FLOOD PREVENTION
IN ANTHRACITE MINES

ANTHRACITE REGION OF PENNSYLVANIA

Projects Nos. 4 and 5

By S. H. Ash, H. A. Dierks, D. O. Kennedy, and P. S. Miller
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Projects Nos. 4 and 5

By


Summary

This report covers the fourth and fifth in a series of five projects into which the proposed Conowingo tunnel system has been divided for geographical and practical reasons. It outlines the work constituting Projects Nos. 4 and 5, which consists principally of the following: (A) Project No. 4, to construct a drainage tunnel to connect drainage facilities proposed in Project No. 2 (Western Middle and Southern fields) with those proposed in Project No. 3 (Wyoming), which would integrate all the tunnels proposed in Projects Nos. 1, 2, and 3 into a single gravity-tunnel system. This tunnel would be 14 feet in diameter, circular, concrete lined, and have a gradient of 1 foot per mile. (B) Project No. 5, to construct a drainage tunnel connecting with the drainage tunnel proposed in Project No. 2 (Western Middle and Southern fields) and the Susquehanna River near tidewater at a point below the Conowingo Dam, Md. This tunnel would be 16 feet in diameter, circular, concrete lined, and capable of handling volumes over the normal discharge of all mines to be drained by the Conowingo tunnel system.

Permanent emergency pumping plants for the entire system have been provided for in Projects Nos. 2 and 3. No pumping plants are required for the gravity-flow tunnels proposed in Projects Nos. 4 and 5.

The report lists the estimated cost of the items comprising each project and provides time schedules for the construction periods of each project.

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INTRODUCTION

Three separate reports covering Projects Nos. 1, 2, and 3, respectively, of the series of five projects have been published by the Federal Bureau of Mines (22, 23, 25).

This report, the fourth of the series, covers Projects Nos. 4 and 5, which provide for tunnels connecting with Projects Nos. 1, 2, and 3 to create a continuous gravity-drainage tunnel. The complete undertaking, to be known as the Conowingo tunnel system, would provide facilities for collecting the mine waters from the three major anthracite fields of Pennsylvania and for their discharge by gravity to tidewater (14, 22, 23, 25).

A general discussion of the mine-water problem in the anthracite region of Pennsylvania and the impact of that problem, unless solved, on the economic and social structure of the region and of the nation is given in previously published reports (1–22). For this reason, economic analysis and discussion are omitted from this report.

SCOPE OF REPORTS

This report covers the following: (a) A brief description of the work proposed under Projects Nos. 4 and 5; (b) the topography, geology, and hydrology of the area into which the sections of the proposed tunnel are to be driven; (c) plans, costs, and construction schedules of the projects; and (d) conclusions and recommendations.

ACKNOWLEDGMENTS

Acknowledgment of indebtedness for aid in collecting data for this report is made to officials of anthracite-mining companies; the Pennsylvania Department of Mines; Pennsylvania Department of Forests and Waters; Geological Survey of the Pennsylvania Department of Internal Affairs; Anthracite Institute; and Herbert D. Kynor, Sr., consultant mining engineer, Bureau of Mines, Blairstown, N. J., who reviewed the manuscript, and Helen Bankovich, Bureau of Mines, Wilkes-Barre, Pa., who reviewed the manuscript and prepared it for publication.
Figure 1.—Extent and configuration of the anthracite region of Pennsylvania.
PROJECTS NOS. 4 AND 5

DESCRIPTION

The extent and general configuration of the four anthracite fields of Pennsylvania and their position relative to the eastern portion of Pennsylvania and the northeastern portion of Maryland are shown in figure 1. The position of the proposed Conowingo drainage tunnel is also shown in this figure.

Figure 2 shows the relative positions of the five separate sections, called projects, into which the proposed Conowingo tunnel system has been divided.

PROJECT NO. 4

Project No. 4 is in Schuylkill and Luzerne Counties; it provides for 19.5 miles of 14-foot, circular, concrete-lined tunnel on a gradient of 1 foot per mile. The southern end of Project No. 4 is 2.6 miles north of No. 11 shaft, which is near Mahanoy City (Project No. 2). Its northern end is 1.0 mile south of No. 15 shaft near Glen Lyon (Project No. 3). Project No. 4 will connect with Project No. 3 (Wyoming) and with Project No. 2 (Western Middle and Southern fields) (23, 25). The line of the tunnel proposed in Project No. 4 runs nearly due north and south and at right angles to the mountain ranges and valleys between them.

The proposed tunnel would pass under the coal basins forming the western end of the Eastern Middle field of the anthracite region. Because this field is approaching exhaustion, no provision has been made to tap existing water pools. The lowest point in the coal basins near the proposed tunnel is at an altitude approximately 1,000 feet higher than that of the proposed tunnel (14). The altitude of the southern end of the tunnel proposed in Project No. 4 is 99.5 feet and that of its northern end, 119.0 feet. No major stream crosses over the course of the proposed tunnel. Three construction shafts, numbered 12, 13, and 14, are provided to give access for tunnel construction. These shafts have been spaced approximately 7 miles apart and, wherever possible, at points having the lowest depths.

Figure 3 (pocket) shows the quantities of water to be handled by the section of the tunnel system in Project No. 4. The average flow conditions are shown.

PROJECT NO. 5

The discharge end of the Conowingo tunnel system is a part of Project No. 5. The portion of the tunnel in Project No. 5 is designed to handle the drainage (total volume) of mine water pumped or drained from the mines of the region. This section would consist of 70.96 miles of 16-foot, circular, concrete-lined tunnel having a gradient of 1 foot per mile. The line of the proposed tunnel runs almost due north and south. The northern end of the tunnel is 3.84 miles south of No. 9A shaft, near Middleport (Project No. 2), at an altitude of 86 feet, and its southern end (discharge) is near the confluence of Octoraro Creek and the Susquehanna River below the Conowingo Dam at an altitude of 15 feet.

