MINE FLOOD PREVENTION AND CONTROL

ANTHRACITE REGION OF PENNSYLVANIA

Final Report of the Anthracite Flood-Prevention Project Engineers

By S. H. Ash, H. A. Dierks, and P. S. Miller

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ANTHRACITE REGION OF PENNSYLVANIA

Final Report of the
Anthracite Flood-Prevention Project Engineers

By
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Summary

MINE DRAINAGE in the anthracite region of Pennsylvania has been discussed in many publications. This report is prepared for submission to the Congress in compliance with the provisions under which funds requested by the Federal Bureau of Mines were authorized by the Congress.

The purpose of the flood-prevention project (the engineering survey) was to obtain information and to present a solution relating to the health, safety, and economic conditions in the anthracite region of Pennsylvania, the State, and the Nation, as affected by the encroachment of mine water, and to provide an engineering background upon which this serious problem could be solved.

In approaching the anthracite-mine-water problem, as related to other problems of water use or control, it has been recognized that under existent flood-control laws Federal participation is properly limited to major mine-drainage improvements.

The engineering survey, summarized in this report, consisted of studies on acid mine water, underground-water pools, the "buried valley" of the Susquehanna River, inundated anthracite reserves, mine pumping plants, surface-water pools, seepage of surface water into mines, barrier pillars between mines, and geologic features of the region that included core drilling along the alignment of the proposed Conowingo tunnel and to some extent along the proposed Marcus Hook alternate tunnel route. A comprehensive study was conducted to determine corrosion and erosion resistance of selected metals.
and alloys and to ascertain their suitability for components of pumps to be used in handling acid mine water. As each study was completed, the information and data acquired were published in detail and became a part of a factual basis for determining remedial measures to solve the mine-water problem.

One hundred and six billion gallons of water was impounded at the end of 1952 in 150 pools in underground mine workings that are not tributary to present drainage systems. The closing down of mines in 1954 and 1955 has increased this volume tremendously.

An investigation on water impounded in stripping excavations in the Northern, Eastern Middle, Western Middle, and Southern fields of Pennsylvania was conducted in the spring of 1948 and procured factual data on 141 water pools in abandoned stripping excavations. These pools contained 2.3 billion gallons of water and affected the safe operation of active anthracite mines, in addition to making future underground operations hazardous.

An evaluation of factual data related to the mine-water problem in the anthracite region reveals a serious mine-water problem in every one of the four fields into which the region is naturally divided. Different ideas and plans to remedy the mine-water problem, including 13 tunnel proposals and schemes for central pumping plants, were considered. Of all these, a gravity-drainage-tunnel system, consisting of a main tunnel and two or more main central pumping plants for emergency use, discharging at tidewater appears to be the most logical, both from an engineering and economical standpoint, because it provides the maximum in relief to all fields for an unlimited period with a minimum of maintenance and operating costs. The main tunnel would convey the water to a point near tidewater outside the anthracite region. The mine water would be collected at its source and conveyed to the main tunnel by a network of lateral and sublateral tunnels.

The proposed comprehensive plan, presented in this report, is based on data and facts obtained in the only comprehensive study ever made of the anthracite-mine-water problem. The plan provides immediate and permanent solution of the mine-drainage problem, by means of a gravity-drainage-tunnel system, in the sequence of five proposed projects throughout the entire anthracite region; it not only will prevent further decline of the anthracite industry and additional loss of anthracite reserves because of inundation but will make it possible to revitalize the industry and insure the conservation of additional reserves for the future welfare of the Nation. The gravity-drainage-tunnel system would extend either from tidewater in the Delaware River at Marcus Hook, Pa., or from tidewater in the Susquehanna River just below the Conowingo Dam in Maryland (Project No. 5) to near Eddy Creek, Pa., in the Northern field (Project No. 1).

Projects Nos. 1 (Lackawanna), 2, and 3 (Wyoming) (37–39) deal principally with collecting mine water from active and abandoned mines in the various anthracite fields. Project No. 1 of the comprehensive plan is the first phase of the entire drainage-tunnel scheme and is necessary to provide a temporary pumping plant capable of handling all mine water in the Lackawanna Basin at all times until an extension of the tunnel to another pumping plant, and ultimately to the portal at tidewater, is accomplished. An arrangement can be made whereby the water can be discharged by gravity into the Susquehanna River on completion of Project No. 3.

Project No. 2, designed to keep producing mines active in the Western Middle and Southern fields and to make available, when the demand arises, the large tonnage of anthracite that is now inaccessible, is a self-contained unit, like Project No. 1, and is intended to be joined with other portions of the comprehensive plan into a complete mine-drainage system, but which will be effective in the area it serves whether or not the other projects are completed.

Project No. 3, a self-contained drainage unit, will permit unwatering inundated mines and safeguarding active mines in the Wyoming Basin of the Northern field and also will handle the water in the Lackawanna Basin.

*Italicized figures in parentheses refer to items in the bibliography at the end of this report.*
Projects Nos. 4 and 5 (36) cover that portion of the tunnel system that must dispose of the mine water by gravity to the lowest possible altitude, which is near sea level. Project No. 4, in Schuylkill and Luzerne Counties, will connect with Projects Nos. 2 and 3, and the proposed tunnel would pass under the coal basins forming the western end of the Eastern Middle field. 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 anthracite region.

The need for water in the anthracite region and the Atlantic coastal cities will increase greatly with the continued development of the entire area. Until the need for fresh water has been satisfied, only the irreducible minimum of anthracite mine water that cannot be treated and conserved should be discharged to coastal waters to be lost to the area for useful purposes.

The proposed comprehensive plant will benefit all anthracite fields fully and equally so that each field can maintain its competitive position within the industry. It will provide the most economical and most effective means of draining inundated mines that form a constant threat to adjoining mines in all the anthracite fields. It will also reduce considerably the hydrostatic pumping head for most mines, and for some it will dispense with pumping entirely.

The information presented will provide better understanding of the problem involved and thereby assist in conserving anthracite reserves and promoting safety of the men employed in the mines in this area if ample precautions are taken to prevent inundation.
INTRODUCTION

BACKGROUND

Mine drainage in the anthracite region of Pennsylvania has been discussed in many publications (11, 16–26, 31–48, 56, 110, 122, 123, 133, 147, 161, 177, 178, 183, 188, 194, 206, 216–220, 238, 260, 262, 277, 278, 288, 289). This matter was emphasized at meetings of the Anthracite Section of the American Institute of Mining and Metallurgical Engineers (AIME) in 1940. Its members believed that the subject should be presented at an institute meeting with particular reference to the interest and aid the industry could expect from Government. Accordingly, a paper was presented on October 25, 1940, before the Anthracite Section of the AIME; this paper was published by the Bureau of Mines as Information Circular 7175 in June 1941 (17).

The National Resources Planning Board was actively interested. An inquiry was conducted in the region by this Board, and a report was prepared and submitted to its members on January 14, 1941 (110).

It was generally recognized throughout Pennsylvania that the adverse economic condition of the anthracite region was the No. 1 social problem in the State (93, 122, 204, 220, 260). This fact was also recognized by the 1st session, 77th Congress of the United States, to the extent that a joint commission was created. As a result, House Joint Resolution 255 was adopted by both the House and the Senate by unanimous vote and approved by the President on December 19, 1941. This joint resolution required creation of a commission to investigate ways and means for improving economic conditions in the anthracite region. The commission submitted a report (122) that recognized the gravity of the mine-flood problem and contained pertinent statements regarding it.

The history of the efforts put forth regarding the mine-water problem is well known to persons to whom the anthracite industry is a means of livelihood, and a “high-water” mark was reached when a bill (H. R. 7090) was presented by the Hon. Ivor D. Fenton before the 2nd session, 77th Congress, on May 14, 1942. This bill was referred to the Committee on Mines and Mining and subsequently died in committee.

A stalemate followed this failure to obtain recognition by legislation defining the Federal Government’s responsibility to develop an engineering method that will solve the mine-water problem and keep anthracite mines in operation, although this responsibility has long been recognized (16, 17, 122, 133, 277, 279). Because a primary function of the Federal Bureau of Mines is to promote safety and efficiency in the mineral industries, this Bureau continued its interest in the matter.

The broad objective of the investigative work conducted before July 1948 was to obtain factual data that concerned the problem. This work showed the extreme urgency for prompt remedial action and served as the basis for discussion on the prevention of flooding of anthracite mines at a meeting of the Anthracite Investigations Advisory Committee held September 25, 1947, after which a proposed bill was discussed by representatives of the Anthracite Investigations Advisory Committee and the Hon. Ivor D. Fenton, who introduced a bill (H. R. 4837) in the House of Representatives on January 6, 1948. This bill was referred to the Committee on Public Lands, and hearings were held on it; as a consequence a report (279) was submitted containing the following statements:

The Committee on Public Lands, to whom was referred the bill (H. R. 4837) to provide an engineering study of the mine-water problem of the Pennsylvania anthracite mining area for the purpose of obtaining information and presenting a solution relating to the health, safety, and economic conditions of the area, State, and Nation, as affected by the encroachment of water that progressively floods the mines, threatens to destroy the anthracite reserves of the Nation, contributes to a waste of a valuable natural resource, and seriously affects the whole economy of the anthracite mining area, having considered the same, report favorably thereon without amendment and recommend that the bill do pass.

The object of this bill, therefore, is to provide an engineering background upon which the solution of this serious problem can be effected. The expenditure of the money authorized by this legislation is trivial when compared with the vast natural resources it will save or the direct livelihood of more than a million and a half persons it will continue, as well as enhancing the economy of many millions of other people.

This is wealth-saving legislation. Unless this legislation is enacted, large parts of the anthracite industry will be lost to the Nation; additional fuel oil will be consumed to replace that lost. In addition, bituminous coal will have to be used after hauling it long distances—
INTRODUCTION

this when there is also a shortage of transportation equipment and of fuel oil.

The Committee on Public Lands unanimously recommends the enactment of this bill, which has the approval of the Department of the Interior. A further explanation of the bill is set forth in a communication dated January 16, 1948, from the Secretary of the Interior, the Hon. J. A. Krug, to the Hon. Richard J. Welch, chairman of the Committee on Public Lands.

H. R. 4837 was passed unanimously by the House of Representatives on March 1, 1948. It was referred to the Committee on Interior and Insular Affairs, United States Senate, where it subsequently died because the Federal Bureau of the Budget construed that the Bureau of Mines had adequate authority to make studies of the character embodied in H. R. 4837.

During the fiscal years 1949–54, Congress appropriated funds for anthracite-mining investigations in response to requests from the United States Department of the Interior for funds to make an engineering study embracing the following:

1. Obtaining information relating to the anthracite mine-water problem, the causes of surface-water infiltration, and the magnitude and locations of underground water pools. The ultimate objectives are:
   (a) To reestablish the anthracite industry on a sound economic basis, thus stimulating prosperity in the anthracite-producing and anthracite-consuming communities.
   (b) To promote the health and welfare of the many persons dependent on the industry for their livelihood.
   (c) To conserve, for other purposes, fuels that are competitive with Pennsylvania anthracite.
   (d) To extend the usefulness of the valuable transportation system that serves the anthracite region.
   (e) To prevent loss of life and property damage in major mine disasters.

2. Preparation and dissemination of reports, studies, statistics, and other informative data regarding the prevention or control of surface-water infiltration into anthracite mines and the protection of operating mines from the hazards of water impounded against barrier pillars. This information will be made public in summary or detailed form as soon as practicable after its acquisition.

3. Reporting to Congress the results of investigations and recommendatory measures concerning the anthracite-mine-water problem, which will outline methods for its solution, benefits, costs, and means of financing.

4. Preparation of plans and specifications for construction projects for overcoming the anthracite-mine-water problem, based on the data and information obtained.

This report is prepared for submission to the Congress in compliance with the provisions under which funds requested by the Federal Bureau of Mines were authorized by the Congress.

PURPOSE AND SCOPE OF REPORT

The purpose of the flood-prevention project (the engineering survey) was to obtain information and to present a solution relating to the health, safety, and economic conditions in the anthracite region of Pennsylvania, the State, and the Nation, as affected by the encroachment of mine water, and to provide an engineering background upon which this serious problem could be solved (277, 279).

In approaching the anthracite-mine-water problem, as related to other problems of water use or control, it has been recognized that, under existing flood-control laws, Federal participation is properly limited to major mine-drainage improvements.

The engineering survey consisted of studies made on acid mine water, underground-water pools, the "buried valley" of the Susquehanna River, inundated anthracite reserves, mine pumping plants, surface-water pools, seepage of surface water into mines, barrier pillars between mines (16–27, 32–48), and geologic features of the region that included a program of core drilling along the alignment of the proposed Conowingo tunnel and to some extent along the proposed Marcus Hook alternate tunnel route (40, 48). A comprehensive study was conducted to determine corrosion and erosion resistance of selected metals and alloys and to ascertain their suitability for components of pumps to be used in handling acid mine water (55). As each study was completed the information and data acquired were published in detail and became a part of the factual basis for determining remedial measures for a solution of the mine-water problem. The publications are listed in the bibliography at the end of this report.

In view of the factual data collected, measures taken or proposed were reviewed, and recommendations are made for a solution of the mine-water problem. The recommendations cover a long-range program for the solution of the mine-drainage problem.

An evaluation of factual data related to the mine-water problem in the anthracite region reveals a serious mine-water problem in every one of the four fields into which the region is naturally divided. Different ideas and plans to remedy the mine-water problem, including 13 tunnel proposals and schemes for central pumping plants, were considered. Of all these, a gravity-drainage-tunnel system discharging at tidewater appears to be the most logical, both from an engineering and economical standpoint, because it provides the maximum in relief to all fields for an unlimited period with a minimum of maintenance and operating costs.

The comprehensive plan, for geographic and practical reasons, has been divided into five integral parts or projects (36–39). Requiring congressional appropriations subsequent to proper Commonwealth of Pennsylvania and local cooperation for its realization, it was considered expedient for the protection of human life and the well-being of the Northern anthracite region to assign the first project to the area
between Pittston City and Peckville Borough in the Northern field, which needs help more urgently than other parts of the anthracite region because of the number of active mines, large number of people employed, large tonnage of current anthracite production, and the large tonnage of anthracite reserves affected by a shutdown of local mines due to the mine-water problem. It also will remove the threat of mine water in the Lackawanna Basin flowing into the Wyoming Basin over the structural saddle at Moosic, Pa.

The final report covers the following: (a) A brief description of the anthracite region; (b) the economic development of the anthracite region and the improvements desired; (c) geology and hydrology of the region; (d) the problems considered; (e) a brief description of the proposed Conowingo tunnel and the Marcus Hook alternate route tunnel, which would drain the anthracite mines of Pennsylvania into the Susquehanna River at Conowingo, Md., or into the Delaware River at Marcus Hook, Pa.; (f) the basic problems, plans, and costs, and the construction scales of the projects; (g) economic analyses and justification of the projects; and (h) final recommendations, including financing and cooperation of local interests.

ORGANIZATION OF ANTHRACITE FLOOD-PREVENTION PROJECT

The engineering study comprising the anthracite flood-prevention project cost more than $2 million, considering services and engineering data contributed by operating companies.

Because the anthracite industry is vitally concerned, because millions of dollars must be expended by both the anthracite industry and Government if a solution of the problem is to be obtained, because representatives of the industry (management and labor) personally appeared before the House Committee on Public Lands to present the case (279), and because the entire action program since its inception has been conducted in cooperation with the anthracite industry, it is logical that the organization, in general, should follow that set forth in the Congressional hearings on H. R. 4837 (279); the anthracite industry, as represented by an advisory engineering committee, should approve and have a voice in deciding who should direct the job and the organizational basis on which the work would be done.

ANTHRACITE ADVISORY BOARD
ENGINEERING COMMITTEE

In accordance with the above-mentioned plan on organization, the Director of the Bureau of Mines, on July 1, 1948, invited several anthracite mining engineers from the different fields to establish the Anthracite Advisory Board Engineering Committee, the function of which has been to participate in deliberations on the action program of the anthracite flood-prevention project. The invitation was accepted by these engineers. The following served on this committee:

- H. A. Diers, vice president and general manager, Glen Alden Coal Co., Wilkes-Barre, Pa.
- Cadwallader Evans, Jr., president, The Hudson Coal Co., Scranton, Pa.
- Michael Kosik, president, district 1, United Mine Workers of America, Miller Building, rooms 508–510, Scranton, Pa.
- Frank Cardoni, United Mine Workers of America, Wilkes-Barre, Pa. (alternate).
- P. Edgar Kudliche, chief engineer, Glen Alden Coal Co., Wilkes-Barre, Pa.
- William P. Millington, mining engineer, 800 Mahantongo St., East, Pottsville, Pa.
- Joseph J. Walsh (deceased), past deputy secretary of mines, Pennsylvania Department of mines, Harrisburg, Pa.

This committee also took an active part in the organization and selection of personnel of the Anthracite Flood-Prevention Section of the Bureau of Mines, having field offices in the anthracite region with the main office in Wilkes-Barre and temporary offices in Scranton, Hazleton, and Pottsville. The Anthracite Advisory Board Engineering Committee met numerous times with the staff of the field offices, as well as with the Director of the Bureau of Mines, to receive interim reports on the progress of the flood-prevention study and to discuss variations of the program to be followed.

Through this advisory engineering committee, which was composed of the managers and chief engineers of the larger mining companies and representatives of the United Mine Workers and the Pennsylvania Department of Mines, the anthracite industry was fully informed of the findings and plans of the Federal engineers and took a very active part in supplying comprehensive data, maps, and records necessary to the success of the study and the completion of this final report (37).

