase, would be an 80% increase,

The final resolution of facilities cost vs. construction methods is beyond the scope of this initial survey.