The only major stream crossing the tunnel line is the Little Schuylkill River. The northern portion of the tunnel passes under several mountain ranges (Sharp Mountain, Blue Mountain, and Second Mountain). The middle and southern portions would lie under moderately rolling terrain of the rich Pennsylvania farmlands of southeastern Pennsylvania, in which the South Mountain and Pine Ridge are the only prominent mountain formations.

The political subdivisions traversed by the tunnel are Schuylkill, Berks, and Lancaster Counties. The extreme southern portion of the tunnel is in Cecil County, Md.

Ten construction shafts are planned for efficient and economical tunnel construction. The exact positions of these shafts must await the outcome of negotiations for easements and right-of-way and can be determined only when execution of the project is authorized. Suggested approximate positions and their designations from No. 1 shaft to No. 8A shaft are shown in figure 3, which also shows average quantities of mine water to be conveyed.

The mouth or portal of the tunnel could be near the junction of Octoraro Creek and the Susquehanna River. This area is about 0.75 mile downstream from the Conowingo Dam. At that point, U. S. Highway 222 passes over the creek by means of a concrete bridge. The mine water discharging from the portal of the tunnel is proposed to be conveyed in an open, concrete-lined canal far enough into the stream bed of the Susquehanna River to assure effective and rapid dilution and neutralization at all times. The design of facilities for this purpose is a job to be handled as part of the completed project.

DISPOSAL OF WATER FROM TUNNEL

Any plan for draining mine water into surface streams must take into consideration the problems of stream pollution. At present, nearly 75 percent of the water from the anthracite
Figure 2.—Line of Proposed Conowingo Tunnel.
mines is entering the Susquehanna River (4–6, 9, 12, 15, 17–20, 24). The acidity of this mine water is neutralized, and the soluble salts are carried along to the mouth of the river under present conditions (12, 15, 20, 26, 29, 32). The changes that will result if the mine water is collected and discharged at one point must be given careful study (29, 30, 32). The flow of the streams in the Susquehanna drainage basin fluctuates more violently than the pumping load in the mines. Under flood conditions, the flow in the Susquehanna River may increase several hundred times above the average flow, whereas during these same periods the mine pumping increases only to one and a half times the average load. Similarly, in dry seasons the flow in the Susquehanna River decreases to one-tenth of its average flow, whereas the mine pumping decreases only to two-thirds of the average pumping load (20, 26).

The confluence of the Lackawanna and Susquehanna Rivers at Pittston, Pa., presents a good example of the neutralizing effect of discharging a large volume of acid mine water into an alkaline stream and can serve as a guide in attempting to forecast the effect of conveying all the mine water by a drainage tunnel and discharging it into the Susquehanna River at one place (12, 15, 20, 29, 32).

The Lackawanna River flows through the Lackawanna Basin and receives the entire discharge of the mine pumps in this basin. Minimum, average, and maximum flow records of this river at Old Forge, just before it enters the Susquehanna River, for 1944 show it carries from two-thirds to 15 times the amount of water pumped from the mines in this basin. Samples taken in the Lackawanna River at the south end of the Lackawanna Basin show that this stream is usually acidic as a result of the inflow of mine water. This stream enters the Susquehanna River just above Pittston, and all samples taken in the Susquehanna River at or below Pittston show that the acidic inflow is neutralized even during the dry seasons under conditions of low stream flows (15, 18, 20, 24, 29, 32). The following table for 1944 shows the relationship between the flow in the two rivers and volume of mine water pumped in the Lackawanna Basin.

<table>
<thead>
<tr>
<th>River flows and mine water pumped, 1944</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Susquehanna River at Wilkes-Barre, second-feet</td>
</tr>
<tr>
<td>Minimum monthly flow: 1,150</td>
</tr>
<tr>
<td>Average monthly flow: 9,005</td>
</tr>
<tr>
<td>Maximum monthly flow: 81,200</td>
</tr>
</tbody>
</table>
This results in periods when no water is flowing in the river below the dam. During these periods mine water from a tunnel discharging below the dam would mix with the standing water in the river between Fort Deposit and Havre de Grace.

Studies of the salinity in the Chesapeake Bay indicate that the salinity of the bay at the mouth of the river is usually about 1 gram per liter and that the water standing in the river is virtually river water (31, 34, 35). This is supported by the fact that drinking water is taken out of the river at Fort Deposit and Havre de Grace, although some difficulty has been reported at Havre de Grace in periods of extremely low flow in the river above the dams. Even in such periods the amount of water standing in the river should still provide for complete neutralization of the acid mine water before entering the Chesapeake Bay. The fluctuations of the river between a low of 2,000 second-feet and a high of 875,000 second-feet dwarf the significance of the 180 second-feet additional water that might be added to the Chesapeake Bay by draining mine water into the Susquehanna River from all mines instead of from 75 percent of them, as is now done.

Studies made by Beaver and Engle show that flows of 100,000 to 875,000 second-feet, as are common under flood conditions, are the determining factors in limiting the location of oyster beds in the Chesapeake Bay because of variations in the salinity of the Upper Bay area (27, 28).

The conclusions drawn from preliminary studies of available data indicate that, although some problems may arise by changing the method of disposal of the mine water from the anthracite mines, they can be solved to everyone’s satisfaction by a thorough review by the U. S. Public Health Service and the Fish and Wildlife and Bureau of Reclamation services of the U. S. Department of Interior. The Susquehanna River at present does not always supply potable water for the communities below Conowingo Dam, and a better source of water for these communities should be considered in this connection.

GEOLOGIC STRUCTURE

The geologic structure of the region to be traversed by Project No. 4 is typically basin-and-range. The general strike of the folds near the line of the proposed tunnel is approximately 75° northeast.

The principal structures are the coal measures (post-Pottsville formations) of the western end of the Eastern Middle field where the proposed drainage tunnel will pass beneath the coal measures and the Berwick (Montour) anticline where the northern portion of Project No. 4 will penetrate this structure.