The anthracite industry, through its members on the advisory engineering committee, has on
numerous occasions expressed its desire to have the Federal Government not only make a study of the mine-water problem but undertake the solution of it to lift the burden of excessive pumping costs off industry and to remove the very real threat of inundation of all operating mines to preserve a very vital industry and an unquestionably valuable source of energy to the Nation (37, 122, 275, 277, 279).

**PLAN OF ORGANIZATION AND WORK**

A meeting of the advisory board engineering committee was held at Washington, D. C., on September 17, 1948, for discussing with the Director an action program relating to the organization and work of the anthracite flood-prevention project.

A plan of organization was submitted and discussed and an organizational scheme devised that defined the project to cover the water problems of the entire region, including all mines that were still operating. The matter was to be studied with a view to (a) protecting active operations from water hazards; (b) relieving existing pumping loads when loads were excessive; and (c) unwatering underground accumulations of water already existing, which might be in mines or sections of abandoned flooded mines.

The study was conducted on a general basis for logical subdivisions of the region by specific studies of the water problems of individual mining operations or connected groups of operations. The work in the several fields was directed toward specific projects after January 1, 1954.

Presentation of the survey and preparation of the many reports on it have been based on the work of the Anthracite Flood-Prevention Section of the Bureau of Mines and on voluminous records of previous surveys and studies made by anthracite-mining companies and others.

**EARLIER REPORTS**

Much has been written regarding the history and special problems of the anthracite region of Pennsylvania. Mine operators, State agencies, Federal departments, and private investigators have made reports showing the seriousness of the mine-water problem at one field or another that emphasize the magnitude of the problem for the region. The consensus expressed in these reports was that a comprehensive survey of the mine-water problem in the entire region was essential, but that such a survey was beyond the ability of a few individuals or companies to undertake. These reports are largely responsible for the present interest of the Federal Government, as reflected by the appropriations made by Congress during the past few years for a comprehensive survey of the anthracite-mine-water problem.

Earlier reports and studies, both published and unpublished, have been utilized in preparing this report. Among the unpublished reports is one by the Secretary of the Lackawanna Water Commission, recognizing the seriousness of the mine-water problem in the Lackawanna region and describing restrictive rules regarding mining adjacent to the Lackawanna River. Another unpublished study of the mine-water problem, made in 1945 by L. N. Evans, retired State mine inspector, recommends a drainage tunnel from the Northern anthracite field to the Delaware River in the vicinity of Easton, Pa., for the solution of the ever-increasing flood hazards.

In 1950 the Pennsylvania State Planning Board also recognized the importance of the anthracite industry and the increasing danger to this important economic unit from flooding and recommended the creation of a joint legislative committee for the study of the problem and for preparing engineering plans for the construction of mine-drainage tunnels.

**ACKNOWLEDGMENTS**

Acknowledgment of indebtedness for aid in collecting data for this report is made to officials of anthracite-mining companies; Pennsylvania Department of Mines; Pennsylvania Department of Forests and Waters; Anthracite Institute; I. A. Winter, chief, Hydraulic Machinery Branch, and staff, Federal Bureau of Reclamation, Denver, Colo.; Kenneth M. Huston, senior research engineer, and Armco Steel Corp., Baltimore, Md.; Roy Carter, manager Volute Pump Section, Worthington Pump Co., Harrison, N. J.; H. D. Kynor, Sr., consulting mining engineer, and W. H. Lesser, consultant mechanical and electrical engineer, Federal Bureau of Mines; E. W. Felger, mining engineer, Bureau of Mines, San Francisco, Calif.; and Catharine S. Hower, administrative assistant, of the Washington staff, Bureau of Mines, who reviewed the manuscript.
DESCRIPTION OF ANTHRACITE REGION

The coal measures in the anthracite region of Pennsylvania comprise an area of 480 square miles in 9 counties (Carbon, Columbia, Dauphin, Lackawanna, Luzerne, Northumberland, Schuylkill, Susquehanna, and Wayne) in the northeastern portion of that State. The anthracite region contains four separate and distinct fields—Northern, Eastern, Middle, Western, and Southern. The fields are described in detail in reports relating to the water problem (22, 23, 25, 30, 37, 43, 47, 93). The field boundaries conform closely to the actual geologic conditions that largely influence mining methods and costs of operation.

The anthracite region covers approximately 3,508 square miles (8 percent of the area of the Commonwealth of Pennsylvania). It is in the heart of the richest and most densely populated area in the United States. Every important industry on the North Atlantic coast is within 48-hour freight service of the area. Seventy million people reside within a radius of 500 miles from the region, and 130,000 manufacturing plants employ 8 million factory workers who receive more than 60 percent of the industrial payroll of America (220). The extent and general configuration of the four fields and the region are shown in figures 1 and 2.

ANTHRACITE INDUSTRY

ECONOMIC DEVELOPMENT

Mining, preparation, shipping, and marketing of anthracite, the services and supplies required to maintain the anthracite industry, and the buying power of the anthracite industry's employees obviously affect an area extending far beyond the borders of the State. In fact, the economy of the entire northeastern section of the United States depends to an appreciable degree on the anthracite industry (21, 112, 213, 219, 259).

Although the anthracite region of Pennsylvania contains one of the most valuable of fuels, it has been in a depressed condition for more than 3 decades. The original economy of the area was based predominantly on the exploitation of anthracite deposits. Regional economies, based on mineral exploitation, have had long periods of decline in the past, with resultant economic depression for such areas. Solving the social problems of the area has seldom gone beyond giving temporary relief funds by governments. Frequently, this type of aid has perpetuated a depressed economic region (22, 33, 204, 214, 220, 260).

Because the demand for anthracite has been declining since 1920, a loss of income for the region has resulted. Plans to develop other industries have been sporadic. The area continues to be one of the economic trouble spots in the State. Unemployment is always highest in this area. Economic opportunities are lacking in the region, and the population is decreasing because the young people migrate to areas of greater opportunity. Unless the present problems are solved, the area will continue to decline and so affect the entire economic stability of the State and the Nation.

The position of the United States in World affairs depends, to a large degree, on her success in maintaining supplies of minerals essential to her industrial well-being. Coal is the primary requisite for making steel, and distribution of the coal reserves will continue to be the principal factor determining the industrial pattern of the world of tomorrow (51, 55, 78, 214, 260). The significance of conserving the anthracite reserves of Pennsylvania for the Nation is of paramount importance, and their judicious conservation is a responsibility of government. As of January 1, 1952, anthracite-reserve data can be summarized as shown in table 1.

SIZE AND IMPORTANCE

Anthracite mining, although still a major producer of mineral wealth in the United States, has shrunk greatly. During World War I, the anthracite industry employed 180,000 men and produced 100 million tons of anthracite a year, while in 1952 it employed only 65,923 men and produced 40,582,558 tons. The payroll for these employees in 1952 was $228 million—more than the payroll for the entire metal-mining industry throughout the United States for that year—and the anthracite had a value of $379,714,076. Employment in 1952 was the lowest since 1878, and production the lowest since 1886 (93). As
Figure 1.—Extent and Configuration of the Anthracite Region of Pennsylvania.
Figure 2.—Line of Proposed Main Drainage Tunnel From Throop (Eddy Creek), Pa., to Conowingo, Md., or to Marcus Hook, Pa.
Table 1.—Summary of anthracite reserves, January 1, 1952

<table>
<thead>
<tr>
<th>Field</th>
<th>Original estimate, million tons</th>
<th>Depletion, million tons</th>
<th>Left, million tons</th>
<th>Recovery under present mining practice, percent</th>
<th>Available, million tons</th>
<th>Life, years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lackawanna Basin</td>
<td>2,030</td>
<td>1,605</td>
<td>425</td>
<td>70</td>
<td>297</td>
<td>33</td>
</tr>
<tr>
<td>Wyoming Basin</td>
<td>4,010</td>
<td>2,140</td>
<td>1,870</td>
<td>70</td>
<td>1,309</td>
<td>65</td>
</tr>
<tr>
<td>Eastern Middle</td>
<td>685</td>
<td>624</td>
<td>61</td>
<td>79</td>
<td>48</td>
<td>12</td>
</tr>
<tr>
<td>Western Middle</td>
<td>5,140</td>
<td>1,706</td>
<td>3,434</td>
<td>66</td>
<td>2,265</td>
<td>190</td>
</tr>
<tr>
<td>Southern</td>
<td>10,880</td>
<td>1,434</td>
<td>9,446</td>
<td>50</td>
<td>4,723</td>
<td>420</td>
</tr>
<tr>
<td>Subtotal</td>
<td>22,745</td>
<td>7,509</td>
<td>15,236</td>
<td></td>
<td>8,642</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>Total</td>
<td>22,805</td>
<td>7,509</td>
<td>15,236</td>
<td></td>
<td>8,702</td>
<td></td>
</tr>
</tbody>
</table>

anthracite is sold and used for heating homes and generating industrial power throughout the northeastern part of the United States and Canada, the anthracite industry thus provides additional substantial revenues to railroads, truckers, and retailers in a great number of localities.

Estimated figures indicate that during 1954 only 41,500 persons were employed and 26.1 million tons of anthracite was produced. The payroll for these employees in 1954 was $165 million, and the anthracite had a value of $285 million. Employment in 1954 was the lowest since 1871, and production the lowest since 1878. Seven mines were closed during April 1954 (25 were closed during April 1955). The transportation of anthracite from the mines to the ultimate consumers throughout the northeastern part of the United States and Canada provided additional revenues of approximately $84 million to United States railroads, $10 million to Canadian railroads, $12 million to truckers, $100 million to retail dealers for distribution, and $1.5 million as transportation taxes to the Federal Government. Although 1954 may rank as the poorest year in the history of the anthracite industry, it contributed almost $500 million to the national economy.

As mining is the basic industry in the anthracite region, the abandonment of properties will have a marked, deleterious effect on the people, industries, and local communities dependent on the anthracite industry for a livelihood.

Because coal reserves in Pennsylvania are taxed as real estate, anthracite-producing companies are assessed for their coal holdings. Consequently, the municipalities and counties in the area depend largely for their local taxes on assessments levied on active coal reserves. Inundated coal reserves, however, are not assessed or are assessed at very reduced rates; hence the flooding of mines, active or abandoned, not only deprives the area of income from mining but also from tax revenue.

The threat to the economy of the anthracite region posed by the water problem is complicated by another—competition from other fuels. Since the close of World War II, the anthracite industry has lost heavily to oil and natural gas in the residential heating market. The susceptibility of anthracite to competition may be attributed to several factors, but spectacular increases in costs of producing and transporting anthracite have been responsible for some of the loss (22, 37, 45, 74, 93, 122, 220).

Experience gained in World War II indicates that, should the country become involved in a world-wide conflict, Pennsylvania anthracite again would have to assume a larger part of the fuel load. The United States became a net importer of petroleum products in 1947 for the first time and has continued in that position. If our supplies of foreign oil should be cut off by enemy action, the rapid expansion of our domestic oil and coal production would be necessary. A rapid increase in the output of coal can be accomplished only by a healthy coal industry; therefore, further increases in the cost of mining anthracite, additional losses to

**ECONOMIC DISCUSSION**

Five billion tons of anthracite has been mined and marketed from a relatively small area of northeastern Pennsylvania during the past 150 years, yet the most reliable estimates indicate enough anthracite remains to support current production for about 200 years (37, 51, 54, 55, 73). The value of anthracite produced in any recent year has totaled hundreds of millions of dollars, and this vast reserve of fuel is extremely valuable to the economy of the United States.
competitive fuels, and the possibility of losing billions of tons of an extremely valuable natural resource are conditions seriously affecting the future of the anthracite industry.

DISTRIBUTION AND MARKETING

The Pennsylvania anthracite fields have contributed heavily to the fuel requirements of the eastern United States. Their nearness to heavily populated centers and the vast bituminous-coal fields lying to the south and west resulted in Pennsylvania anthracite being distributed most widely in the area north of the Potomac and east of the Allegheny Mountains. Anthracite's primary market area consists of the New England and Middle Atlantic States, Delaware, Maryland, and the District of Columbia. This market took slightly more than 80 percent of total shipments and about 96 percent of all shipments to destinations in the United States during the 1951–52 coal year. Canada, with approximately 9 percent of the 1951–52 coal-year shipments, ranks as the second most important market, and the Great Lakes area ranks third.

Although exports of anthracite to Europe were substantial in some years after World War II, the demand for American anthracite is expected to disappear entirely as European production improves. The Canadian market may continue to take an important tonnage of Pennsylvania anthracite for many years, but Great Britain may be expected to make every effort to expand her trade in Welsh anthracite in that direction.

Important changes have occurred during the past 2 or 3 decades in the distribution of anthracite, not only in the volume shipped to particular markets but in greater utilization of the smaller sizes. Another significant development has been the growth of truck shipments. Before the 1930's, truck transportation of anthracite outside the producing region area was a minor factor; however, during the 1951–52 coal year, 3,652,000 net tons was shipped by truck to points outside the region. The movement of anthracite by truck not only has remained fairly stable over the past few years but has actually increased its percentage of the industry's total output. On the other hand, falling production has had serious repercussions on the traffic handled by rail, lake, and tidewater carriers.

Before the 1930's, pea and the larger sizes of anthracite accounted for more than 70 percent of the total shipments. The introduction of the automatic stoker and improvements in grates, boilers, and firing techniques for industrial and commercial installations have increased the demand for smaller sizes. However, as pea and larger sizes at higher prices represent profit items and the smaller sizes at lower prices break even or, in some cases, are loss items, the decline in shipments of the larger sizes has created a serious problem for producers. Although the cost of fuel may not always be the deciding factor in residential-heating installations, heating value delivered per dollar is of primary concern to the large commercial or industrial consumer. Moreover, the anthracite industry in the past has found that in many localities outside the anthracite region (where the industry enjoys the advantage of short hauls) prices quoted on the smaller sizes had to be equal to, or lower than, the cost of equivalent heating units obtained from bituminous coal, residual oil, or off-season natural gas. Thus, should the industry attempt to stimulate sales of the larger sizes by price cutting, the consequent necessity of raising prices on the smaller sizes might jeopardize the position of anthracite in the commercial and industrial fields.

RAILROAD FREIGHT REVENUE

The drastic decline in anthracite production has been accompanied by a serious decrease in the revenue obtained by the railroads from anthracite traffic. Increases in freight rates in the past few years have not offset the effects of reduced traffic and, to a certain extent, may have stimulated truck haulage. While anthracite rail traffic has been decreasing at a rapid rate, the tonnage hauled by truck to distant points has not decreased, and the percentage hauled to market by truck has been increasing in recent years. For instance, truck shipments totaled 7,602,772 tons for the 1948–49 coal year, or 15.7 percent of total reported shipments; shipments by truck during the 1951–52 coal year totaled 7,159,857 tons, or 17.9 percent of total reported shipments.

According to a report released by the Interstate Commerce Commission, class I railroads received just under $114 million from the transportation of Pennsylvania anthracite in 1951. In addition, it was estimated in the same report that Canadian lines earned approximately $12 million from the same traffic. The importance of anthracite as a railroad-revenue producer, even in years of low production, is shown by the fact that on the lines of the Eastern District it ranked first on 7 lines, second on 2, and third on 3 in 1951.

Class I roads derived $127 million from anthracite traffic in 1947 and $114 million for the year ending September 30, 1952, a decrease of 9.8 percent despite the increase of 29.5 percent in raw coal charges and 31.9 percent on prepared coal.

The decrease of 34.4 percent, or 16,288,206 tons, between 1948 and 1952 in anthracite traffic on the 9 anthracite-originating lines re-
sulted in less working time for freight crews, yardmen, and administrative personnel and in a loss of business to the industries supplying the railroads. On the basis of an average rate of $3.44 per ton, the decline in tonnage between 1948 and 1952 would have provided the railroads an additional revenue of about $56 million annually.

The latest information available from the Interstate Commerce Commission shows that on the average about 48.5 percent of railroad gross income is used for the payment of wages and approximately 12.6 percent for taxes. On the basis of the 1951 revenue data, it is calculated that rail transportation of anthracite resulted in the payment of approximately $55 million in wages to railroad workers, $14 million in taxes, and an undetermined amount to shareholders in the form of dividends. In addition to the direct taxes paid by the railroads, an unknown but substantial amount of income taxes accrued to Federal and several State governments.

As anthracite ranked first in 1951 as a revenue producer on 6 of the smaller originating lines, second on the Reading, third on the Erie, and tenth on the Pennsylvania, the range in decline of 25.8 percent in anthracite traffic on the Reading to 61.6 percent on the New York, Ontario, and Western between 1948 and 1952 indicates clearly just how severe the impact has been on the earnings of those railroad employees who reside in the anthracite region (11, 36-39, 93, 220).

Undoubtedly, a considerable share of the blame for the present plight of the anthracite industry is attributable to monopolistic or quasi-monopolistic attempts, both in the past and at present, to maintain prices at untenable levels. Much of the damage is already done; it will be a prodigious task to avoid further disruption. If the State should fail to act, the need for conservation of anthracite would indicate that the Federal Government should assume responsibility (23, 43, 45, 113, 237).

IMPACT ON COMMUNITY

Economic conditions have been depressed for many years in the anthracite region of Pennsylvania. As anthracite mining has been the base of the regional economy for decades, fluctuations in demand for coal have been reflected in the economic status of the area. Decreased employment and less job opportunities for younger men entering the labor market result from declining coal production. For instance, in 1940 the industry employed only about one-half as many workers as it did 25 years earlier. As a result of general economic conditions, the United States Department of Labor for some time has classified almost the entire region as a Group IV labor-market area, or one in which the current and prospective labor supply substantially exceeds requirements.

Although the population of the United States increased 14.5 percent, the population of the anthracite-producing counties declined 11 percent between 1940 and 1950. In 1940 about 144,900 workers in the anthracite region were either jobless or employed on Federal emergency work projects; however, increases in categories other than mining and a decrease of 58,600 in the available labor supply had helped to reduce the level of unemployment to 29,300 by 1950. This reduction in unemployment, it is suspected, was effected more largely by a decrease of 132,800 in the population than by a marked improvement in job opportunities (11, 36-39, 93, 220).

The indicated net increase in total employment over the 1940-50 period in the region conceals an important factor in the region's labor conditions. Manufacturing, which is dominated by the apparel industry, has displaced mining as the largest employer. Male workers far outnumber women in the mining industry, but 9 out of 10 employees on apparel-plant payrolls are women. Although total employment increased substantially in the anthracite region over the 10-year period, women jobholders accounted for over 60 percent of the new employment. This change in the composition of the labor force has resulted in a comparative decrease of jobless females and an increase in unemployment among males. The resulting shortage of female workers as contrasted to a substantial surplus of males constitutes a labor condition somewhat peculiar to the anthracite region.

Significant employment increases were registered in many nonmining fields during the decade 1940-50, but the loss in purchasing power due to the decline in coal production, payrolls, and mine employment has been tremendous. On the basis of an average 1952 f.o.b. mine value of $9 per ton, the decrease in output of approximately 17 million tons of anthracite between 1947 and 1952 represents a loss in sales revenue of about $160 million. Inasmuch as the industry as a whole is now thought to be making little or no profit and labor costs, both direct and indirect, represent the major part of the total cost of production, the direct loss to labor may be over $100 million annually. This loss in wages has had a severe depressive effect on all business and financial activities of the region and has, no doubt, adversely affected the local standard of living.

Scranton (Lackawanna County) Area.—The Scranton labor-market area lies in the northern part of the Wyoming coal region and is coextensive with Lackawanna County, which
produced 13 percent of the 1951 output of anthracite. Indicative of the area's lag in industrial activity is its decline in population from 301,200 in 1940 to 257,400 in 1950, a decrease of 14.6 percent as compared with a national increase of 14.5 percent. In 1950 the population of Carbondale was 43,738 and of Greater Scranton 181,778.

Anthracite mining dominated the economy of the Scranton area until late in the 1920's. However, mining employment declined steadily thereafter and in 1952 was only 9,210 men, as compared with 17,800 in 1940 (37, 38). The increased industrial activity due to World War II had only a slight impact on Scranton, as few defense activities entered the area. The major war plant, The Murray Corp., with a peak employment of about 3,600, closed after V-J Day. This establishment has since reopened for the manufacture of household equipment, but the number employed is not up to the wartime level. The percentage of employment in general manufacturing has increased, chiefly because a number of new textile and apparel plants have located in the area since the 1930's. In November 1952, of a total of 85,650 non-agricultural workers, 30,650 were employed in manufacturing, 15,650 in the wholesale and retail trade, and 12,700 in transportation and public utilities.

The Scranton area has been characterized by a serious unemployment problem since 1930. The 1940 census indicated that 39,254 persons, representing 33 percent of the total labor force, were unemployed or engaged in emergency work. This total was reduced considerably during the war, primarily because of emigration and military withdrawals, but the area continued to have a substantial labor surplus throughout the war years. After the close of hostilities, unemployment again skyrocketed and ranged between 10 and 20 percent of the total civilian labor force, falling in November 1952 to 8.7 percent of the labor force. As is thought to be characteristic of the region as a whole, two-thirds of the jobless were males.

Wilkes-Barre (Luzerne County-Wyoming Region) Area.—The portion of the anthracite region in the Wilkes-Barre area with which the following economies are principally concerned is the western portion of the Northern field and is entirely in Luzerne County. Project No. 3 covers the major portion of Luzerne County (59). Over the canoe-shaped coal basin, which reaches a maximum width of over 5 miles in the vicinity of Wilkes-Barre, is situated the most densely populated area of the anthracite region. One large and two medium-sized cities and several smaller communities have a population of over 300,000 people, according to the 1950 census, distributed as follows:

<table>
<thead>
<tr>
<th>Area</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Pittston</td>
<td>61,750</td>
</tr>
<tr>
<td>Greater Wilkes-Barre</td>
<td>169,006</td>
</tr>
<tr>
<td>Greater Nantico</td>
<td>28,881</td>
</tr>
<tr>
<td>Small independent communities</td>
<td>47,672</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>308,300</strong></td>
</tr>
</tbody>
</table>

Because the Wyoming and Lackawanna regions, which form the Northern field, are so closely interconnected economically as to make it difficult to separate them statistically in describing economic conditions of the Wyoming region in detail, special reference is made to the data given under Economic Discussion in Project No. 1 (Lackawanna), which also cover the Wyoming region as well as the Lackawanna region (37).

The Wyoming region, within the last 5 years, has felt the depressed conditions of the anthracite industry and its effect on the local economy as much as any other area in the anthracite region. A decrease in the production of anthracite and a corresponding reduction in employment in the mines have been as pronounced as in other sections of the anthracite region. Although a decrease of 11 percent in the population in the Wyoming region has resulted in a loss of market for anthracite, the people of the Wyoming region have not significantly replaced anthracite with other fuels for home heating, and the Wyoming region still constitutes a market area for local anthracite production.

The Wyoming Basin contains most of the coal reserves of the Northern field and has a potential economic life of over 75 years, provided that flooding from the overflow of the Lackawanna Basin and the cumulative flooding of idle mines within the Wyoming Basin itself can be prevented by the means described in Projects Nos. 1 and 3, which are integral parts of the comprehensive plan (37—39).

If anthracite mining in the Wyoming Basin should be curtailed because of the ever-increasing mine-water problem, the large population centers situated therein will suffer severe economic distress, as the present effort to invite new industries into the region does not appear to meet with reasonable success. Because active and minable coal reserves in Pennsylvania are taxable and unminable or inundated reserves are not taxable, progressive flooding of mines and the extinction of anthracite mining will deprive Luzerne County and the communities in the coal-bearing area of the Wyoming region of a tax revenue, which in 1953 was over $3 million, based on an assessed coal-land valuation in excess of $53 million.

As in other sections of the anthracite region the increase in the number of employed persons in the Wyoming region is deceptive, as the increase is due to more women working in textile, apparel, and similar plants and does not
show the decline in employment of men in the mines. Employment in Luzerne County mines was 27,213 in 1952, as compared with 39,000 in 1940. The drop in the production of anthracite from 19 million short tons in 1944 to 13 million in 1952 represents a loss of $80 million in sales revenue. The direct loss to labor may be over $50 million annually, and this loss in wages has had a depressive effect on all business and financial activities in the Wyoming region (39, 99).

Hazleton (Eastern Middle Field) Area.—The Hazleton (Eastern Middle field) area is in the east-central part of Pennsylvania. Most of it is in the southern part of Luzerne County, and the remaining portions are in the adjoining areas in Schuylkill, Carbon, and Columbia Counties (47).

Completion of the Beaver Meadow Railroad from Beaver Meadow to a shipping point on the Lehigh Canal in 1836 gave anthracite mining in the Hazleton area its real beginning; although a small amount of anthracite had been mined before 1836, shipments in that year were 1,473 gross tons. Production increased with the increase in transportation facilities and the demand for anthracite to a peak of 8,855,989 net tons, including fuel used at the collieries, in 1914. Production was maintained near this figure until 1923, when a gradual reduction began. In 1952 the production was 2,945,505 net tons (93).

Employment likewise increased at the mines until 1894, when 19,329 people were employed and 7,704,332 net tons of anthracite was produced. By 1948 the employment had dropped to 6,599, a figure almost identical with the employment for 1870, when 6,578 people were employed and 3,584,159 net tons of anthracite was produced (47).

Three factors that contributed to this decrease in the number of employees after 1894 were (1) the development of strip mining, (2) the introduction of mechanical equipment, and (3) the depletion of the more readily minable anthracite.

During the 1870's the recovery of anthracite by stripping the overburden was begun. In its infancy, this was done by hand-loading the material into dump carts. This method yielded to more efficient methods and mechanical equipment, such as steam shovels; later, dragline shovels, driven by electric motors or diesel engines, were used. These units increased in size and efficiency through the years and provided a greater range for stripping operations. Shortly before 1920 experiments were made with mechanical coal-loading equipment. These early types were relatively crude and inefficient; but, as later models were developed, their use became more general. The application of me-

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chanical equipment increased the production for each man employed.

The third and most serious factor in the decreased number of men employed is the decrease in the amount of anthracite in beds of minable thickness and good quality that remain in the field. Depletion of reserves in this field has progressed with diminishing employment and production, and this trend probably will continue. Low points (1887, 1902, 1922, and 1925) in employment and production were caused by periods of suspended operation.

The downward trend in employment of those engaged in anthracite production in the Hazleton area is evident. Nevertheless, the importance of the industry to the economic life of the area must be considered. In 1948 more than 6,500 people were employed at the mines. This figure was drastically reduced during 1952-54. When the number of employees in allied and related occupations is added to this figure, the number of wage earners directly and indirectly dependent for their livelihood upon the production of anthracite is approximately 8,000. It may be assumed that 40,000 of the approximately 95,000 people who live in this area depend wholly or in part upon anthracite mining for their livelihood.

During 1948, anthracite production in this field amounted to 4,524,632 net tons, including the fuel used at the mines. The value of this production at the breaker exceeded $44 million. In 1952 the production had dropped to 2,945,505 net tons at a value of $26,510,000.

Pottsville (Carbon, Schuylkill, Columbia, and Northumberland Counties) Area.—The portion of the anthracite region comprising the Pottsville area in turn comprises the Western Middle and Southern fields, extending over a four-county area—Carbon, Schuylkill, Columbia, and Northumberland Counties. Within this area about two-fifths of the population (generally allocated to the anthracite region) resides in medium-sized communities, the most important of which, with 1950 population figures, follow:

<table>
<thead>
<tr>
<th>Communities</th>
<th>Population, 1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lansford</td>
<td>7,487</td>
</tr>
<tr>
<td>Tamaqua</td>
<td>11,308</td>
</tr>
<tr>
<td>Pottsville</td>
<td>23,640</td>
</tr>
<tr>
<td>Minersville</td>
<td>7,783</td>
</tr>
<tr>
<td>Tremont</td>
<td>2,102</td>
</tr>
<tr>
<td>Mahanoy City</td>
<td>10,934</td>
</tr>
<tr>
<td>Shenandoah</td>
<td>15,704</td>
</tr>
<tr>
<td>Ashland</td>
<td>6,192</td>
</tr>
<tr>
<td>Mount Carmel</td>
<td>14,222</td>
</tr>
<tr>
<td>Shamokin</td>
<td>16,879</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>116,451</strong></td>
</tr>
</tbody>
</table>

The economic condition in this four-county area has been depressed for many years because of the steady decline in production and sale of
anthracite. As a result, many high-cost mines were closed and subsequently permitted to fill with water, adding considerably to the already high pumping costs of adjoining operating mines. In 1953, 40 percent of the once active mines in the area were idle and filled with water, and, with the exception of a few, all still contain considerable anthracite reserves that can be recovered only if the immense pools of water covering them can be drained.

The Schuylkill County area, which accounts for 32 percent of the production of anthracite, showed a decline of almost 28,000 in the population between 1940 and 1950. Anthracite mining is the area’s principal activity, employing about one-fourth of the 58,300 wage earners in the area in 1952. Unemployment in 1952 was estimated at 7.5 percent of the total labor force, and 90 percent of the jobless were males. Reduction of unemployment since 1940, when the unemployed was almost 35 percent of the total labor force, is largely the result of out-migration and the practice of illegal mining, which is commonly known as “bootlegging” (20).

The region comprising the Pottsville (Western Middle and Southern fields) area is serviced by five railroads, which derive a total revenue of approximately $80 million per year from anthracite traffic. In 1952 the region produced 21,129,-161 net tons, which is slightly over 50 percent of the annual output of the entire industry; this contributed to the economy of the area an estimated annual income of $130 million in payroll, from which an undeterminable amount for Federal income taxes was realized (38, 98).
The importance of adequate subsurface investigation in planning large engineering projects is so generally accepted that it requires little discussion. The extent of such investigation is, however, a matter of the most critical judgment and demands an analysis from several points of view. The only way to get a true, undisturbed sample of the bedrock is by core drilling, and the cores may be obtained by a diamond drill or a shot drill (40, 48).

The presence of enormous volumes of water in anthracite mines is attributable to both nature and man (21, 28, 31, 37, 40, 41, 45-48). The geologic structure of the coal measures in the anthracite region is typically "basin-and-range," and the beds dip from the mountainsides to the valleys below, thus facilitating the accumulation of water. All drainage in the valleys must flow over the coal measures, and the anthracite fields are traversed by 750 miles of rivers and streams in two drainage basins—the Susquehanna River and the Delaware River—straddled by the anthracite measures (130). These rivers and streams normally lose water through their beds, and mining operations near or under these stream beds disturb natural conditions and increase seepage into the mines.

Since the beginning of mining in the Pennsylvania anthracite region, the configuration of the terrain has changed, adversely affecting the original drainage. Continued increase in the number and size of culm banks, cinder dumps, and stripping spoil banks blocks the normal flow of water to surface streams, so that much water now collects in low places and eventually seeps underground. Cracks and caves caused by subsidence permit water to enter underground workings (70, 72, 96, 98, 101-104, 108, 117, 125, 135, 142, 143, 158, 165, 169, 181, 187, 189, 190, 195-197, 200, 201, 208, 235, 234, 239, 240, 289). Denuded woodlands destroy a control of runoff, and solids from breakers and banks pollute and choke stream channels. When streams are in flood stage, water spreading out beyond normal stream banks further increase seepage (23, 27, 29, 30, 43, 52, 50, 101-103, 125, 132, 166).

Early mining took only the best, thickest, and most accessible beds, and little thought was given to conserving reserves for the future. Subsequent mining was made more difficult by this early lack of foresight. Mining at that time was conducted with the primary objective of extracting as much of the beds as possible, without, judicious forethought to the effect of such mining on mine drainage. This is particularly true in the Northern field where the "buried valley" of the Susquehanna River (a clay, sand, and gravel deposit) overlies much of the coal measures and complicates the water problem (21, 96, 145).

Anything which would tend to increase water inflow into a mine, either slowly or rapidly, through cracks or fissures in the rock cover, cave holes caused by subsidence, porous earthen materials, or valley-fill deposits deserves serious consideration (2, 21, 37, 134, 135, 143, 155, 196, 202, 204, 230, 233, 236, 240).

In some respects mining beneath water-bearing valley-fill deposits is similar to submarine mining. No one can predict the volume of water, the water-soaked materials, or the movement of broken strata that might be encountered if the rock cover fails. A valley-fill deposit, having a deep layer of clay covering the bedrock is favorable for sealing small fissures; however, where the bedrock is bare or covered by only a thin mantle of mud and silt and the valley-fill deposit is composed largely of sand and gravel, rapid inundation of the mine workings is possible if the rock cover is broken (14, 15, 21, 27, 49, 57, 70, 72, 145, 168, 202, 236).

Darton has covered faults in the region that contains the buried valley of the Susquehanna River (98). The worst disaster in the history of undersea mining—namely, the complete flooding of the Higashieizome colliery, Japan, in 2 hours in 1915, with the loss of 237 lives—was attributed to a fault. The risk of inundation is increased by the presence of deep channels filled with loose material (as in the Wyoming Basin) and of faults, which, if not afoffing an easy ingress to water, may provide such when subsidence has taken place (21, 23, 29, 32, 33, 50, 70, 236).

The terrace deposits that blank the valley and the glacial-till deposits are described in detail by Darton (96) and Itter (157).

Experience confirms the fact that inaccurate plans or maps or their absence has been the primary cause of accidents by inundation of water or water-laden materials (14, 15, 28, 49, 57, 71, 258, 291). Neglect of precautions is the
second cause, followed by errors of judgment.

A comprehensive report (21) gives detailed data on the buried valley of the Susquehanna River that will be helpful in solving the anthracite mine-water problem. It discusses the physical characteristics and the influence of the buried valley of the Susquehanna River on anthracite mining in the Wyoming Valley area of the Northern field, correlates pertinent data relating to the buried valley, presents accurate contour maps showing the position of the top of solid rock underlying the water-soaked valley-fill deposits in the buried valley, and presents cross sections at regular intervals across the buried valley showing the irregularities in trend and bottom as well as the thickness, configuration, and nature of the materials composing the water-bearing valley-fill deposits (21, 60).

The information presented will provide better understanding of the problem involved and thereby assist in conserving anthracite reserves and promoting safety of the men employed in the mines in this area if ample precautions are taken to prevent inundation.

The information in the report was obtained and correlated by studying geological maps and cross sections, mine maps and cross sections showing underground mine workings, borehole records, and other pertinent data obtained from anthracite mining companies and from previous reports (96-98, 119, 134, 145, 176, 287) on the subject.

Twenty-nine boreholes were drilled by the Federal Bureau of Mines in significant areas where data were lacking. Logs of 12,100 boreholes were listed, checked, and then plotted on 125 maps to develop the rock-surface contours underlying the buried valley; however, extensive field work was necessary (1) to establish the position of outcrops of the anthracite measures that protrude through the clay, sand, and gravel deposits to the surface and (2) to correlate data obtained from several mining companies (21).

Mining is conducted with the primary object of safely extracting as much of the anthracite as possible. Although it may be safe to remove a definite portion of the beds, too little attention is being paid to the effect of such mining on the problem of mine drainage.