Figure 4 is a geologic map of the area along the line of the section of the Conowingo drainage tunnel proposed in Project No. 4. Figure 5 (pocket) is a longitudinal section along the line of the section of the Conowingo drainage tunnel proposed in Project No. 4, which shows the relative position of the drainage tunnel to the coal measures of the Eastern Middle field and the geologic formations to be penetrated by the tunnel.

The coal measures containing the anthracite beds occur in comparatively small parallel basins or troughs that are shallow, narrow, canoe-shaped, and complicated by minor flexures. The synclinal axes of these basins trend eastward and westward. The anthracite beds in this area are discontinuous because the crests of the anticlines of the coal measures have been eroded, and the broad areas that separate the basins are immediately underlain by the several members of the Pottsville conglomerate, which contain no anthracite.

The core of the Berwick anticline consists of the Chemung, Portage group, Hamilton, Marcellus shale, and Onondaga formations. The Chemung formation is stratigraphically the highest, and the rest follow in a descending order. The Catskill and overlying formations appear on the flanks of the anticline.

The line of the drainage tunnel proposed in Project No. 4 is nearly at right angles to the axes of the folds. It is anticipated that the tunnel would penetrate all the formations in the continuous area, except the post-Pottsville and Pottsville formations, which are not expected to be present at the altitude of the drainage tunnel, as can be seen in figure 5.

Beginning at the southern end of Project No. 4, the tunnel is expected to penetrate the Mauch Chunk formation almost exclusively for nearly 10 miles. From this point northward for the remaining 9.5 miles of its length, the tunnel is expected to penetrate, in sequence, the Pocono, Catskill, Chemung, associated formations, and the Catskill formation again at the extreme northern end of the project.

All the formations, with the exception of the Pocono and Onondaga, are composed chiefly of sandstones, siltstones, and shales. The Pocono sandstone formation is composed chiefly of hard sandstone with some conglomerate and quartzite locally. This formation is an impure limestone that generally is very thin, being only 10 to 15 feet thick locally. No large, water-filled solution cavities are expected to be encountered because of this formation. The Mauch Chunk red shale formation is known to have some soft shale strata among its component parts, but no serious difficulty from this cause is anticipated.
Figure 4.—Geologic Map of Area Along the Line of Section of the Conowingo Drainage Tunnel Proposed in Project No. 4.
in tunneling that cannot be dealt with by using steel or bolts for temporary roof support followed by permanent concrete lining.

The strata overlying the proposed drainage tunnel in Project No. 4 has a minimum thickness of 440 feet and a maximum thickness of 1,875 feet. Because of this, water in possible connected openings, such as in open faults, joints, and dipping bedding planes in the strata above the tunnel, can be under substantial hydrostatic pressures at the proposed tunnel horizon (16, 23).

To safeguard the drainage tunnel from possible failure if critical internal or external pressure, or both, should be exerted against the walls, the voids in a zone of rock immediately surrounding the concrete-lined bore should be filled to an adequate thickness with grout applied under pneumatic pressure greater than any hydrostatic pressure that might be exerted against the walls of the tunnel (16, 23).

Three diamond-drill holes, numbered 12, 13, and 14 and shown in figure 5, were drilled near the line of the drainage tunnel proposed in Project No. 4. The detailed logs of these holes have been published (16, 23).

Table 1 gives a condensed log of the foregoing boreholes as well as those near the line of the tunnel proposed in Project No. 5.

The geologic structure of the formations that would be penetrated by the tunnel proposed in Project No. 5 for the Conowingo tunnel system is complex and not definitely correlated.

Twenty-six boreholes were drilled to altitudes approximating those of the floor of the proposed tunnel to supplement existing geological data. Pertinent information concerning these boreholes has been published (16, 21). Of the 26 boreholes, 12 were drilled on the line of that portion of the Conowingo tunnel system that constitutes Project No. 5. The cores agree in a general way with the geologic structure indicated on the Geologic Map of Pennsylvania, published in 1931. A condensed log of these boreholes is in table 1.

Figure 6 (pocket) is a geologic map of the area along the line of the tunnel proposed in Project No. 5. This map has been adapted from the Geologic Map of Pennsylvania, published in 1931.

Figure 7 (pocket) shows the topography of the area along the line of the tunnel proposed in Project No. 5, indicated as far as they are known, as follows: (a) The position of the drainage tunnel relative to the surface and configuration; (b) the approximate location of construction shafts; and (c) the geologic formations to be penetrated by the tunnel.

In sequence, from north to south, the tunnel proposed in Project No. 5 will penetrate the Pocono, Catskill, Chemung, and Oriskany formations, which consist chiefly of sandstones but contain beds of red to brownish shale. These formations belong to the Lower and Middle Devonian age group and underlie conformably the Carboniferous formation of the southern anthracite field. They rise to the surface and dip from 30° to 60° along a line running parallel with the ridge of Blue Mountain, through which the Schuylkill River passes at Port Clinton (the Schuylkill Gap).

South of the outcrop of the Oriskany formation, the tunnel will enter the Helderberg, Cayuga, and Clinton formations, consisting chiefly of limestone, often shaly, and alternating with layers of shale and some thin beds of hematite. Large areas of Hudson River and Martinsburg shale formations occur farther to the south; these extend to the vicinity of a point due west of Reading where the proposed tunnel enters the Martic overthrust, which is crisscrossed by many faults running in various directions.

The formations in the Martic overthrust block belong chiefly to the Ordovician and Cambrian period and are overlain with layers of Gettysburg shale formations consisting of soft red shale and sandstones.

Continuing farther south, the proposed tunnel will pass through limestone and dolomite measures of the Beekmantown, Gatesburg, and Conocodleague series; these are followed by Leesport cement rock and Conestoga limestone formations.

South of Quarryville the tunnel will enter the Wissahickon formation, consisting in the northern section of albite chlorite schist and in the southern section of Peters Creek schists, which are characterized by chlorite and sericite schist and quartzite.