The engineers of the Federal Bureau of Mines have ascertained wherever possible:

1. The accuracy of plans and maps.
2. The size and thickness of barriers or barrier pillars necessary to hold water safely at various conditions.
3. The effect of faults paralleling or intersecting barriers.
4. The effect of subsidence on a barrier.
5. The method of approach to abandoned or flooded mine workings under different circumstances.

7. The presence of overlying and underlying water and water ahead at a higher level.
8. The circumstances where boreholes are necessary.
10. Precautions to be observed in and after tapping water.
11. The depth at which mining is conducted.
12. The nature of the rock cover.
13. The number and thickness of the beds being worked in the area underlying the buried valley.
14. Any faults or dislocations of the strata that may be present in the area.
15. The method of mining.
16. The proportion of the beds that must be left in place.
17. The thickness of the rock cover that must be maintained.

The geologic structure of the coal measures in the anthracite region is well known because of the hundreds of miles of mine workings and the geological studies that have been made (40, 49, 50, 55, 72, 78, 80, 94, 96-98, 119, 134, 155, 142, 145, 150, 157, 166, 225, 234, 264). The geologic structures concerning mine drainage and formations on or near the alignment of the proposed drainage tunnel are described in the reports on recommended projects (36-39).

Because of the number of anthracite beds, extent of strippings and mine workings near the outcrops, general subsidence, cost of remedial measures, cost of mining active mines, and lack of legal control of mine-drainage practice, it does not appear feasible to prevent undue seepage of surface waters.

An evaluation of the engineering survey by the authors of this report shows that both a short-range and a long-range solution of the anthracite mine-water problem can be best served by a gravity tunnel system, consisting of a main tunnel and two or more main central pumping plants for emergency use. The main tunnel would convey the water to a point near tidewater outside the anthracite region (44). The mine water would be collected at its source and conveyed to the main tunnel by a network of lateral and sublateral tunnels.

A geological study and a set of borings are important to the engineer for the design and location of a structure; they are even more important to the contractor and practical tunnel man. They are like an X-ray plate to the experienced and thoughtful surgeon. They enable them to appraise the hazards and to determine the method of attack, thus permitting the preparation of an intelligent and low estimate. In short, they are the basis for the program of work.

A proper geological study and a good set of borings permit the practical tunnel man to determine his anticipated progress, the quantity of water to be expected, and how to cope with it. They enable him to select the equipment to be used, the amount and kind of drill
steel and dynamite to be utilized, and the means for narrowing down the elements of risk.

As the condition of the ground is the unknown factor in tunneling, obviously the more information available the less the risk and the lower the bid.

In general, the alignment of the proposed gravity-drainage tunnel traverses areas fairly well explored and geologically mapped. Hence, it may be assumed that enough data exist for a preliminary study. However, the history of engineering construction is replete with examples of failure through excessive generalization from previous knowledge and studies. To rely exclusively on adjacent experience or related studies is as hazardous as depending exclusively on test borings (36, 40).

The importance of petrographic examination and identification of the rocks composing the core drillings cannot be overestimated, and no large tunneling project should be attempted without enough core drillings along the tunnel line at tunnel depth. Complete sections and profiles must be drawn to illustrate and record all features in terms that can be evaluated by the contractor and his engineers.

From petrographic data obtained by core drillings, the health and safety hazards, methods of working, time factors, and costs concerning the tunneling project can be evaluated intelligently to formulate specifications, bids, and contracts.

In determining the extent and places to obtain core borings for the proposed tunnel, it was recognized that the present status of the project did not warrant a too extensive investigation; therefore, it was important that the borings yield a maximum of information. The objectives desired were threefold:

1. To confirm and substantiate the geologic profile developed from existing data and surface observations.
2. To determine the conditions to be encountered in shaft sinking.
3. To establish to a reasonable degree the character of the rock.

Consideration of these limited objectives led to diamond drilling at each of the 15 shaft sites of the proposed main drainage tunnel. This decision proved to be sound and yielded information well within the scope of the investigation. The 15 boreholes are approximately 8 miles apart and range in depth from 292 to 1,082 feet (40).

The question was raised as to whether or not water seeps into the mine workings from formations outside the coal measures or whether mine water from the Southern field is seeping or may seep into formations in which the portion of the proposed Conowingo tunnel between the Southern field and the Susquehanna River would be constructed.

To answer the foregoing question, as well as to procure additional geological data that will be of immense value for designing the gravity-drainage-tunnel system, 11 diamond-drill holes were drilled in selected sites (36, 48). Moreover, the Southern field contains the largest amount of anthracite reserves that will be worked to great depths, and mine workings will eventually provide catch basins into which water may seep after mining is completed in the other fields. For the foregoing reasons, it is important to have geological data on adjoining strata. It is believed that the data obtained by the core drilling is adequate for determining the possibility of unusual seepage into or from the mines concerned (36, 40, 48).

A comprehensive study was made of the cores recovered from each of the 26 holes so that the route of the proposed tunnel could be selected to better advantage and contracting firms might have a better understanding of the geological and petrographic qualities of the subsurface strata (36, 40, 48).

Mineral hardness was determined by the standard Mohs' scale of hardness; this information enables a contractor to compute approximate drilling speeds and mucking time. Determinations of free silica were made so that an average percentage of silica is known for each type of rock; therefore, a contractor can, if necessary, remove the dust hazard and prevent occupational disease from harmful dust.

The cores, totaling 13,793 feet in length, are stored at the Bureau of Mines experiment station at Schuylkill Haven, Pa.

The procedure employed for determining the physical and other pertinent qualities of the cores has been described in a Bureau of Mines report (40).

The importance of adequate subsurface investigation in planning large engineering projects consisting of tunnels and underground passageways is so generally accepted that it requires little discussion. The 26 boreholes described in the original reports give a general description of the type and character, particularly the porosity and the permeability, of some of the rocks to be encountered in driving a tunnel from Conowingo, Md., or from Marcus Hook, Pa., to the end of the Northern field (40, 48).

It is recognized, however, that before a project of the magnitude of the proposed gravity-drainage-tunnel system is actually constructed a thorough investigation must be made of the subsurface conditions outside the anthracite measures and adjoining formations. It is further recognized that subsequent inquiry may necessitate changes in alignment. It is
with these purposes in mind that the additional 11 boreholes were completed as part of a comprehensive drilling program (48).

Most of the tunnel in the portions within the coal measures is expected to be driven in hard rock; however, there appears no reason to believe that unusual construction difficulties or excessive costs will result because of adverse geologic conditions (36–39).

No appreciable inflow of water is expected because of the low porosity and the low permeability of the strata that the drainage tunnel will penetrate. Although local faulting occurs in the overlying coal measures, no serious trouble is anticipated (when the tunnel is driven) from large inrushes of water, caving, and squeezing ground because of water-laden fault zones in the hard underlying Pottsville formation. There are no large water-filled solution cavities expected to be encountered, because no known soluble limestone members are present in the formations to be penetrated by this tunnel (36–39).

Information obtained by drilling the 26 boreholes and examining and analyzing the cores recovered shows that seepage into or from the strata penetrated is not unusual, and, with the proper equipment, little difficulty should be experienced in driving underground passageways in the formations. Although some of the holes penetrated strata containing a high percentage of silica, the health hazard from silica dust can be removed by using proper dust-control equipment (40, 48).

The 26 boreholes reveal that no unusual seepage of water from the Southern field is entering into the strata penetrated by those holes. Limestones encountered in the holes did not reveal that unusual difficulties from water could be expected (48).
HYDROLOGY

The hydrology of the anthracite region is set forth in detail and is summarized in reports of the Anthracite Flood-Prevention Section (21, 26, 31, 41, 48).

RAINFALL IN THE ANTHRACITE REGION

Mine water originates as rainfall. The seepage of surface water into mine workings varies greatly. Surface streams flowing over glacial deposits overlying coal measures in the Northern field introduce another seepage factor that confuses the direct relationship between rainfall and infiltration. It is therefore difficult to evaluate the benefits that have been derived from any work that has been done toward preventing or minimizing the seepage of surface waters or to show definite economies to be derived by diverting the runoff into flumes, ditches, and pipes (21, 41-44).

Over a long period some mine operators have vigorously attempted to control the seepage of surface water, but in spite of these efforts the volume of surface water seeping into the mines continues to trend upward. Local improvements in surface-drainage facilities undoubtedly have resulted in reducing the quantity of water seeping into the mines, and future projects designed for that purpose will continue to do so. There is little doubt that in every instance water retained on the surface of the ground and diverted to surface-drainage channels has been handled more economically than it would have been by pumping it from the mines (41, 47, 150). The wide difference in rainfall from year to year and from locality to locality during the past 24 years is characteristic of the Pennsylvania anthracite region.

Table 2 shows the annual rainfall for 24 years (1930-53) as recorded at gaging stations in the anthracite region at Wilkes-Barre and Scranton in the Northern field, Hazleton in the Eastern Middle field, Shamokin and Mahanoy City in the Western Middle field, and Pottsville in the Southern field. The annual rainfall recorded ranges from a minimum of 26.12 inches at Scranton in 1930 to a maximum of 66.74 inches at Pottsville in 1952. The average annual rainfall at individual stations from 1930 to 1953 ranges from 37.31 inches at Wilkes-Barre to 49.12 inches at Pottsville. Figure 3 shows the average rainfall and trend for 1930-53.

![Graph showing average rainfall and trend, based on readings from six stations in the Anthracite Region, 1930-53.](image-url)
Hydrology

Maximum values of rainfall are important in the anthracite region. Pumping and drainage facilities and reserve sump capacity must be able to handle the maximum inflow of water from flash floods, which are prevalent. Sudden flooding of mine workings has occurred, sometimes with loss of life, but always with loss of wages and anthracite production and with considerable expense to mine owners for unwatering and reopening the mines (21, 25, 46).

Table 2.—Rainfall in anthracite region (inches), 1930–53

<table>
<thead>
<tr>
<th>Year</th>
<th>Northern field</th>
<th>Eastern Middle field</th>
<th>Western Middle field</th>
<th>Southern field</th>
<th>All fields (average)</th>
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<tbody>
<tr>
<td></td>
<td>Wilkes-Barre¹</td>
<td>Scranton²</td>
<td>Hazleton³</td>
<td>Shamokin⁴</td>
<td>Mahanoy City⁵</td>
</tr>
<tr>
<td>1930</td>
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<td>26.12</td>
<td>29.86</td>
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<td>37.07</td>
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<td>46.15</td>
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<td>35.26</td>
<td>47.07</td>
<td>43.88</td>
<td>50.44</td>
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</table>

Average: 37.31  37.36  46.80  42.83  47.91  49.12  43.55

Taken from the records of:
¹ Wilkes-Barre Water Co.
² Scranton Water Co.
³ Hazleton City Authority.
⁴ Roaring Creek & Bear Gap Water Co.
⁶ Philadelphia and Reading Coal and Iron Co.
SEEPAGE OF SURFACE WATERS INTO MINES

As part of the engineering study by the Federal Bureau of Mines, surface-water-seepage problems were investigated in the Lackawanna Basin, Wyoming Basin, Western Middle field, and Southern field (26, 31, 41, 48).

The volume of water entering mine workings during and after any period of rainfall varies greatly in adjoining basins and even in adjoining mines in the same field because of differences in the condition of the strata as affected by the progress of the extraction of the anthracite, particularly that from the uppermost beds. The ratio between runoff and seepage varies for each period of rainfall in any given area because of variables in the rate of rainfall, duration of storms, rate of evaporation that depends on the temperature and humidity, transpiration dependent on the season and the amount of vegetable life, status of the water table, frost that seals crevices in the ground, and the presence of anchor ice that seals the bottoms of streams.

Surface water that seeps into underground mine workings can be attributed to the following sources:

1. Stream-bed seepage.
2. General surface seepage.

Little is known about barrier-pillar seepage (24, 34, 48).

STREAM-BED SEEPAGE

Seepage from the beds of streams is an important source of water that seeps into mine workings. Every stream crossing the coal measures loses some of its water, which eventually enters underground mine workings. Because the loss at any particular point is usually small and the distance between the point where the water left the stream and the point where it entered into the mine workings may be great, it is impossible to measure accurately the amount of such seepage or to apply corrective measures, except in small streams.

Natural stream beds are pervious; however, streams must continue to serve as the ultimate discharge points for mine pumps and underground drains, unless some other means are utilized. Stream beds overlying the coal measures are usually less pervious than the ground surrounding them because mining operations directly beneath the streams have been conducted to prevent or to minimize breaks in the rock strata underlying the streams; moreover, water escaping from the channels of rivers and streams enters into the mine workings through fissures and cracks caused by subsidence, bedding planes in the rock strata, natural cleavage planes, and faults.

Although many small apertures in the rock strata become sealed with silt and sludge, numerous openings are made by mining subsidence. A large volume of water seeps into the mine workings through these openings in the 750 miles of stream beds crossing the coal measures (53).

Water pumped or drained from a mine and conducted to a natural surface watercourse is not necessarily confined to this watercourse but may contribute to the volume of water that must be pumped from some other mine that is farther downstream.

The addition of a relatively small volume of water, such as the discharge from a pump or the flow from a mine drift or drainage tunnel, does not necessarily increase the seepage that will occur from a stream channel in a given distance. Stream seepage is a function of the number and size of openings lying within the wetted perimeter of the stream channel, rather than the quantity of water flowing in the stream. The seepage will not increase unless the volume of water added to the stream is enough to increase appreciably the cross section of the stream channel in contact with the water (191). A noticeable increase in the depth of water flowing in the channel of a river or stream after a heavy rain will denote an increase in seepage because of the increase in the wetted perimeter of the stream channel (191).

Many of the smaller streams lose all their water soon after crossing the outcrop of the lowest anthracite bed where they enter the area that overlies the coal measures. These streams carry water throughout their original length only during periods of heavy runoff. Throughout the greater part of the year, their entire flowage, ranging from a few gallons to several thousand gallons per minute, seeps into the mine workings (38).

A study of larger streams (32) shows a very marked decrease in flow between where they intersect the outcrop of the coal measures and
the confluence of these streams with the main stream at almost all periods when relatively low water permitted comparable observations. However, at the same stages of water, such decrease did not occur when the bed of the stream was sealed by anchor ice.

GENERAL SURFACE SEEPAGE

Rock fissures, cave-ins, fissures in outcrops, and strippings, either on the flood plains of streams or on drainage areas, provide easy ingress to much of the surface water that seeps into both active mines and abandoned mine workings. Strippings particularly contribute heavily to this seepage because of the removal of overburden and because of the longitudinal extent of strippings along the outcrops of the anthracite beds. Many fissures and cave-ins are not visible on the surface because they are hidden under refuse banks or are partly filled with dirt; nevertheless, these openings contribute much to water seepage.

The dry beds of thousands of small former watercourses are evidence of the general disturbance of the surface of the ground that follows extraction of the anthracite beneath them. Some operating companies have dug ditches and built flumes to divert the runoff into natural stream channels after a rainstorm in permeable areas. However, that part of the precipitation that would have become ground water and later would drain into these small watercourses now seeps into mine workings and thus leaves these watercourses dry (22, 43).

A reconnaissance was made of each stream and its drainage area from where it enters the coal measures to its confluence with a major stream. Inhabitants in the affected locality were questioned as to the frequency of dry-stream-bed occurrence and the extent of areas inundated during flood periods.

Because of the number of beds, extent of strippings and mine workings near the outcrops, general subsidence, likelihood of squeezes as mining progresses, cost of remedial measures, cost of mining active mines, and lack of legal control of mine-drainage practice, it is impossible to prevent undue seepage of surface waters (24, 43–45, 47). Drainage tunnels in the anthracite region should be maintained and their destruction prevented.

LACKAWANNA BASIN, NORTHERN FIELD

The Lackawanna River and its tributaries drain a troughlike area of 345 square miles. The syndinal axis of this trough lies within the coal measures. All surface drainage into the valley must traverse some part of the coal measures. On the basis of 45.03 inches of rainfall recorded by the Scranton station of the United States Weather Bureau for 1948, the runoff from the Lackawanna River drainage area during that period was 155 billion gallons, approximately 3 times the volume of water pumped by all mine pumping plants in the Lackawanna Basin of the Northern field during 1948. In other words, because of the pervious condition of the strata overlying the mine workings, approximately one-third of the total runoff in the Lackawanna River drainage area becomes mine water.

Fifty-two streams (excluding the Lackawanna River) overlying the Lackawanna Basin were investigated and are covered in a report (41). This report reveals that less than 7 percent of the 72 miles of pervious stream beds examined between Archbald and Pittston have been improved.

Approximately 22 percent of the water pumped annually from mines in the Lackawanna Basin arrives underground as a result of direct surface seepage (41, 45). An equal volume seeps into mine workings through the pervious beds of 52 streams, which flow over some portion of the coal measures. The remaining 56 percent of mine water pumped to the surface seeps into mine workings through the bed of the Lackawanna River.

A program of remedial measures, designed to prevent the major portion of surface-water seepage into mines underlying the Lackawanna River drainage area, must not only consider seepage from streams and their watersheds but also the insuperable problem of stream-bed seepage from the Lackawanna River itself. Such a program must also consider proper maintenance of surface works until reserves are exhausted in the Northern field (Lackawanna and Wyoming Basins) (31, 41). Any concerted effort to prevent surface-water seepage into mine workings of the Lackawanna Basin cannot achieve more than half its objective unless the bed of the Lackawanna River is made impervious.

Because the problem of making the bed of the Lackawanna River (contributing 56 percent of the leakage) impervious is economically and physically impossible and because the beds of all streams contribute only an estimated 22 percent of the total seepage, remedial measures applied to these streams would rectify only a minor part of the total problem. The investigation shows that, in some instances, much can be done to lessen the pumping load by repairing the beds of streams in the areas most seriously affected and thereby relieve the burden of cost now borne by some mining companies.
WYOMING BASIN, NORTHERN FIELD

The magnitude of the anthracite industry's drainage problem in the Northern field, of which the Wyoming Basin is the major part, is realized when it is known that for the 8-year period 1944–51 all pumping plants in this region pumped an average volume of 112.5 billion gallons of water from the mines to the surface each year. This is more than 214,000 gallons per minute (g.p.m.) pumped against an average hydrostatic head of 400 feet each year for that period. By comparison, Lake Wallenpaupack, the largest artificial body of water lying wholly within Pennsylvania, contains 71 billion gallons of water in its 24-square-mile area. The average volume of water pumped from the mines in the Northern field each year during the 8-year period was 58 percent more than the volume impounded in Lake Wallenpaupack.

The natural configuration of the drainage area overlying the Northern fields subdivides the total area into two major drainage areas— the Lackawanna River drainage area and the drainage area of the Susquehanna River overlying the Wyoming Basin (31, 41). Although the 169-square-mile drainage area overlying the Wyoming Basin is slightly less than half that of the Lackawanna River drainage area, the total volume of water pumped to the surface from mines in the Wyoming Basin is 21 percent more than the total volume pumped to the surface from mines in the Lackawanna Basin. From this, it is apparent that the Susquehanna River flowing over the pervious deposits in the buried valley in its course across the coal measures of Wyoming Valley is the greatest single source of mine water affecting mines in this area. Because of its relatively flat terrain the wide flood plain of Wyoming Valley does not facilitate rapid runoff; consequently, much of the surface water seeps directly into the buried-valley deposits and eventually into the mine workings (21).

Approximately 30 percent of the water pumped annually from mines in the Wyoming Basin arrives underground as a result of direct surface seepage. Twenty-one percent seeps into mine workings through the pervious beds of 59 streams, which flow over some portion of the coal measures. The remaining 49 percent of mine water pumped to the surface seeps into mine workings through the bed of the Susquehanna River (31, 45).

A program of remedial measures designed to prevent the major portion of surface-water seepage into mines underlying the Susquehanna River drainage area must not only consider seepage from streams and their watersheds but also the insuperable problem of stream-bed seepage from the Susquehanna River itself. Such a program must also consider proper maintenance of surface works until reserves are exhausted in the Northern field (Lackawanna and Wyoming Basins). Any concerted effort to prevent surface-water seepage into mine workings of the Wyoming Basin cannot achieve more than half its objective unless the bed of the Susquehanna River is made impervious (19, 22, 31, 45).

Because the problem of making the bed of the Susquehanna River (contributing 49 percent of the leakage) impervious is economically and physically impossible and because the beds of all sidestreams contribute only an estimated 21 percent of the total seepage, remedial measures applied to these streams would rectify only a minor part of the total problem. This investigation shows that, in some instances, much can be done to lessen the pumping load by repairing the beds of streams in the areas most seriously affected and thereby relieve the burden of cost now borne by some mining companies.

WESTERN MIDDLE FIELD

The magnitude of the drainage problem of the anthracite industry in the Western Middle field is realized when it is known that in 1951 the pumping plants in the mines in this field pumped nearly 36 billion gallons of water to the surface. This is almost 68,000 g. p. m. pumped against an average hydrostatic head of 350 feet for that year. In 1948 over 20,000 g. p. m. was pumped by relay pumps against an average hydrostatic head of 265 feet. In addition to the water pumped to the surface it is estimated that 15,000 g. p. m. overflows to the surface from underground pools in idle mines. The volume (second-feet) of water pumped and overflow water is almost 1 ½ times the average mean flow of the Schuylkill River at Pottsville for the 8-year period 1944–51 (26, 45).

The Mahanoy and Shamokin Creeks drain an area of 99 square miles in the Western Middle field, and all surface drainage in this area must traverse some part of the coal measures before entering these streams. On the basis of 46.03 inches of rainfall (the weighted average of 6 recording stations for 1948), the runoff from the drainage area during that period was 51 billion gallons, approximately 1 ½ times the volume of water pumped by all mine pumping plants in the Western Middle field. Because of the pervious strata overlying the mine workings, approximately two-thirds of the total runoff in the drainage area becomes mine water tributary to the pumping plants.

A major problem in the Western Middle field is the surface-water seepage that enters active mines from pools in abandoned mines because of inadequate barrier pillars; this seepage is ap-
proximately 27 percent of the water pumped to the surface (24, 26, 43, 45).

Approximately 67 percent of the water pumped annually from mines in the Western Middle field arrives underground as a result of direct surface seepage, 5 percent from pervious stream beds, and 1 percent from the beds of the Mahanoy and Shamokin Creeks. The remaining 27 percent of mine water pumped to the surface seeps into underground pools in idle mines and then flows to various pumping plants through or around barrier pillars that are not capable of confining the water to the respective pools.

Approximately 90 percent of the seepage into the mines (active and idle) in the Western Middle field is due to general surface seepage from the watersheds; the remaining 10 percent is from stream beds. There is no justification for any program of remedial measures to be applied to the stream beds, as this would rectify a very minor part of the total problem.

**SOUTHERN FIELD**

In 1951 pumping plants in the Southern field pumped 17 billion gallons of water to the surface from the mines. This is almost 32,000 g. p. m. pumped against an average hydrostatic head of over 440 feet for that year. In addition to the water pumped it is estimated that 40,000 g. p. m. overflowed to the surface from underground pools in idle mines. The total of the water pumped and overflow water is almost 1½ times the average mean flow of the Schuylkill River at Pottsville for the 5-year period 1944-48 (45, 48).

The streams investigated drain an area of 211 square miles. On the basis of 58.56 inches of rainfall recorded at Pottsville for 1951, the runoff from the drainage area during that period was 107 billion gallons, approximately 3 times the total volume of water pumped and overflow water. Because of the pervious condition of the strata overlying the mine workings, approximately one-third of the total runoff in the drainage area becomes mine water tributary to pumping plants and underground pools (48).

Approximately 92 percent of the seepage into the mines (active and idle) in the Southern field is general surface seepage from the watersheds; the remaining 8 percent is seepage from stream beds.

Of the 211 square miles of drainage area, 88 are outside the coal measures, 75 are under-mined, and 48 are within the coal measures, which are relatively undisturbed by mining and have favorable runoff conditions.

Seepage into mines in the Southern field is concentrated within the 75-square-mile area, which is approximately 41 percent of the area (181 square miles) of the coal measures in the Southern field (48).

Because of the number of anthracite beds, the extent of strippings and mine workings near the outcrops, general subsidence, cost of remedial measures, cost of mining active mines, and lack of legal control of mine-drainage practice, it does not appear possible to prevent undue seepage of surface water into the mines (24, 43, 45, 48).

The largest reserves of anthracite lie in the Southern field where mining conditions are the most difficult. The future problem is concerned with providing such facilities as will permit the operation of mines at minimum expense and maximum safety. Future drainage arrangements are of major importance, because ultimately this field will be the sole remaining source of anthracite production that must come from underground mines.
UNDERGROUND WATER POOLS

One hundred and six billion gallons of water was impounded at the end of 1952 in 150 pools in underground mine workings that are not tributary to present drainage systems (19, 22, 48, 49, 129). The closing down of mines in 1954 and 1955 has increased this volume tremendously.

Abandoned mines will accumulate pools of water because no one is financially interested in removing them. The operator of the adjoining property is forced to protect his own property and the lives of his workmen by holding the water in the abandoned property at an altitude deemed safe and determined in consultation with the State mine inspectors for the district. If this active mine, in turn, ceases operation for any reason whatsoever, the same procedure is followed, resulting in the enlargement of the pool and possibly a rise in the altitude of the water level (24, 123, 133, 221, 233).

In some instances pools of water have been created purposely in parts of active mines having barrier pillars that separate the active mines from the abandoned mines filled with water. These pools have a stabilizing effect and reduce the hydrostatic pressure exerted on the barrier pillars by water in the abandoned mines.

In addition to the known underground water pools in the separate anthracite fields, hundreds of small pools are present in abandoned bootleg mines. These pools are a menace to future mining because it is impossible to obtain information in regard to their size and position, not necessarily because of the volume of water impounded in them. Thousands of these small mines have been opened from the outcrops and other areas where only a thin mantle of overburden is present. No record exists of the work done in the great majority of these mines. In many instances, the openings to these small mine workings have soon become obliterated because of caving and other physical changes in the landscape. When this occurs, it is impossible to obtain data on the extent and position of the underground workings (21, 32).

WATER POOLS IN ABANDONED STRIPPING EXCAVATIONS

An investigation on water impounded in stripping excavations in the Northern, Eastern Middle, Western Middle, and Southern fields of Pennsylvania was conducted in the spring of 1948 and procured factual data on 141 water pools in abandoned stripping excavations. These pools contained 2.3 billion gallons of water and affected the same operation of active anthracite mines, in addition to making future underground operations hazardous (32, 43).

Shallow pools formed in stripping excavations by runoff from local rainstorms or spring thaws were not considered because of their temporary nature; moreover, such pools usually disappear during an extended dry period.

Many new pools were being formed and old ones filled or drained by numerous active stripping operations at the time of the investigation. This was especially true in the Southern and Western Middle fields. Some of these surface pools are small; others, veritable lakes. A few are near villages or are visible from public highways, but, by far, most of them are found only by diligent search among spoil banks and numerous abandoned stripping excavations.
IMPROVEMENTS DESIRED

Improvements in conditions in the anthracite region must give consideration to prevent further sinking of the economic level in the communities and to conserve the reserves of anthracite as a source of energy for the future (11, 37, 54, 88, 113, 122, 175, 214, 216).

Local interests are discouraged by the futility of repairing or restoring local surface drainage facilities that are inadequate because of existing conditions and by the lack of action on short-range and long-range mine-drainage projects that will contribute to the restoration of markets and remove the threat of inundation of active mines and anthracite reserves. They find themselves unable to cope with the problem of mine drainage for both short-range and long-range mining operations. They now ask for a comprehensive plan of flood protection and mine-water control and are convinced that the solution of the problem lies in a coordinated plan of improvement for the region as a whole. They feel that the scope and complexity of such a plan places it beyond the capabilities of State or local agencies. In certain instances the desires of local interests are in conflict to such an extent that nothing can be accomplished by local agencies. Under a coordinated plan of improvement, such as is outlined in the Bureau reports (35–39), most of these conflicts would be removed, and works best meeting the present and future needs of the region would be obtained (11, 37, 54, 88, 110, 113, 122, 175, 214, 215, 260).

PROBLEMS CONSIDERED

BASIC PROBLEM

Of the various factors affecting the future of the anthracite industry, the flooding of abandoned mines becomes one of major importance. The loss of markets for anthracite has resulted in closing down many mines where pumping is burdensome. Because of the close relationship of adjoining mines in these coal measures, the abandonment of a mine and the suspension of pumping in that mine do not reduce pumping costs in a particular basin but usually mean adjoining mines must prepare to handle more water seeping through barrier pillars or to maintain the water in the abandoned mine at such an altitude that the barrier pillar will not fail or excessive seepage does not occur. Thus, the operating mines gradually assume the pumping loads of all abandoned mines in their basin. With ordinary mine facilities, this is rapidly approaching a physical impossibility, and mine pumps have been reinstalled in abandoned mines as one means of preventing the flooding of active mines. Unfortunately, such methods can only result in higher pumping costs for the remaining mines, with little hope of relief. The ultimate inundation of deeper reserves in each field is only delayed by this action. Once flooded, the hope of reopening such mines becomes remote if the enormous quantities of water in them must be pumped to the surface.

The basic problem facing the anthracite industry is to find means to prevent the loss of a natural resource and its markets in the face of fluctuating demands for anthracite production, competition of other energy sources, rising costs, and threat of widespread inundation of active mines. If our economy demands a sudden increase of anthracite production for security reasons, the assurance that anthracite reserves will be available and not hopelessly lost under a veritable sea of water is necessary (36–39).

BARRIER PILLSARS

Investigation of barrier pillars is part of the comprehensive study of the mine-water problem in the anthracite region of Pennsylvania by the Federal Bureau of Mines (16, 22, 23, 25, 34, 37, 43, 46).

A barrier pillar in the anthracite region of Pennsylvania is that portion of a coal bed that is left unmined along the property line or lines of adjoining mining properties, between mines, or between parts of mines. A barrier pillar performs an important function in anthracite mining operations. Its principal function is to act as a dam to prevent water that accumulates in a mine from suddenly breaking into an adjacent mine or into adjacent mine workings and causing loss of life, property, or both (23, 24, 43, 237).
To obtain a clear picture of the mine-water problem and the relation of underground and surface-water pools to that problem, it is necessary to understand the part played by the barrier pillars that separate active, abandoned, or flooded mine workings. The barrier-pillar system in the anthracite region, exclusive of a few barrier pillars in the Eastern Middle field, consists of 433 barrier pillars in mines in the Lackawanna and Wyoming Basins of the Northern field and in the Western Middle and Southern fields. These barrier pillars affect 218 mines, have a total length of 344 miles, and confine 150 underground pools, which, at the end of 1952, contained more than 106 billion gallons of water.

The barrier pillars in the Eastern Middle field play a comparatively minor role, as the area is drained to a large extent by local drainage tunnels, and the remaining coal reserves will support only a short economic life for this field.

A survey of the size, position, and physical condition of the component barrier pillars substantiates the uncertainty that exists in the minds of those concerned, not only as to the method by which the size of a barrier pillar was established but also as to the stability of those that may be expected to act as dams. Where a barrier pillar must act as a dam, its failure may result in loss of life, the mine, or both; it would be far better had the barrier pillar never existed and thereby given a false sense of security (21–25, 34, 37, 43, 46, 237).

Investigation revealed that damage from subsidence to many barrier pillars can be anticipated. Few can be depended on to act as dams because they are too small, are partly removed, may be damaged by subsidence, or are punctured, or encroachments render their stability uncertain. Often, barrier pillars are punctured by passageways in which masonry or concrete dams are constructed to resist hydrostatic pressure. If a barrier pillar is unstable, a masonry dam in any such barrier pillar can fail even before the barrier pillar itself collapses.

Present-day problems would be much simpler if the need and value of barrier pillars had been realized 75 years ago, when mining at depth was getting underway. Unfortunately, anthracite-bearing lands were not generally controlled in large blocks by one company or individual; because of the irregular shape of holdings, the quantity of anthracite that would have had to be left for adequate barrier pillars was too great to be considered (237).

Unfortunately, in the past barrier pillars were not established soon enough. Excavations were made too close to property lines before there was any attempt to establish a barrier pillar, and, obviously, all that could be done was to make the best of what existed.

The subject of barrier pillars needs the attention of everybody interested in anthracite mining so as to conserve a basic industry and safeguard life and property.

The present barrier-pillar law does not provide for defined and legal barrier pillars where single ownership exists for adjoining mines; consequently, no protection is assured to mines of the future where single ownership prevails and the coal basins are, or are being, inundated. The safety of mine workers in adjoining mines of the same company is as important as the safety of those in adjoining mines having different owners (21–25, 237).

If judicious forethought is not given to future mining, vast underground lakes will be formed above the unmined reserves in many localities where adjoining mines or properties are owned by a single landowner (23, 25, 237).

**LACKAWANNA BASIN, NORTHERN FIELD**

The Lackawanna Basin comprises the eastern portion of the Northern field and is in Lackawanna County. It extends from Old Forge to Forest City, a distance of 24 miles, and has an average width of 3 miles. The area of the anthracite measures in this basin is 73 square miles.

Most of the lowest anthracite bed in the coal measures comprising the Lackawanna Basin outcrops on the mountain slopes on each side of the Lackawanna Valley at altitudes ranging from 1,200 feet near Old Forge to 1,800 feet at Forest City (33, 34).

The barrier-pillar system in the Lackawanna Basin consists of 93 barrier pillars between Archbald and Taylor, Pa. These barrier pillars affect 48 mines, have a total length of 87 miles, and confine 21 underground pools, which contain more than 10 billion gallons of water. An investigation of these barrier pillars definitely indicated that damage to many of them can be anticipated. Draw lines of subsidence indicate that many barrier pillars are or will be affected by subsidence. Few can be depended on to act as dams if either mine adjoining the barrier pillar fills with water.

Only two barrier pillars (near Archbald) extend across the Lackawanna Basin and are intact. Their continued ability to withstand the hydrostatic pressure and to prevent inundation of adjoining mines is uncertain. It is known that some water seeps through these barrier pillars, especially during and after heavy rainfall.

Five barrier pillars near Taylor extend across the Lackawanna Basin and comprise a group of barrier pillars that are intact to altitude 543 feet. With the exception of these five, the others
that extend across the basin between Archbald and Taylor are incapable of acting as dams because of punctures and points of weakness. Very few barrier pillars in the Lackawanna Basin are wide enough to make it feasible to construct within them watercourses connecting to a drainage-tunnel system, a central-pumping-plant system, or a combination of the two.

Anthracite mines in the Lackawanna Basin are in the mature stage. Because of this and the fact that the barrier pillars are already determined and their extent limited by mining already done, it is futile to propose the application of a method for determining their correct size in future mining in this basin.