Near the outlet of the proposed tunnel some quartz and granitic gneiss and some serpentine and pyroxinite formations will be encountered.

The portal of the proposed Conowingo tunnel would be in Maryland. This section will pass through glacial drift material, consisting of sand, clay, and gravel overlying areas of gabbro and hornblende gneiss. Because the tunnel will penetrate chiefly sandstone, shale, limestone, and schist formations, no serious construction difficulties are anticipated.

The strata overlying the proposed drainage tunnel in Project No. 5 has a minimum thickness of 320 feet and a maximum thickness of 790 feet. Water in open faults, joints, bedding planes, or porous formations can be under considerable hydrostatic pressure at the proposed tunnel horizon. However, no water-filled solution cavities are expected as none of the boreholes encountered any artesian flows, except borehole No. 8, where an inflow of a few gallons per minute was observed.
### Table 1.—Data on test boreholes on line of proposed drainage tunnel in Projects Nos. 4 and 5

<table>
<thead>
<tr>
<th>Designation of boreholes</th>
<th>Approximate altitude, feet</th>
<th>Condensed lithology of strata penetrated</th>
<th>Interval, feet</th>
<th>Dip of strata, degrees</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Overburden—decomposed schist.</td>
<td>0 to 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schist and some quartzite.</td>
<td>42 to 391</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overburden—decomposed schist.</td>
<td>0 to 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schist, green muscovite, chlorite.</td>
<td>30 to 414</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>601</td>
<td>Overburden—decomposed schist.</td>
<td>0 to 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gray and brown schist—quartzite.</td>
<td>12 to 580</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>525</td>
<td>Overburden, sand and schist.</td>
<td>0 to 14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schist, limestone, and marble.</td>
<td>14 to 481</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>3B</td>
<td>828</td>
<td>Overburden, clay and schist.</td>
<td>0 to 53</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schist and pegmatite alternately.</td>
<td>53 to 790</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>360</td>
<td>Overburden—decomposed dolomite.</td>
<td>0 to 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limestone and dolomite.</td>
<td>0 to 306</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overburden, sand, clay, and gravel.</td>
<td>0 to 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limestone, dolomite, and quartzite.</td>
<td>15 to 531</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>372</td>
<td>Overburden—fractured limestone.</td>
<td>0 to 0.5</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overburden—weathered shale (red).</td>
<td>9.5 to 313</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shale, sandstone, siltstone, and conglomerate.</td>
<td>0 to 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>429</td>
<td>Overburden—decomposed shale.</td>
<td>30 to 370</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shale—black carbonaceous.</td>
<td>0 to 292</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overburden—yellow clay.</td>
<td>0 to 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gray sandstone and black shale.</td>
<td>20 to 405</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>329</td>
<td>Overburden—soil and pebbles.</td>
<td>0 to 14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black shale and gray quartzite.</td>
<td>14 to 411</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1,150</td>
<td>Overburden—boulders, gravel, and sand.</td>
<td>0 to 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sandstone, shale, and siltstone.</td>
<td>30 to 966</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>899</td>
<td>Overburden—clay and boulders.</td>
<td>0 to 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shale, sandstone, and quartzite.</td>
<td>9 to 702</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>600</td>
<td>Overburden—boulders in gravel.</td>
<td>0 to 54</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbonaceous shale.</td>
<td>54 to 397</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**TREATMENT OF MINE WATER**

Where only mine water is available for coal washeries, the water is often treated with soda ash, hydrated lime, or limestone to reduce corrosion of plant equipment. The expense of neutralization is justified by a saving in the replacement costs of plant equipment (15).

From information available, attempts to treat the entire drainage from the mine before
discharge into surface streams have not been successful because of difficulties encountered, and neutralization at the mine does not appear feasible.

Drainage from abandoned mines has been found to be just as acid even 25 years after abandonment as during the active working years. To be effective any neutralizing treatment would have to be continued indefinitely after mining was completed. This does not appear economically feasible (12, 15, 29).

Sealing abandoned mines to reduce the acidity of mine drainage is a controversial subject, and not enough evidence is available to justify large expenditures of money. Most recent data from a number of free-flowing, abandoned drift mines over a 5-year period after sealing show no reduction in oxygen content of the atmosphere inside the mine or in the average amount of acid produced per year (29, 32).

Most of the recommended practices for treating mine water relate to economy and efficiency in removing water from operating mines. Of equal importance are procedures to abate stream pollution by the acid discharge. Although no method is known to prevent acid formation, it is the responsibility of every operator to remove the water from his mine in a manner that will prevent pollution to the extent possible. All water should be continuously removed from all areas, both abandoned and operating, as quickly as possible by continuous rather than intermittent pumping. Pooling should be kept at a minimum unless pools are at a constant level with no overflow. The controlled gravity-drainage tunnel system proposed in this report affords the only long-range solution of the anthracite acid-mine-water problem. Employment of a trained drainage engineer, whose energies are devoted to water problems, will (a) show an economy in operation; (b) provide for accumulation of information sorely needed to abate the destruction of our water supplies by acid mine water; and (c) provide the mine operator with a qualified representative who can speak authoritatively before water boards in regard to the operator’s practices (12, 15, 32).

PROBLEMS CONSIDERED

In recent years, the lowest recorded flow in the Susquehanna River was 4,000 second-feet. Factors that must be considered in regard to the flow in the river are: (a) Whenever the flow is less than 8,000 second-feet, the flow is regulated by the power requirements of the power plant at the York Haven Dam, and (b) in times of less than average flow the power plant at the Conowingo Dam is operated on a part-time basis while water is being stored behind the dam to permit operating at full-turbine capacity as many hours as the water supply will permit (33).