The original estimate of anthracite reserves in the Lackawanna Basin was 2,030 million short tons (34, 37). To January 1, 1952, 1,605 million tons had been depleted, which leaves a reserve of 425 million short tons. Recovery in the Lackawanna Basin has been accepted as 70 percent; this leaves 297 million tons that would be assumed to be recoverable under existing conditions. The present rate of depletion is 9 million short tons a year. On that basis, the maximum life of the field would be 33 years. Informed people have placed the life expectancy of this field at 10 to 15 years under favorable conditions. If the water problem is solved, it is reasonable that a life expectancy of 33 years is not too farfetched.

Moreover, probably a considerable tonnage tied up in barrier pillars could be recovered economically if a tunnel system is designed to reach the lowest mine workings in the basin. This in itself will extend the life of the affected area.

WYOMING BASIN, NORTHERN FIELD

The Wyoming Basin comprises the western portion of the Northern field and is in Luzerne and Lackawanna Counties; it has an area of 103 square miles, extends 38 miles from Shickshinny on the west to Old Forge on the east, and has a maximum width of 5 miles and an average width of 3 miles.

The barrier-pillar system in the Wyoming Basin consists of 224 barrier pillars that affect 60 mines and have their component parts in anthracite beds, ranging in number from 2 to 16 and in total thickness from 9 to 106 feet. Each barrier pillar is composed of an average of 9 beds having a total average thickness of 57 feet. The barrier pillars, considered as units, have a total length of 171 miles and confine 34 underground pools, which contain 21 billion gallons of water; this is an increase of 15 pools since 1948 (23).

Because of the buried valley of the Susquehanna River (21), no combination of barrier pillars crosses the Wyoming Basin transversely or is intact to an altitude high enough to act as a dam against which water could rise and flow to the surface, except for two barrier pillars west of Glen Lyon.

Only six combinations of barrier-pillar groups, suitable for use as dams, cross the Wyoming Basin transversely and are intact to altitudes as listed in the original report (23). Except for these barrier pillars, those that cross the basin transversely between Old Forge and Shickshinny are capable of acting as dams only at altitudes much lower than those listed because of punctures and points of weakness.

The future of the Wyoming Basin lies in depth. The engineering study, to date, reveals that the present pumping load in the Wyoming Basin is 66,000 million gallons (36,700 billion foot-gallons) per year, which costs $4.7 million. With the proposed gravity-drainage-tunnel system, the pumping load would be reduced to 31,100 million gallons (9,800 billion foot-gallons) per year, which would cost $1.3 million. If the drainage problem is not solved and water is permitted to flow from the Lackawanna Basin into the Wyoming Basin, minerals in this basin would have to handle the pumping load of the entire Northern field (23, 45, 48).

The original estimate of anthracite reserves in the Wyoming Basin was 4,010 million short tons. To January 1, 1952, 2,140 million tons had been assigned to depletion, leaving a reserve of 1,870 million short tons. Recovery in the Wyoming Basin has been accepted as 70 percent; this leaves 1,300 million short tons that could be assumed to be recoverable under existent conditions. The present rate of depletion is 13 million short tons per year. On that basis, the maximum life of the basin would be 100 years. Informed people have placed the life expectancy of the Wyoming Basin at 75 years under favorable conditions; if the water problem is solved, it is reasonable that a life expectancy of 100 years is not too farfetched. A gravity-drainage-tunnel system can make this possible. Moreover, if a tunnel system is constructed, probably 35 percent of the 186 million short tons tied up in barrier pillars (65 million tons) could be recovered economically. This in itself would extend the life of the area for 5 years. The value at the breaker of anthracite recovered from this source alone would exceed $715 million.

WESTERN MIDDLE FIELD

The Western Middle field is in Schuylkill, Columbia, and Northumberland Counties. It has an area of 94 square miles, extends 42 miles from Delano on the east to Trevorton on the west, and is 2 to 5 miles wide.

The investigation of barrier pillars in the Western Middle field procured data on 81
barrier pillars that affect 69 mines and have their component parts in anthracite beds ranging in number from 1 to 13 and in total thickness from 5 to 176 feet. Each barrier pillar is composed of an average of 6 beds having a total average thickness of 39 feet. The barrier pillars have a total length of 67 miles and confine or partly confine the 58 water pools that contain 38 billion gallons of water (43, 45, 46). Seven of these pools are in active mines, where their water level is controlled by pumps. Abandoned mines contain 27 that overflow to the surface; 11 that overflow at places where the flow is controlled into active mines, from where the water must be pumped; and 13 where pumping plants control their water level (45). The physical condition of barrier pillars confining 31 pools is such that for safe mining in active mines the hydrostatic pressure against each barrier pillar must be maintained below a predetermined figure (23, 24).

A survey of the component barrier pillars indicated that damage through subsidence is to be expected to many as mining continues. Few can be depended on to act as dams if either adjoining mine is filled with water; 14 of the 81 are intact in all beds; 27 are punctured, and the adjoining mines interconnected; and 39 are partly removed by 1 or more encroachments, and their stability as dams is uncertain.

Passageways through some barrier pillars are sealed with masonry dams, and, if the barrier pillar is unstable as a result of ground movement or subsidence, the masonry dams will fail even before the barrier pillar collapses. The condition of the barrier pillars is unknown in many abandoned mines, as well as in some parts of active mines.

The original estimate of anthracite reserves in the Western Middle field was 5,140 million short tons (46). To January 1, 1952, 1,706 million tons has been assigned to depletion, which leaves a reserve of 3,434 million short tons. Recovery has been estimated at 62.5 to 71.6 percent in the Western Middle field, and, using an average of 66 percent, 2,265 million tons could be assumed to be recoverable under existing conditions. At the present rate of production (11.7 million short tons per year), the life of this field would be 190 years. If the economic future of the anthracite industry justifies any expenditure of funds to reduce pumping costs, the life expectancy of this field makes it imperative to expend such funds for the optimum reduction. Without some relief, pumping costs in this field will become prohibitive, and vast quantities of reserves will remain inundated. The life of this field will be reduced at least one-half and possibly two-thirds, or to 90 or 60 years, respectively. The loss of such large quantities of a great natural resource would seriously affect the economy of the Nation. The value at the breaker of the anthracite recovered by a gravity-drainage-tunnel system would exceed $11 billion. Moreover, probably half the 70 million tons tied up in barrier pillars could be recovered economically from these barrier pillars if a tunnel system was designed to drain water from as low an altitude as appears possible. The value of the anthracite recovered from barrier pillars alone would probably exceed $440 million.

SOUTHERN FIELD

The Southern field is in Carbon, Schuylkill, Dauphin, and Lebanon Counties. It has an area of 181 square miles, extends 70 miles from Mauch Chunk on the east to the Susquehanna River on the west, and is 1 to 6 miles wide.

Abandonment of mines in the Southern field has resulted in the flooding of 34 percent of the field. The largest tonnage of reserves of anthracite lies in this field, where mining conditions are the most difficult. Large reserves of anthracite underlie workings of the abandoned mines, and, before a great part of these reserves can be developed and extracted, the abandoned workings must be unwatered and kept drained.

The investigation of barrier pillars in the Southern field procured data on 35 barrier pillars that affect 41 mines and have their component parts in anthracite beds ranging in number from 1 to 13 and in total thickness from 7 to 95 feet. Each barrier pillar is composed of an average of 4 beds having a total average thickness of 33 feet. The barrier pillars have a total length of 19 miles and confine or partly confine 37 water pools that contain 37.3 billion gallons of water (25, 43). Three of these pools are in active mines where the water level is controlled by pumps; abandoned mines contain 32 that overflow to the surface and 2 in which pumping plants control the water level.

The size, position, and physical condition of the component barrier pillars indicate that damage through subsidence can be expected to several as mining continues. Three of the 35 barrier pillars are intact in all beds; 15 are punctured, and the adjoining mines are interconnected; and 17 are partly removed by one or more encroachments, and their stability as dams is uncertain. The condition of barrier pillars is unknown in many abandoned mines, as well as in some parts of active mines (25).

A gravity-drainage tunnel will remove the need for pumping at most mines and greatly reduce the cost of pumping at others by draining the pools or by maintaining their level at altitudes where mining can be conducted for many years without danger of sudden flooding.
The future of the Southern field lies in depth, where great quantities of anthracite are estimated to be located. The engineering study to date reveals that the present pumping load in the Southern field is 18,300 million gallons (8,400 billion foot-gallons) per year, which costs $1.1 million; with the proposed gravity-drainage-tunnel system, the pumping load would be reduced to 900 million gallons (200 billion foot-gallons) per year and cost but $20,000 (25, 45, 48).

The original estimate of anthracite reserves in the Southern field was 10,880 million short tons (26). To January 1, 1952, 1,434 million tons has been depleted, leaving a reserve of 9,446 million short tons. Using an average recovery of 50 percent, 4,723 million tons could be assumed to be recoverable reserves. At the present rate of depletion (11.25 million short tons per year), the life of this field would be 420 years. If the economic future of the anthracite industry justifies any expenditure to reduce pumping costs, the life expectancy of this field makes it imperative to spend such funds for the optimum reduction. Without some relief, pumping costs in this field will become prohibitive, and vast quantities of reserves will remain inundated. Mathematically, the life of this field will be reduced at least to 200 years; however, unless the drainage problem in this locality is solved, underground mining in the Southern field will be impossible in decades, not hundreds of years.

**MINE PUMPING PLANTS**

A study of pumping plants in the anthracite mines of Pennsylvania was one part of the comprehensive study of the anthracite mine-water problem by the Federal Bureau of Mines (16–26, 29–43, 162, 177, 178). A comprehensive report records the data on pumping that are necessary to solve the anthracite-mine-water problem and covers removal of the water from the mines by pumping plants for the 8-year period 1944–51 (45). The report includes a vicinity map showing the four anthracite fields comprising the anthracite region and the route of a proposed gravity tunnel; pictures of typical mine pumping plants; a graph and a table of annual rainfall in the anthracite region from 1930 to 1951; a map of the anthracite region showing mine pumping stations, existing drainage-tunnel discharge portals, proposed tunnel, temporary central pumping plant, and emergency central pumping plants; graphs giving the altitude of suction and discharge points of the major pumping stations at each mine for 1944–51; and tables listing the number and kind of pumps used in the region and including data that explain the pumping load.

Data on the volume and quality of anthracite mine water were obtained in 1941, 1946–50, and 1952. Such data are necessary to ascertain the volume and character of the mine water handled in the region and can be utilized in determining a satisfactory mine-water disposal system to remove and convey the mine water collecting in mines producing normally 50 million tons of anthracite annually.

Although many kinds of water pumps are manufactured, those generally used in the anthracite mines are:

- Centrifugal pumps: Horizontal, Vertical, Standard, Deep-well, Shaft
- Displacement pumps: Plunger, Piston

Table 3 shows the number and percentage of the different kinds of pumps used in the anthracite region.

**Table 3.——Number and percentage of various types of pumps used in anthracite region, 1951**

<table>
<thead>
<tr>
<th>Anthracite region</th>
<th>Horizontal-centrifugal</th>
<th>Vertical-centrifugal</th>
<th>Deep-well</th>
<th>Displacement</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent 1</td>
<td>Number</td>
<td>Percent 1</td>
<td>Number</td>
</tr>
<tr>
<td>Lackawanna Basin</td>
<td>86</td>
<td>11.98</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Wyoming Basin</td>
<td>319</td>
<td>44.42</td>
<td>4</td>
<td>0.56</td>
<td>5</td>
</tr>
<tr>
<td>Eastern Middle field</td>
<td>29</td>
<td>4.04</td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Western Middle field</td>
<td>118</td>
<td>16.16</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Southern field</td>
<td>105</td>
<td>14.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>656</td>
<td>91.36</td>
<td>4</td>
<td>0.56</td>
<td>27</td>
</tr>
</tbody>
</table>

1. Does not include small gathering pumps in many mines.
2. Percentage of total pumps in region.
Lesser recently covered the utilization of deep-well pumps, shaft pumps, and centrifugal pumps in the Pennsylvania anthracite mines (177, 178).

Data on all major mine pumps and their performance in the 4 anthracite fields were obtained for the 8-year period 1944–51 through visits to mines or offices of mining engineers of the anthracite-mining companies. The following data were obtained for each pump:

1. Serial number.
2. Kind.
3. Rated capacity, gallons per minute.
4. Altitude of the pump and its point of discharge.
5. Size and number of discharge lines.
7. Hydrostatic head.
8. Driving unit and control data.
9. Where pump is installed.

**VOLUME OF ANTHRACITE MINE WATER**

The operating time (in hours) of the major pumps in each anthracite field, by months, for 1944–48 was obtained. The gallons of water pumped monthly for the 5 years was computed from the rated or tested capacity of each pump. Tested capacities were used where pump discharges were measured by a weir. In addition, the total gallons of water pumped each year and the average gallons per minute per year for the 5-year period were computed.

The operating time (in hours) of the major pumps discharging to the surface in each field, by years, for 1949–51 was obtained in 1952. The total gallons of water pumped each year and the average gallons per minute per year for the 3-year period and the 8-year period, 1944–51, were computed.

It is beyond the scope of this report to give details concerning the pumping data that are given in the detailed report (45) on this subject, but they are summarized in tables 4 to 9.

**Table 4.—Pumping data, Lackawanna Basin**

<table>
<thead>
<tr>
<th>Year</th>
<th>Pumping to surface</th>
<th>Relay pumping</th>
<th>Surface and relay, millions of gallon-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. p. m.</td>
<td>Thousands of gallons</td>
<td>Millions of gallon-feet</td>
</tr>
<tr>
<td>1944</td>
<td>74,940</td>
<td>39,496,063</td>
<td>13,246,012</td>
</tr>
<tr>
<td>1945</td>
<td>104,693</td>
<td>55,026,593</td>
<td>19,053,862</td>
</tr>
<tr>
<td>1946</td>
<td>89,822</td>
<td>47,210,639</td>
<td>16,537,099</td>
</tr>
<tr>
<td>1947</td>
<td>90,261</td>
<td>47,441,177</td>
<td>16,480,822</td>
</tr>
<tr>
<td>1948</td>
<td>76,910</td>
<td>40,534,728</td>
<td>14,768,209</td>
</tr>
<tr>
<td>Subtotal</td>
<td>229,709,197</td>
<td>80,086,004</td>
<td></td>
</tr>
<tr>
<td>Average, 5 years</td>
<td>87,313</td>
<td>45,941,839</td>
<td>16,017,201</td>
</tr>
<tr>
<td>1949</td>
<td>75,267</td>
<td>39,555,098</td>
<td>13,983,569</td>
</tr>
<tr>
<td>1950</td>
<td>86,255</td>
<td>45,335,710</td>
<td>15,927,548</td>
</tr>
<tr>
<td>1951</td>
<td>88,256</td>
<td>46,387,304</td>
<td>16,857,908</td>
</tr>
<tr>
<td>Subtotal</td>
<td>131,278,122</td>
<td>46,769,025</td>
<td></td>
</tr>
<tr>
<td>Average, 3 years</td>
<td>83,256</td>
<td>43,759,370</td>
<td>15,589,675</td>
</tr>
<tr>
<td>Total</td>
<td>360,987,309</td>
<td>126,855,029</td>
<td></td>
</tr>
<tr>
<td>Average, 8 years</td>
<td>85,793</td>
<td>45,123,414</td>
<td>15,856,879</td>
</tr>
</tbody>
</table>
### Table 5.—Pumping data, Wyoming Basin

<table>
<thead>
<tr>
<th>Year</th>
<th>Pumping to surface</th>
<th>Relay pumping</th>
<th>Surface and relay, millions of gallon-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. p. m.</td>
<td>Thousands of gallons</td>
<td>Millions of gallon-feet</td>
</tr>
<tr>
<td>1944</td>
<td>103,439</td>
<td>54,516,735</td>
<td>23,758,736</td>
</tr>
<tr>
<td>1946</td>
<td>132,800</td>
<td>69,799,569</td>
<td>26,640,157</td>
</tr>
<tr>
<td>1947</td>
<td>137,227</td>
<td>72,179,071</td>
<td>30,677,037</td>
</tr>
<tr>
<td>1948</td>
<td>132,197</td>
<td>69,673,209</td>
<td>29,642,949</td>
</tr>
<tr>
<td>Subtotal</td>
<td>341,013,188</td>
<td>145,978,996</td>
<td>129,706,567</td>
</tr>
<tr>
<td>Average, 5 years</td>
<td>120,619</td>
<td>68,202,638</td>
<td>29,195,799</td>
</tr>
<tr>
<td>1949</td>
<td>122,824</td>
<td>64,556,331</td>
<td>28,342,684</td>
</tr>
<tr>
<td>1950</td>
<td>133,883</td>
<td>69,948,161</td>
<td>30,215,346</td>
</tr>
<tr>
<td>1951</td>
<td>124,625</td>
<td>65,502,954</td>
<td>28,123,048</td>
</tr>
<tr>
<td>Subtotal</td>
<td>300,007,446</td>
<td>86,681,078</td>
<td></td>
</tr>
<tr>
<td>Average, 3 years</td>
<td>126,844</td>
<td>66,669,149</td>
<td>28,883,693</td>
</tr>
<tr>
<td>Total</td>
<td>541,020,634</td>
<td>232,660,074</td>
<td></td>
</tr>
<tr>
<td>Average, 8 years</td>
<td>128,579</td>
<td>67,627,579</td>
<td>29,082,509</td>
</tr>
</tbody>
</table>

| Number of mines | 44 | Rated capacity of surface pumps | g. p. m. | 443,445 |
| Number of surface pumping stations | 96 | Rated capacity of relay pumps | do | 183,445 |
| Number of relay pumping stations | 183 | Total rated capacity of pumps | do | 607,370 |
| Total number of stations | | Total connected horsepower | | 58,692 |
| Number of surface pumps | 212 | Average head, surface pumping | | 439 |
| Number of relay pumps | 131 | Average head, relay pumping | | 439 |
| Total number of pumps | 343 | Average head, all pumping | | 509 |

### Table 6.—Pumping data, Eastern Middle field

<table>
<thead>
<tr>
<th>Year</th>
<th>Pumping to surface</th>
<th>Relay pumping</th>
<th>Surface and relay, millions of gallon-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. p. m.</td>
<td>Thousands of gallons</td>
<td>Millions of gallon-feet</td>
</tr>
<tr>
<td>1944</td>
<td>13,353</td>
<td>7,037,839</td>
<td>2,061,633</td>
</tr>
<tr>
<td>1945</td>
<td>15,855</td>
<td>8,333,203</td>
<td>2,344,934</td>
</tr>
<tr>
<td>1946</td>
<td>14,955</td>
<td>7,860,485</td>
<td>2,211,210</td>
</tr>
<tr>
<td>1947</td>
<td>16,064</td>
<td>8,443,303</td>
<td>2,357,370</td>
</tr>
<tr>
<td>1948</td>
<td>17,313</td>
<td>9,230,129</td>
<td>2,500,322</td>
</tr>
<tr>
<td>Subtotal</td>
<td>40,904,959</td>
<td>11,484,469</td>
<td>2,061,633</td>
</tr>
<tr>
<td>Average, 5 years</td>
<td>15,548</td>
<td>8,180,992</td>
<td>2,296,894</td>
</tr>
<tr>
<td>1949</td>
<td>11,621</td>
<td>6,108,002</td>
<td>1,284,311</td>
</tr>
<tr>
<td>1950</td>
<td>13,756</td>
<td>7,230,230</td>
<td>1,592,394</td>
</tr>
<tr>
<td>1951</td>
<td>12,924</td>
<td>6,792,692</td>
<td>1,495,237</td>
</tr>
<tr>
<td>Subtotal</td>
<td>20,130,924</td>
<td>4,371,942</td>
<td>1,284,311</td>
</tr>
<tr>
<td>Average, 3 years</td>
<td>12,767</td>
<td>6,710,308</td>
<td>1,457,314</td>
</tr>
<tr>
<td>Total</td>
<td>61,035,883</td>
<td>15,856,411</td>
<td>1,457,314</td>
</tr>
<tr>
<td>Average, 8 years</td>
<td>14,506</td>
<td>7,629,485</td>
<td>1,982,051</td>
</tr>
</tbody>
</table>

| Number of mines | 7 | Rated capacity of surface pumps | g. p. m. | 78,426 |
| Number of surface pumping stations | 16 | Rated capacity of relay pumps | do | 9,426 |
| Number of relay pumping stations | | Total rated capacity of pumps | do | 78,426 |
| Total number of stations | 16 | Total connected horsepower | | 6,956 |
| Number of surface pumps | 31 | Average head, surface pumping | | 281 |
| Number of relay pumps | 0 | Average head, relay pumping | | 281 |
| Total number of pumps | 31 | Average head, all pumping | | 281 |
## Table 7.—Pumping data, Western Middle field

<table>
<thead>
<tr>
<th>Year</th>
<th>Pumping to surface</th>
<th>Relay pumping</th>
<th>Surface and relay, millions of gallon-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. p. m.</td>
<td>G. p. m.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thousands of gallons</td>
<td>Millions of gallon-feet</td>
<td>Thousands of gallons</td>
</tr>
<tr>
<td>1944</td>
<td>51,904</td>
<td>27,355,670</td>
<td>10,331,979</td>
</tr>
<tr>
<td>1945</td>
<td>73,210</td>
<td>38,478,981</td>
<td>13,345,278</td>
</tr>
<tr>
<td>1946</td>
<td>61,938</td>
<td>32,554,740</td>
<td>11,521,374</td>
</tr>
<tr>
<td>1947</td>
<td>64,683</td>
<td>33,997,517</td>
<td>12,280,360</td>
</tr>
<tr>
<td>1948</td>
<td>60,993</td>
<td>32,145,866</td>
<td>11,613,098</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>164,532,394</strong></td>
<td><strong>59,092,098</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 5 years</strong></td>
<td><strong>62,539</strong></td>
<td><strong>32,906,479</strong></td>
</tr>
<tr>
<td>1949</td>
<td>53,275</td>
<td>28,001,432</td>
<td>9,948,539</td>
</tr>
<tr>
<td>1950</td>
<td>64,888</td>
<td>34,105,069</td>
<td>11,758,155</td>
</tr>
<tr>
<td>1951</td>
<td>67,641</td>
<td>35,552,012</td>
<td>12,424,561</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>97,658,513</strong></td>
<td><strong>34,131,255</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average 3 years</strong></td>
<td><strong>61,934</strong></td>
<td><strong>32,552,838</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>262,190,907</strong></td>
<td><strong>93,223,353</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 8 years</strong></td>
<td><strong>62,312</strong></td>
<td><strong>32,773,863</strong></td>
</tr>
</tbody>
</table>

Number of mines: 24  Number of surface pumping stations: 34  Number of relay pumping stations: 36  Total number of stations: 82  Number of surface pumps: 88  Number of relay pumps: 82  Total number of pumps: 140

Rates of capacity of surface pumps: 201,715  Rated capacity of relay pumps: 70,655  Total rated capacity of pumps: 272,370  Total connected horsepower: 38,365  Average head, surface pumping: 339  Average head, relay pumping: 334  Average head, all pumping: 436

## Table 8.—Pumping data, Southern field

<table>
<thead>
<tr>
<th>Year</th>
<th>Pumping to surface</th>
<th>Relay pumping</th>
<th>Surface and relay, millions of gallon-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. p. m.</td>
<td>G. p. m.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thousands of gallons</td>
<td>Millions of gallon-feet</td>
<td>Thousands of gallons</td>
</tr>
<tr>
<td>1944</td>
<td>29,018</td>
<td>15,293,458</td>
<td>6,246,822</td>
</tr>
<tr>
<td>1945</td>
<td>39,408</td>
<td>20,713,145</td>
<td>8,956,154</td>
</tr>
<tr>
<td>1946</td>
<td>33,220</td>
<td>17,722,922</td>
<td>7,769,972</td>
</tr>
<tr>
<td>1947</td>
<td>35,015</td>
<td>18,403,513</td>
<td>7,702,023</td>
</tr>
<tr>
<td>1948</td>
<td>32,841</td>
<td>17,308,359</td>
<td>7,180,708</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>89,441,697</strong></td>
<td><strong>38,075,679</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 5 years</strong></td>
<td><strong>33,997</strong></td>
<td><strong>17,888,339</strong></td>
</tr>
<tr>
<td>1949</td>
<td>25,474</td>
<td>13,389,272</td>
<td>6,130,659</td>
</tr>
<tr>
<td>1950</td>
<td>29,417</td>
<td>15,461,710</td>
<td>6,801,740</td>
</tr>
<tr>
<td>1951</td>
<td>31,787</td>
<td>16,707,096</td>
<td>7,200,451</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>45,558,078</strong></td>
<td><strong>20,132,830</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 3 years</strong></td>
<td><strong>28,933</strong></td>
<td><strong>15,186,026</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>134,999,775</strong></td>
<td><strong>58,208,509</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 8 years</strong></td>
<td><strong>32,084</strong></td>
<td><strong>16,874,972</strong></td>
</tr>
</tbody>
</table>

Number of mines: 17  Number of surface pumping stations: 38  Number of relay pumping stations: 38  Total number of stations: 55  Number of surface pumps: 76  Number of relay pumps: 32  Total number of pumps: 108

Rates of capacity of surface pumps: 155,570  Rated capacity of relay pumps: 41,000  Total rated capacity of pumps: 197,070  Total connected horsepower: 30,429  Average head, surface pumping: 439  Average head, relay pumping: 429  Average head, all pumping: 470
### Table 9.—Pumping data, anthracite region

<table>
<thead>
<tr>
<th>Year</th>
<th>Pumping to surface</th>
<th>Relay pumping</th>
<th>Surface and relay, millions of gallon-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. p. m.</td>
<td>Thousands of gallons</td>
<td>Millions of gallon-feet</td>
</tr>
<tr>
<td>1944</td>
<td>272,654</td>
<td>143,699,765</td>
<td>55,645,182</td>
</tr>
<tr>
<td>1945</td>
<td>375,564</td>
<td>197,398,526</td>
<td>75,950,345</td>
</tr>
<tr>
<td>1946</td>
<td>333,235</td>
<td>175,148,352</td>
<td>67,689,812</td>
</tr>
<tr>
<td>1947</td>
<td>343,350</td>
<td>180,464,681</td>
<td>69,717,621</td>
</tr>
<tr>
<td>1948</td>
<td>320,454</td>
<td>168,892,111</td>
<td>65,714,286</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>865,601,435</strong></td>
<td><strong>334,717,246</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 5 years</strong></td>
<td><strong>329,016</strong></td>
<td><strong>173,120,287</strong></td>
</tr>
<tr>
<td>1949</td>
<td>286,373</td>
<td>151,610,135</td>
<td>59,689,762</td>
</tr>
<tr>
<td>1950</td>
<td>327,399</td>
<td>172,080,880</td>
<td>66,295,183</td>
</tr>
<tr>
<td>1951</td>
<td>325,232</td>
<td>170,942,058</td>
<td>66,101,185</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
<td><strong>494,633,073</strong></td>
<td><strong>192,086,130</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 3 years</strong></td>
<td><strong>313,694</strong></td>
<td><strong>164,877,691</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>1,360,234,508</strong></td>
<td><strong>526,803,376</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average, 8 years</strong></td>
<td><strong>323,274</strong></td>
<td><strong>170,029,313</strong></td>
</tr>
</tbody>
</table>

Number of mines: 111
Number of surface pumping stations: 227
Number of relay pumping stations: 154
Total number of stations: 381
Number of surface pumps: 478
Number of relay pumps: 240
Total number of pumps: 718

**Rated capacity of surface pumps (g. p. m.)**: 1,147,588
**Rated capacity of relay pumps (g. p. m.)**: 822,725
**Total rated capacity of pumps (g. p. m.)**: 1,970,313
**Total connected horsepower**: 200,387
**Average head, surface pumping**: 230
**Average head, relay pumping**: 447

### Table 10.—Relationship between the volume of water pumped to the surface and volume of rainfall for the 8-year period, 1944-51, in the anthracite region, percent

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall, millions of gallons</th>
<th>Water pumped, millions of gallons</th>
<th>Relationship between volume of water pumped and volume of rainfall, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1944</td>
<td>342,486</td>
<td>143,700</td>
<td>42.0</td>
</tr>
<tr>
<td>1945</td>
<td>290,519</td>
<td>168,396</td>
<td>38.9</td>
</tr>
<tr>
<td>1946</td>
<td>364,940</td>
<td>178,149</td>
<td>40.1</td>
</tr>
<tr>
<td>1947</td>
<td>471,579</td>
<td>188,465</td>
<td>38.3</td>
</tr>
<tr>
<td>1948</td>
<td>432,017</td>
<td>168,589</td>
<td>39.0</td>
</tr>
<tr>
<td>1949</td>
<td>357,856</td>
<td>151,610</td>
<td>42.4</td>
</tr>
<tr>
<td>1950</td>
<td>460,732</td>
<td>172,081</td>
<td>36.6</td>
</tr>
<tr>
<td>1951</td>
<td>463,487</td>
<td>170,942</td>
<td>37.7</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>3,601,316</strong></td>
<td><strong>1,360,234</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Average</strong></td>
<td><strong>444,166</strong></td>
<td><strong>170,029</strong></td>
</tr>
</tbody>
</table>

The volume of water pumped to the surface from the anthracite mines depends on so many factors that it is impossible to ascertain a definite relationship between rainfall and volume of water pumped (45). Table 10 gives the rainfall, expressed in millions of gallons of rainfall, in the anthracite region, the volume (millions of gallons) of water pumped to the surface, and the relationship, expressed in percent, between the volume of water pumped to the surface and the volume of rainfall from 1944 to 1951, inclusive.

It is apparent that during the years of greatest rainfall more water was pumped from the mines than during the years of less rainfall. The relationship of the volume of water pumped to the surface and the volume of rainfall, when expressed in percent, may depend in magnitude upon the physical characteristics of the individual field and ranges from 91.6 percent in the Northern field to 9.6 percent in the Southern field.

Because of the canoe-shaped form of the Northern field, rainfall over this field drains to the lowest points in the broad single valley overlying the coal measures, contributing to the seepage of surface water into both active and abandoned mines. The continuous nature of the anthracite beds in this field makes seepage of rainfall into most abandoned mines a pum-
The wide variance in the tons of water pumped to the surface per ton of anthracite produced underground in the different fields throughout the region can be explained, in part, as follows: The Northern field produced nearly 60 percent of all anthracite produced underground in the anthracite region. (See table 12.) Most of the anthracite beds in this field lie below the natural drainage horizon of the area and thus afford favorable opportunity for seepage of surface water into the mines. The Eastern Middle field is composed of a number of parallel isolated basins, most of which lie above the natural drainage horizon. There are a number of drainage tunnels in this field that materially reduce pumping. The Western Middle field contains a number of contiguous, nonproducing, abandoned mines, which contain large underground pools of water. The overflow from these pools must be handled by mining companies operating in this area; consequently, such operating companies must handle water that originates in areas remote from their operations. The Southern field supplied over 14 percent of the underground production of the anthracite region. It includes a number of abandoned mines containing underground water pools from which the water overflows naturally to the surface, in most instances, and does not seep into active mine workings.

From 1944 to 1951, 63.93 percent of the total anthracite production was obtained by underground mining, and 36.07 percent was recovered from stripplings, refuse banks, and stream dredging. The day is not too far distant when there will be no anthracite from refuse banks, and the anthracite beds presently available for surface stripping will be depleted. Unless beds underlying cities and other surface improvements become available for surface mining, it will be necessary to resort to underground mining alone to maintain production. When this time arrives, mine operators will not only be deprived of the lower cost anthracite produced from surface stripplings and banks but will be burdened further with additional pumping expense.

**Pollution Abatement and Public Health**

Many of the cities and towns in the anthracite region discharge sewage effluent and polluting wastes into local streams. The comprehensive plan discussed in this report does not contemplate the removal of sewage effluent, although there is no good reason why the present discharge of sewage effluent into the vast worked-out areas and pools in abandoned mines could not be greatly increased, thereby removing much of that pollutant.

Few national problems have so consistently received congressional interest as has the pollu-
### Table 11.—Comparison of net tons of water pumped to the surface with net tons of anthracite produced in the anthracite region, 1944–51

<table>
<thead>
<tr>
<th>Year</th>
<th>Total production, net tons</th>
<th>Underground production</th>
<th>Water pumped to the surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Net tons</td>
<td>Percent of total production</td>
</tr>
<tr>
<td>1944</td>
<td>63,554,146</td>
<td>41,655,512</td>
<td>65.54</td>
</tr>
<tr>
<td>1945</td>
<td>54,732,594</td>
<td>34,220,365</td>
<td>63.60</td>
</tr>
<tr>
<td>1946</td>
<td>60,399,784</td>
<td>38,021,943</td>
<td>62.95</td>
</tr>
<tr>
<td>1947</td>
<td>57,147,049</td>
<td>36,926,564</td>
<td>64.62</td>
</tr>
<tr>
<td>1948</td>
<td>57,077,624</td>
<td>37,112,967</td>
<td>65.02</td>
</tr>
<tr>
<td>1949</td>
<td>42,681,634</td>
<td>27,010,560</td>
<td>63.28</td>
</tr>
<tr>
<td>1950</td>
<td>44,050,013</td>
<td>28,131,082</td>
<td>63.86</td>
</tr>
<tr>
<td>1951</td>
<td>42,641,235</td>
<td>26,313,477</td>
<td>61.71</td>
</tr>
<tr>
<td>Total</td>
<td>422,304,079</td>
<td>269,992,670</td>
<td>63.93</td>
</tr>
</tbody>
</table>

1 Underground, strip pits, culm banks, and river dredging.  
2 Factor of 240 gallons per ton used.

### Table 12.—Total and underground production in anthracite region for 8-year period, 1944–51

<table>
<thead>
<tr>
<th>Field</th>
<th>Total production</th>
<th>Underground production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net tons</td>
<td>Total production, percent</td>
</tr>
<tr>
<td>Northern</td>
<td>190,111,000</td>
<td>45.02</td>
</tr>
<tr>
<td>Eastern Middle</td>
<td>36,563,308</td>
<td>8.66</td>
</tr>
<tr>
<td>Western Middle</td>
<td>99,144,908</td>
<td>23.47</td>
</tr>
<tr>
<td>Southern</td>
<td>96,484,863</td>
<td>22.85</td>
</tr>
<tr>
<td>Total for region</td>
<td>422,304,079</td>
<td>100.00</td>
</tr>
</tbody>
</table>

1 Underground, strip pits, culm banks, and river dredging.

The solution of the Nation’s watercourses. During the past 50 years, more than 100 bills have been introduced into the Congress relating to Federal regulation and control of stream pollution. No informed person can fail to recognize the need for correcting the present gross contamination of rivers, lakes, and tidal waters, but so far groups fostering regulatory measures have been unable to agree on the nature and extent of Federal control. Industry generally is recognizing its responsibilities in the matter of industrial wastes, although it has not yet fully recognized that disposal of waste is just as much a manufacturing cost as sweeping scraps from around a machine (1, 4, 75, 88, 154, 199, 201, 203, 207, 242–244, 264, 265).