The method of arbitrary river-flow control artificially creates periods in which no water is flowing in the river below the Conowingo Dam. During these periods, mine water from the tunnel discharging below the dam would mix with the standing water between Fort Deposit and Havre de Grace. Studies made by The Johns Hopkins University Chesapeake Bay Institute indicate that the salinity of the bay at the mouth of the Susquehanna River is usually about 1 gram per liter, indicating that the water standing in the river mouth is virtually fresh water (31, 35). This is also confirmed by the fact that the domestic water supply for Fort Deposit, Bainbridge, and Havre de Grace is taken out of the river. At Havre de Grace, however, some difficulty has been experienced during periods of extremely low flow in the river above the dams. Even in such periods of low flow or no flow at all, the quantity of fresh water standing in the river mouth will still provide for complete neutralization of the mine water before it enters the Chesapeake Bay.

The conclusions drawn from preliminary studies of available data indicate that, although some problems may arise due to the proposed changing of the present practice of discharging mine water into the Susquehanna River at many points along its course to discharging it at a single point below the Conowingo Dam, these problems are not insurmountable. They require, however, further studies by other State and Federal agencies, such as the U. S. Public Health Service and the Bureau of Fish and Wildlife and Bureau of Reclamation, U. S. Department of the Interior.

The Susquehanna River does not always supply potable water for these communities situated below the Conowingo Dam that use the river water as their source of supply. This is not due to acid mine water, which would neutralize excess salinity. Serious consideration should be given to secure a better water supply for these communities, either from behind the Conowingo Dam or from fresh-water streams and reservoirs in their vicinity.

Although investigations demonstrate that mine water from the proposed anthracite drainage tunnel would not cause such hardship and harm as to make it inadvisable to proceed with the project, a similar tunnel could be planned that would discharge the mine water into the Delaware River at a point between Chester and Marcus Hook. Here, the Delaware is now polluted by industrial wastes, and the addition of mine water would have a beneficial instead of a detrimental effect.
The length of such a tunnel and its diameter and gradient would remain unchanged from the design for the Conowingo tunnel. Figure 8 (pocket) shows the alignment of this alternate tunnel, which would be constructed in its entirety within the boundaries of Pennsylvania.

In this instance, Projects Nos. 1, 2, 3, and 4, as discussed earlier in this report, would remain unchanged. Project No. 5 would have to be altered only as to the alignment of the tunnel. The estimate of construction costs and construction schedule are fully applicable to the alternate tunnel location without important changes.

The tunnels provided for in Projects Nos. 4 and 5, respectively, will in themselves not tap water from any mines. These two tunnels are, in effect, merely a conduit for the gravity discharge of mine water collected by the facilities and tunnels proposed in Projects Nos. 1, 2, and 3.

Project No. 1 proposes construction of a tunnel and related facilities effectively to drain the Lackawanna field, Project No. 2 the Western Middle and Southern fields, and Project No. 3 the Wyoming field. Project No. 3 provides for connection with the works proposed in Project No. 1, and Project No. 4 now provides for connection with the works proposed in Project No. 2. Finally, Project No. 5 proposes construction of a tunnel to serve as the conductor and discharge member of the system integrated by Project No. 4.

Project No. 4 proposes construction of 19.5 miles of 14-foot, circular, concrete-lined tunnel, having a maximum altitude of 119.0 feet at its northern end. Project No. 5 proposes construction of 70.96 miles of 16-foot, circular, concrete-lined tunnel, having a minimum altitude of 15 feet at its southern end. This is the lowest altitude on which a gravity-tunnel system can be planned. The two sections of tunnel uniformly have a gradient of 1 foot per mile and run on an almost straight line that is nearly due north and south.

In combination, Projects Nos. 4 and 5 provide for draining the anthracite mines and fully exploit the opportunity for gravity discharge afforded by the terrain. If, in the future, consideration is accorded the relatively exhausted Eastern Middle field, some or all of the mine water pools in this field may be tapped by driving a short lateral tunnel off the portion of the main tunnel proposed in Project No. 4, into which the mine water could be drained through boreholes made 8 to 12 inches in diameter.

All shafts provided in Projects Nos. 4 and 5 are construction shafts only, and they will not be used for any purpose, except possibly for natural ventilation, once the entire Conowingo tunnel system is completed and placed in operation.

**PLAN OF PROPOSED IMPROVEMENTS**

The work units of Projects Nos. 4 and 5 consist of the main tunnels and construction shafts.

**MAIN TUNNELS**

The length of the tunnel proposed in Project No. 4 is 19.5 miles, the distance between the terminal points of Projects Nos. 2 and 3, which it will connect (23, 25). Its southern end is 2.6 miles north of No. 11 shaft (Project No. 2) and 82.44 miles north of the proposed Conowingo tunnel portal. Its northern end is 1 mile south of No. 15 shaft (Project No. 3).

The tunnel will be circular in cross section, concrete lined, and have a finished diameter of 14 feet. The gradient will be 1 foot per mile. The altitude of its southern terminal is 99.44 feet and that of its northern terminal 118.95 feet. These altitudes are at the tunnel invert.

The length of the tunnel proposed in Project No. 5 is 70.96 miles, the distance between its connection with the tunnel proposed in Project No. 2 and the portal below the Conowingo Dam. Its northern end is 3.84 miles south of No. 9A shaft near Middleport (Project No. 2).

The altitude of the portal is 15 feet. The altitude of the invert at the northern terminal of Project No. 5 is 85.96 feet. The tunnel will be circular in cross section, concrete lined, and have a finished diameter of 16 feet. The gradient will be 1 foot per mile.

The tunnel is designed to handle volumes over the normal flow of mine water, as determined from the present average pumping load of all mines tributary to the system.

Circular tunnel sections have been selected because they afford the most favorable hydraulic and structural properties. The hydraulic properties of the various sections are shown in figures 9 to 11, inclusive.

To support the different conditions of formations encountered in tunnel driving, three typical cross sections are considered, as follows: (a) Unsupported; (b) supported; and (c) rock bolted.

Typical unsupported and steel-supported tunnel sections are shown in figures 12 and 13.

Rock bolting is to be considered a substitute for steel support, and can be used to advantage when conditions for its application are favorable.
### Hydraulic Properties of Tunnel Sections (Full)

<table>
<thead>
<tr>
<th>TUNNEL DIA.</th>
<th>PRESSURE HEAD</th>
<th>S-1 FOOT PER MILE</th>
<th>Q- DISCHARGE</th>
<th>V- FPS VELOCITY</th>
<th>F- FT HYDR. RAD.</th>
<th>A-SQ FT CROSS-SECTION AREA</th>
<th>FRICTION COEFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>16'-0&quot;</td>
<td>16 FT.</td>
<td>0.000189</td>
<td>880</td>
<td>396,000</td>
<td>4.38</td>
<td>4.00</td>
<td>201.06</td>
</tr>
<tr>
<td>16'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>796</td>
<td>357,000</td>
<td>3.96</td>
<td>4.00</td>
<td>201.06</td>
</tr>
<tr>
<td>15'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>670</td>
<td>301,000</td>
<td>3.79</td>
<td>3.75</td>
<td>176.71</td>
</tr>
<tr>
<td>14'-0&quot;</td>
<td>10 FT.</td>
<td>0.000189</td>
<td>663</td>
<td>298,000</td>
<td>4.31</td>
<td>3.5</td>
<td>153.94</td>
</tr>
<tr>
<td>14'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>557</td>
<td>250,000</td>
<td>3.62</td>
<td>3.5</td>
<td>153.91</td>
</tr>
<tr>
<td>13'-0&quot;</td>
<td>10 FT.</td>
<td>0.000189</td>
<td>571</td>
<td>256,000</td>
<td>4.30</td>
<td>3.25</td>
<td>132.73</td>
</tr>
<tr>
<td>13'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>456</td>
<td>205,000</td>
<td>3.44</td>
<td>3.25</td>
<td>132.73</td>
</tr>
<tr>
<td>12'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>370</td>
<td>166,000</td>
<td>3.27</td>
<td>3.00</td>
<td>113.08</td>
</tr>
<tr>
<td>11'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>294</td>
<td>132,000</td>
<td>3.10</td>
<td>2.75</td>
<td>95.03</td>
</tr>
<tr>
<td>10'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>229</td>
<td>103,000</td>
<td>2.92</td>
<td>2.5</td>
<td>78.54</td>
</tr>
<tr>
<td>9'-0&quot;</td>
<td></td>
<td>0.000189</td>
<td>175</td>
<td>79,000</td>
<td>2.75</td>
<td>2.25</td>
<td>63.82</td>
</tr>
</tbody>
</table>

Figure 9.—Hydraulic Properties of Tunnel Sections (Full).
Figure 10.—Hydraulic Properties of Tunnel Sections (92 Percent Full).
CIRCULAR TUNNEL SECTIONS
SUPPORTED 180°

HYDRAULIC PROPERTIES OF TUNNEL SECTIONS (50% FULL)

<table>
<thead>
<tr>
<th>TUNNEL DIA.-D</th>
<th>S-1 FOOT PER MILE</th>
<th>Q- DISCHARGE</th>
<th>V- F.P.S. VELOCITY</th>
<th>F- FT. HYD. RAD.</th>
<th>A-SQ.FT CROSS-SECTION AREA</th>
<th>N-FRICTION COEFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>16'-0&quot;</td>
<td>.000189</td>
<td>398</td>
<td>178,000</td>
<td>3.96</td>
<td>4.00</td>
<td>100.53</td>
</tr>
<tr>
<td>15'-0&quot;</td>
<td>.000189</td>
<td>335</td>
<td>150,000</td>
<td>3.79</td>
<td>3.75</td>
<td>89.35</td>
</tr>
<tr>
<td>14'-0&quot;</td>
<td>.000189</td>
<td>278</td>
<td>125,000</td>
<td>3.62</td>
<td>3.5</td>
<td>78.95</td>
</tr>
<tr>
<td>13'-0&quot;</td>
<td>.000189</td>
<td>228</td>
<td>102,000</td>
<td>3.44</td>
<td>3.25</td>
<td>68.56</td>
</tr>
<tr>
<td>12'-0&quot;</td>
<td>.000189</td>
<td>185</td>
<td>83,000</td>
<td>3.27</td>
<td>3.00</td>
<td>56.54</td>
</tr>
<tr>
<td>11'-0&quot;</td>
<td>.000189</td>
<td>147</td>
<td>66,000</td>
<td>3.10</td>
<td>2.75</td>
<td>47.51</td>
</tr>
<tr>
<td>10'-0&quot;</td>
<td>.000189</td>
<td>114</td>
<td>51,000</td>
<td>2.92</td>
<td>2.5</td>
<td>39.27</td>
</tr>
<tr>
<td>9'-0&quot;</td>
<td>.000189</td>
<td>87</td>
<td>39,000</td>
<td>2.75</td>
<td>2.25</td>
<td>31.61</td>
</tr>
</tbody>
</table>

Figure 11.—Hydraulic Properties of Tunnel Sections (50 Percent Full).
Construction quantities required for different tunnel sections and type of support are shown in table 2.

**Table 2.**—Tunnel-construction quantities required (excavation and concrete)

<table>
<thead>
<tr>
<th>Diameter, feet</th>
<th>Area, square feet</th>
<th>Cubic yards per foot of tunnel</th>
<th>Area, square feet</th>
<th>Cubic yards per foot of tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>244.94</td>
<td>9.67</td>
<td>43.88</td>
<td>1.63</td>
</tr>
<tr>
<td>15</td>
<td>218.15</td>
<td>8.08</td>
<td>41.43</td>
<td>1.53</td>
</tr>
<tr>
<td>14</td>
<td>192.77</td>
<td>7.14</td>
<td>38.83</td>
<td>1.44</td>
</tr>
</tbody>
</table>

**SUPPORTED 180°**

<table>
<thead>
<tr>
<th>Diameter, feet</th>
<th>Area, square feet</th>
<th>Cubic yards per foot of tunnel</th>
<th>Area, square feet</th>
<th>Cubic yards per foot of tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>259.49</td>
<td>9.61</td>
<td>58.43</td>
<td>2.16</td>
</tr>
<tr>
<td>15</td>
<td>231.91</td>
<td>8.59</td>
<td>55.19</td>
<td>2.04</td>
</tr>
<tr>
<td>14</td>
<td>205.72</td>
<td>7.62</td>
<td>51.78</td>
<td>1.92</td>
</tr>
</tbody>
</table>

1 See figs. 12 and 13.

**CONSTRUCTION SHAFTS**

All shafts planned under Projects Nos. 4 and 5 are for construction purposes only, and all have been spaced, so far as possible, equidistantly. Spacing has been varied to take advantage of lower surface altitudes and thereby obtain the minimum depths of the shafts.

Project No. 4 requires three construction shafts, which are numbered 12, 13, and 14.

Project No. 5 requires 10 construction shafts, which are numbered 1, 2, 3, 3A, 4, 5, 6, 7, 8, and 8A, starting from the portal end of the tunnel.

All construction shafts will be circular in cross section and concrete lined. They will have a uniform diameter of 14 feet, and the shaft layout will be varied to meet the demands of the contractor. Figure 14 is a typical design for a construction shaft.
All shaft appurtenances will be of steel construction. At the surface, a headframe is to be erected on the shaft collar. Fireproof buildings will house the hoisting machinery, fans, compressors, and electric machinery. A small storage building and an adequate bathhouse will be provided.

After all construction work is completed, all surface buildings at the construction shafts will be removed and the tops of the shafts permanently covered with a concrete deck and provided with suitable facilities for access.

Table 3 gives approximate altitudes at the surface and at the tunnel inverts at shaft points and the depths of the construction shafts for Projects Nos. 4 and 5, respectively.

**ESTIMATED COST**

Table 4 is a preliminary estimate of the construction costs for the various items in Project No. 4, based on labor and material costs prevailing during 1951-52. Table 5 provides corresponding data for Project No. 5.

**TABLE 3.—Altitudes and depths of construction shafts, feet**

<table>
<thead>
<tr>
<th>Number of shaft</th>
<th>Approximate surface altitude</th>
<th>Altitude at tunnel invert</th>
<th>Depth of shaft to tunnel</th>
<th>Depth of sump and skip pocket</th>
<th>Total depth of shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.</td>
<td>1,151</td>
<td>102.0</td>
<td>1,049.0</td>
<td>40.0</td>
<td>1,089</td>
</tr>
<tr>
<td>13.</td>
<td>865</td>
<td>110.0</td>
<td>755.0</td>
<td>40.0</td>
<td>795</td>
</tr>
<tr>
<td>14.</td>
<td>600</td>
<td>116.5</td>
<td>483.5</td>
<td>39.5</td>
<td>523</td>
</tr>
</tbody>
</table>

**PROJECT NO. 5**

| 1.              | 400                         | 21.5                      | 378.5                   | 39.5                           | 418                 |
| 2.              | 600                         | 28.0                      | 572.0                   | 40.0                           | 612                 |
| 3.              | 820                         | 34.5                      | 735.5                   | 39.5                           | 825                 |
| 4.              | 411                         | 41.0                      | 400.0                   | 40.0                           | 440                 |
| 5.              | 358                         | 47.7                      | 310.3                   | 39.7                           | 350                 |
| 6.              | 621                         | 54.4                      | 566.6                   | 39.4                           | 606                 |
| 7.              | 561                         | 60.7                      | 500.3                   | 39.7                           | 540                 |
| 8.              | 500                         | 67.8                      | 432.2                   | 39.8                           | 472                 |
| 8A.             | 761                         | 82.1                      | 678.9                   | 39.1                           | 718                 |
Figure 14.—Typical Design for Construction Shaft.
The time schedule for the construction program outlined is given in graphic form in figure 15. The schedule is based on the following work progress:

3 feet per operating day for sinking shafts.
60 feet per operating day for advancing tunnel face.
60 feet per operating day for concreting tunnel.

The work schedule for Project No. 4 covers an estimated construction period of 5½ years. Since the work program varies from year to year, the allocation of funds will be determined by the nature of the work to be performed, as follows:

During the first year, an estimated $1,090,000 will be required for engineering and shaft construction.

The second year will require an allocation of $8,985,000 to finish sinking the shafts and begin excavating the tunnels.

The third and fourth years will require allocations of $7,770,000 and $7,140,000, respectively, to continue tunnel excavation and begin the concrete work.

For the fifth year, $5,460,000 will be required and $2,079,136 for the sixth and final year. The latter appropriation will complete the project.

In all, a total of $30,124,136 will be required.

The work contemplated in Project No. 5 covers the following separate items of construction:

1. Construct the following shafts to the depths indicated:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>418</td>
</tr>
<tr>
<td>No. 2</td>
<td>612</td>
</tr>
<tr>
<td>No. 3</td>
<td>825</td>
</tr>
<tr>
<td>No. 4</td>
<td>940</td>
</tr>
<tr>
<td>No. 5</td>
<td>350</td>
</tr>
<tr>
<td>No. 6</td>
<td>606</td>
</tr>
<tr>
<td>No. 7</td>
<td>540</td>
</tr>
<tr>
<td>No. 8</td>
<td>472</td>
</tr>
<tr>
<td>No. 9A</td>
<td>565</td>
</tr>
<tr>
<td>No. 9A</td>
<td>718</td>
</tr>
</tbody>
</table>

2. Construction of the portal and discharge facilities.
3. Construct the following tunnels from shafts:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Tunnels</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 12</td>
<td>South</td>
<td>2.69</td>
</tr>
<tr>
<td>Do.</td>
<td>North</td>
<td>3.84</td>
</tr>
<tr>
<td>No. 13</td>
<td>South</td>
<td>3.84</td>
</tr>
<tr>
<td>Do.</td>
<td>North</td>
<td>3.36</td>
</tr>
<tr>
<td>No. 14</td>
<td>South</td>
<td>3.42</td>
</tr>
<tr>
<td>Do.</td>
<td>North</td>
<td>2.42</td>
</tr>
</tbody>
</table>

The schedule for the construction program is shown in graphic form in figure 16. In general, the progress and program have been based on performance data similar to Project No. 4, as follows:

3 feet per operating day for sinking shafts.
60 feet per operating day for advancing tunnel face.
60 feet per operating day for concreting tunnel.

1 All work is scheduled for a regular 5-day week.
It is anticipated that Project No. 5 will require 5½ years for completion. Annual allocation of funds will vary from year to year depending on the nature of the work to be performed. The total cost of $120,390,520 will have to be allocated as follows:

The first year an estimated $16,665,000 will be necessary to cover the cost of engineering, shaft construction, and the beginning of tunneling.

The second and third year will be devoted to tunnel excavation and will require an allocation of $28,575,000 and $30,400,000, respectively.

For the fourth year, an allocation of $27,120,000 will be necessary to complete excavation and commence concrete lining of tunnels.

For the fifth year, an allocation of $15,330,000 is necessary to substantially complete the concrete lining.

The remainder of the estimated cost of the project ($2,300,520) will be expended during the first half of the sixth year to complete all work.
COOPERATION WITH LOCAL INTERESTS

The facilities provided by Projects Nos. 4 and 5 are all outside the anthracite region proper, and the benefits to be derived therefrom do not concern the localities where shafts and tunnels will be excavated. Pennsylvania has a great stake in the restoration and preservation of the anthracite industry and, therefore, can reasonably be expected to acquire the necessary land, rights-of-way, and easements for the proper execution of the work contemplated. The Susquehanna River is a potential source of water that can have greater use than at present for the industrial and domestic needs of the citizens of Pennsylvania. As a long-range project, the tunnel could convey water from sources along its route to a densely populated region sorely in need of it. As a short-range project, it can remove acidic mine water from the river and its tributaries and place it where it can be treated (if necessary) or disposed of at tidewater. Pennsylvania, furthermore, will have to enact laws and induce counties, townships, and municipalities to issue ordinances that will permit the unhampered execution of the construction program and safeguard constructed facilities.

Maryland or New Jersey and Delaware (if the Marcus Hook route is selected) are expected to cooperate with Pennsylvania and with the tunnel authority that will have charge of planning, engineering, and executing the projects. The cooperation that can be expected can resolve the questions that will arise in connection with the discharge of acid mine water into the lower Susquehanna River or the Delaware River.

CONCLUSIONS

The problems of mine-flood control for the anthracite mines of Pennsylvania are complex. Previously published Projects Nos. 1, 2, and 3 dealt principally with collecting mine water from active and abandoned mines in the various anthracite fields. Projects Nos. 4 and 5 cover that portion of the tunnel system that must dispose of the mine water by gravity to the lowest possible altitude, which, of course, is near sea level.

Gravity discharge is the most economical method of discharging large quantities of acid mine water. Circular, concrete-lined tunnels, which will neither permit acid mine water to seep into surrounding strata, nor permit ground water to enter the tunnel, are considered the proper mediums to conduct the acid mine water to the mouth of the Susquehanna River, where it would be neutralized in a comparatively short distance by the river water, which is known to be alkaline enough for this purpose.

Problems arising from possible effects of acid mine water entering the Susquehanna River below Conowingo Dam on fish and waterfowl and on the suitability of the river water as a water supply for municipalities situated along the river or otherwise dependent on this source should be studied by State and Federal agencies dealing with such specific problems.

The present rapid neutralization of the acid mine water by the Susquehanna River in its course through the anthracite region and the absence of adverse effects on fish and wildlife along the stream should suffice to allay the fears that discharging mine water into the river below the Conowingo Dam might seriously affect its present condition. A thorough study of these problems by the U. S. Public Health Service and the Bureau of Fish and Wildlife and Bureau of Reclamation of the U. S. Department of the Interior and other competent State and Federal agencies will confirm the foregoing statement, and any questions can be resolved by data obtained in additional investigations by those agencies.
RECOMMENDATIONS

Recommendations made in Project No. 1 (Lackawanna), Northern field (22), Project No 2, Western Middle and Southern fields (23), and Project No. 3 (Wyoming) (27), regarding the creation of a tunnel authority by action of the Pennsylvania Legislature, also apply to Projects Nos. 4 and 5.

For Projects Nos. 4 and 5 it is specifically recommended:

That the Federal Government make a grant of $30,124,136 for Project No. 4 and $120,390,520 for Project No. 5 to defray expenditures for engineering, executing all work, and installing all equipment described in this report.

To conform with provisions made in Projects Nos. 4 and 5 for safeguarding the work for which Federal funds have been made available, it is again recommended:

That no money shall be appropriated by the Federal Government for the prosecution of features of this plan until a tunnel authority is created by the Commonwealth of Pennsylvania and that no Federal money shall be expended on construction until the Commonwealth of Pennsylvania or other responsible political subdivision shall have furnished assurances satisfactory to the Secretary of the Interior that they will provide, without cost to the Federal Government, all surface and coal lands, shafts, easements, and rights-of-way for construction, operation, and maintenance of such works, and their share of the expense of this project.

That no money appropriated by the Federal Government for the prosecution of features of the plan shall be expended on construction until the State and other responsible local interests shall have furnished assurances satisfactory to the Secretary of the Interior that mining operations shall be conducted only in such places and in such a manner that damage will not result to flood-control structures that are considered essential by the Secretary of the Interior for the conservation of anthracite reserves or the protection of human life.

That after construction the works described in this report shall be maintained and operated by the tunnel authority.
BIBLIOGRAPHY


27. Beaver, C. F. Effect of the Susquehanna River Stream Flow on Chesapeake Bay Salinities and History of Past Oyster Mortalities on Upper Bay Bars. Maryland Board of Natural Resources, 3d ann. rept., 1946, pp. 122-123.