A number of problems of industrial-waste disposal have been magnified with industrial growth and development, and sporadic efforts have been put forth during the last 25 or 30 years by groups attempting to solve the difficulties. Despite these activities, it is well known that, except in isolated areas, no broad corrective program has been forthcoming. Existential conditions cannot be indefinitely continued without injustice to groups holding different opinions on the form that stream-pollution control should take (44, 75, 203, 222, 227).

Progress has been made in some areas in minimizing pollution and assuring future control over these matters (154). In other areas, little or no control has been effected. It must be conceded that the problem has not been corrected on a national basis and that gross pollution by sanitary and industrial wastes has outstripped the effort to maintain the national
waterways in a reasonable state of purity. Dark as this picture appears, many industries recognize their responsibilities and have spent and are spending large sums of money on both research and the installation of treatment facilities. During recent years, many leaders of industry have recognized their obligations and are Cooperating with the authorities in an effort to improve conditions on surface watercourses (1, 44, 227, 245).

The pollution problem has grown beyond State borders, and the discharge of sewage and industrial wastes in one State may and frequently does affect the use of water in a neighboring State. That fact does not make Federal pollution control necessary, but the slowness of some States to accept their responsibilities in water-pollution control will hasten Federal legislation.

The main streams in the anthracite region transcend the State's boundaries. Where water pollution spreads and passes State boundaries, a general agreement has grown in some quarters that the problem must be attacked by cooperative action of the affected States (1, 44, 115, 118, 149, 153, 156, 163, 209, 217, 245, 251, 276, 281–283).

Because the anthracite acid-mine-water problem is regionwide and concerns a densely populated area, the statements of policy regarding acid mine water are important, and excerpts of pertinent statements by the National Resources Water Policy Panel, Engineers' Joint Council (44, 149, 209), are as follows:

Stream pollution from coal production falls into two general categories—that due to the acid formed following the opening up of the coal measures and that resulting from the preparation of the coal itself.

The problem of acid mine drainage is so large and the need for a solution to it is so urgent that all agencies capable of cooperating in the work should do so in close cooperation. The role which the Federal Government can most effectively take in the matter is an active study, both by research in the laboratory and by experimentation with actual mines, in close coordination with the work of the States and all other agencies now engaged in this work and which can be effectively enlisted.

It is believed that, without assuming any attitude of direction, the Federal Government, through its Bureau of Mines and through the U. S. Public Health Service, if the latter can contribute to the work, could and probably should engage in an active attack on the problem in close coordination with the other agencies, as previously indicated. When satisfactory answers are found, there will probably be little need to be unduly concerned as to the method of enforcement, because the importance of removal measures will lead to reasonable enforcement through the self-interest of each State involved.

Recognizing that rivers do not respect State lines, it is believed that studies, investigation, and research of pollution due to urban and industrial wastes and the production of oil, coal, and other mineral resources can be facilitated by legislation at the Federal level. Such Federal legislation should use to the greatest possible extent the existing State and interstate river-basin compacts, local authorities, and industries and their facilities for the abatement of stream and groundwater pollution. Federal participation should be through guidance rather than control of procedures.

Because water pollution by acid mine drainage in the anthracite region is similar in character to that in the region affected by the bituminous-coal mines (44, 45, 174, 198, 253), the deleterious effects of this drainage have been accepted as a necessary and unavoidable evil connected with the essential work of producing a fuel that is requisite and indispensable not only to the State but also to the Nation (44, 163, 209).

The success or failure of the coal-mining industry affects the economy of the Nation, particularly anything that influences the cost or manner of operating this industry. The relationship, therefore, between stream pollution and the industry cannot be underestimated (44, 147, 200, 211, 212, 249, 251, 255). The question resolves itself into the manner, methods, and cost of controlling acid mine drainage in each affected area. Whether acid mine drainage will or can be controlled depends largely on how it is done and who is going to pay for it, so that the industry can continue to operate economically (12, 121, 209).

It must be borne in mind that abandoned and not active mines are the principal offenders in uncontrolled mine drainage (44, 61, 64, 69, 87, 146, 209).

What is a reasonable and logical use of a stream for the disposal of wastes is a debatable question; however, a municipality or an industry, because of its mere existence, does not have the right to discharge its wastes into the waters of the State without assuming moral and legal responsibility to prevent, control, or treat efficiently undue pollution of such waters (1, 44, 163, 209).

QUALITY AND CHARACTER OF ANTHRACITE MINE WATER

The designation of water quality depends on the presence or absence of those substances that determine whether the water will serve a particular purpose. It is quite possible to rate a given water as good for one use and poor for another. Water characteristics cannot be put under single groupings because the same substance may be harmful in one combination and harmless in another. Certain conditions must be maintained for the purpose at hand. Ellis and others give a complete bibliography on the determination of water quality (1, 4, 5, 44, 45, 60, 64, 65, 89, 94, 95, 105, 111, 112, 124, 167, 170, 173, 174, 185, 186, 224, 226, 250, 254, 256, 257, 261, 285, 290, 292).

Acid drainage from mining operations in the anthracite region of Pennsylvania is a problem
in stream sanitation confronting communities situated along the banks of the receiving streams and scattered over their drainage basins both in and outside the anthracite region. It is therefore one of the principal factors to be considered in conducting any anthracite mine-flood-prevention program (16, 17, 30, 33, 44, 45, 82, 83, 110, 122, 123, 127, 128, 238, 262).

Complaints have been directed against the anthracite-mining industry concerning the effects of acid mine drainage on the receiving streams. The data available have been too limited either to support or to refute the validity of the complaints, because no previous detailed investigation relating to acid mine drainage in the anthracite region of Pennsylvania has been made. Furthermore, no practicable means for removing the polluting properties of acid mine drainage are known (36, 45, 58, 69, 122).

The object of the study was to determine the effect of acid mine drainage on the receiving streams at the present time and to indicate the effect on the streams if any program for mine flood prevention or control is undertaken in the future.

Braley, Feeley, Selvig, and Ratliff have discussed the characteristics of acid mine water from coal mines and the determination of acidity (61-69, 123, 249). In determining acidity of anthracite mine water, experience in recent years indicates that modifications of the standard methods employed to analyze water are advisable and necessary when analyzing mine water (257). These differences are principally substitution of N/20 caustic solution for N/50 caustic solution and methyl-red indicator for methyl-orange indicator to determine free acidity, the reduction of ferric sulfates by potassium iodide solution before determining free acidity, and the determination of total acidity at boiling point rather than at room temperature. This method was employed by Feeley and others (43, 85, 123, 121, 125, 126, 224) to determine the quality of anthracite mine water.

Studies of acid mine drainage in the anthracite region were conducted by the Bureau of Mines in 1941, 1942, 1946, and 1948. Some results of these investigations were published in 1948, 1949, 1951, and 1955 (35, 43, 44, 123).

Samples of water from mines in the anthracite region have been collected, analyzed, and studied and reports made thereon (35, 43, 44, 123). Factual data regarding water impounded in underground pools and in abandoned stripings have been obtained and constitute an important part of information gathered by the Bureau of Mines pertinent to the collection and ultimate disposal of mine drainage in the anthracite region. At least one sample was collected from every known mine-drainage discharge in the 4 anthracite fields. Many samples were collected from the main rivers and tributaries in the Susquehanna and the Delaware River Basins. The sampling points of these streams are both upstream and downstream from the coal measures, as well as in them (123).

Chemical-quality investigations of surface waters have been conducted by the Commonwealth of Pennsylvania and by Federal agencies, and these investigations have yielded data that give essential facts concerning acid mine drainage in the anthracite region (35, 43-45, 106, 123, 124, 217, 258, 258, 259).

It can be concluded from studying the anthracite-water problem that a tunnel system coupled with emergency central pumping plants is the method by which a long-range drainage scheme for underground mine workings can effectively solve the anthracite-water problem. Such a scheme will obviate acid mine water in surface streams, reduce drainage costs, save anthracite reserves, and materially extend the life of the industry and communities dependent thereon. Details on that scheme are given in this report (pp. 52-79) and in the original reports (36-39, 45).

In conducting experimental work and analyzing a great number of mine-water samples, it is found that the acidity and chemical composition vary considerably. The analyses of samples of water from a pool, from a watercourse to a sump, and that discharged with a pump are not alike, although the different samples may be assumed to be of the same water (61-69, 123, 181, 249).

Although anthracite mine water eventually is destructive to any metal or alloy that has been used to date, it is not nearly as acid as the majority of mine waters formed in bituminous-coal mines (43, 44, 123, 248). The total acidity from mine-pump discharges ranges from a high of 7,695 p. m. (pH 2.3 and free acid (H₂SO₄) 3,610 p. m.) for one mine discharge to a low slightly on the alkaline side. The total acidity as H₂SO₄ (phenolphthalein indicator) is much less than 1,000 p. m. The calculated pH, free-acidity load as H₂SO₄ (methyl-red indicator), and total-acidity load as H₂SO₄ (phenolphthalein indicator) of the mine water that would have to be pumped by the aforementioned proposed emergency central pumping plants are given in the original reports (35, 43, 44, 123).

These reports show that if all the mine water discharged daily (1,376,259 tons) by pumping was pumped from a central pumping plant, the corrosive and erosive actions of the mine water must be considered in the design of pumping equipment to pump water carrying a free-acid load of 274.79 tons (200 p. m.) of H₂SO₄ and a total-acidity load of 655.12 tons (476 p. m.) of H₂SO₄. They show that all
mine-pump and drainage-tunnel discharges (1,532,782 tons daily) from all fields except the Eastern Middle carry a free-acid load of 303.52 tons (198 p. p. m.) of H$_2$SO$_4$ and a total-acid load of 743.35 tons (485 p. p. m.) of H$_2$SO$_4$ (43).

In a long-range program it can be assumed that all mine drainage may be pumped at some time or other from an emergency central pumping plant. The quality of the water to be pumped under such conditions is given in table 10 of the original report (45). The average pH of all mine drainage from the anthracite region, as determined by analyses of samples collected in 1941, is 3.0 (45). The 1,807,719 tons of water discharged daily from the mines in the anthracite region carries a load of 445.29 tons of free acid as H$_2$SO$_4$ and 14.15 tons of alkali (methyl-red indicator) as CaCO$_3$, a total-acid load of 944.00 tons as H$_2$SO$_4$ and an alkaline load of 10.13 tons (phenolphthalein indicator) as CaCO$_3$. Based on the foregoing figures, the average mine-water discharge of 327,000 g. p. m. (472 million gallons per day) reported by Ash and others from a study of pumping records over a 5-year period (1944–48) and an 8-year period (1944–51), given in the report (45), will carry a free-acid load of 431 tons (238 p. p. m.) as H$_2$SO$_4$ and a total-acid load of 934 tons (516 p. p. m.) a day as H$_2$SO$_4$. The average pH of samples collected in 1946, however, is 3.2; therefore, the pH can be said reasonably to range from 3.0 to 3.2 (43–45, 123).

As little or nothing can be done under existing conditions in the anthracite region to change the acidity of the mine water, it is sound to accept this circumstance as fact and deal with the problem accordingly. The final pH of mine water discharged into receiving streams ultimately depends on State, local, and Federal pollution-abatement requirements (44, 911, 118, 163, 209, 245, 250, 263, 281, 286–288, 292).

**CORROSION AND EROSE EFFECTS OF ACID MINE WATERS**

Huge volumes of mine water from underground workings in the anthracite region are pumped, drained, and stored. Data on the volume and quality of these mine waters have been collected and reports made thereon. The study on the corrosive and erosive effects of the acid mine waters on metals and alloys for pumping equipment and other drainage facilities necessary to remove or control the water is one part of the comprehensive investigation of the anthracitemine-water problem by the Federal Bureau of Mines (16–26, 32–48, 123, 162, 177, 178).

In 1921 Selvig and Enos (248) conducted corrosion tests on metals and alloys in acid mine waters from bituminous-coal mines because little attention had been given to the subject. What was true then is true now, and their outstanding contribution on the corrosion of alloys is being used today by manufacturers and users of mine pumps and other equipment exposed to the action of acid mine water.

The corrosive effect of mine water on pumping equipment at normal mine temperatures depends on the kinds of metals or alloys used, the total acidity of the mine water, and the velocity of the water entering and leaving the pump. In selecting drainage equipment for a long-range program, it is necessary to know the corrosive action of the mine water on the various metals and alloys. The effects of erosive and corrosive action can be determined only by actual tests of the metals or alloys where the pump is to be utilized (10, 44, 45, 83, 85, 92, 136, 174, 177, 185, 247, 248, 252, 256).

Corrosion of pumping equipment by acid mine waters has been experienced at tremendous cost by mining companies in the anthracite region of Pennsylvania for many years in many ways. The design and specifications of the large centrifugal pumps as provided in the proposed mine-drainage system make it imperative that a metal or alloy be recommended that has the highest corrosion resistance and, at the same time, acceptable properties suitable for general workability (welding and machining).

It is beyond the scope of this paper to discuss the subject; so many factors are involved and not understood that, when selecting alloys for pumps, corrosion tests should be made under conditions as comparable as possible with those under which the material is to be used (90, 123, 136, 246–248). No satisfactory method of making comparative corrosion tests has been standardized (6–10, 87, 129, 151, 152, 246–248, 273, 274).

A comprehensive study of the corrosive action of anthracite mine water on alloys that are available today was conducted in 1953–54 (35). The data obtained from this study and conclusions that can be drawn therefrom are utilized for recommendations on the selection of pumping equipment wherever acid mine water is handled (35–39).

The proposed controlled gravity-drainage-tunnel system, recommended in this report, comprises a main bore, 2 emergency central pumping plants, and 1 temporary central pumping plant, for which general plans and specifications have been designed (35–39). When selecting mine-drainage equipment, it is necessary to know the quality of the mine water and the corrosive and erosive effect of
that water on the metals and alloys of which the equipment is to be constructed.

The projects (37–39) utilize the three temporary central pumping plants to pump the mine water during emergencies; these plants must be utilized until the proposed gravity-drainage-tunnel system is constructed if the mines in this area are to continue in operation. On this basis, any pumps that are to be utilized will have the longest life if constructed of alloys that resist corrosive and erosive water assumed to carry the maximum foreseeable acid load (35, 45).

Data on the volume and quality of the anthracite mine water and on the corrosion-resistant properties of 25 different metals and alloys exposed to attack by the most highly acid mine water discharged in the anthracite region were obtained and a report (35) made thereon. The most highly corrosive mine waters available for test were those from the Lorraine mine of The Hudson Coal Co., Plymouth, Pa., in the Northern field of the anthracite region (35, 45).

The report (35) is based on field tests conducted cooperatively by the Armco Steel Corp. and the Federal Bureau of Mines from January 1953 to June 1954 to determine the most suitable materials for constructing pumping equipment designed to handle such acid mine waters. The data may be applied to material specifications of individual mining companies in the anthracite or other mining regions for pumps to handle water of a similar character. In mining regions where the character of corrosive mine waters differs from that of acid mine waters in the anthracite region, these data may provide a sound basis for continued applied research on corrosion problems of the mining industry (35, 59, 76, 77, 109, 241).

Corrosion-resistant materials have been used both in surface plants and in underground pumping plants in the anthracite region, as well as in other mining regions (155, 160–162). However, considering the many corrosion problems of the innumerable mining regions of the world, relatively few similar installations have been erected. Even more disconcerting is the fact that the selection of corrosion-resistant materials for use in and around mines seldom appears to have been based on a proved engineering evaluation of the merits of those materials under the specific conditions in which they were used (266–268).

When reporting results of corrosion tests on metals, alloys, and metallic materials, the conditions of the tests must be described in complete detail and special attention given to items outlined in a recommended practice for conducting plant and field corrosion tests (4, 6, 161, 162, 172, 273, 274).

The term “acid-resisting metal” is ambiguous to the extent that it is meaningless unless specific terminology is given. The following examples illustrate this: Steel is an acid-resisting metal to citric or oxalic acids. Some anthracite mine operators consider the 75-percent-copper, 15-percent-lead, 10-percent-tin alloy an acid-resisting metal to acid mine water (35, 44, 162, 177, 178). Therefore, more specific terminology is suggested, and the following definition is used in this report:

Acid-resisting metals, when applied to bronzes and stainless steels, are defined as Bronzes having a corrosion rate of 0.10 i. p. y. (inches penetration per year) or less, and stainless steels having a corrosion rate of 0.010 i. p. y. or less when 5-inch-diameter disks are tested on a revolving spindle at 1,200 r. p. m. for 30 days in acid mine water having a pH between 2.7 and 3.2; free acidity (methyl-red indicator) between 300 and 600 p.p.m., and total acidity (phenolphthalein indicator) between 500 and 1,200 p. m. as H₂SO₄.

Because of the deterioration of bronze parts, the service life of many installations has been measured in terms of months, and bronze impellers of pumps handling the most highly acid anthracite-mine waters have required replacement in a period of weeks. In certain classifier-pump installations at breakers where quantities of silt in the water added severe erosive action to the corrosive attack of the acid, the life of bronze pump parts has been measured in terms of shifts or hours (35, 44, 162, 177, 178).

The ultimate extent of corrosion can be determined exactly only by service exposure, that is, after it has occurred. Concerted and prolonged efforts of corrosion specialists have failed to develop any comprehensive “accelerated corrosion” test that will determine, in advance, the precise extent to which material will corrode in service (171, 172, 285).

Corrosion tests employed in this study utilized the two methods (weight loss and microscopic examination) most likely to yield valid data on the behavior of metals and alloys in the environment in which pumping equipment constructed from these materials will operate (6, 35, 45, 92, 116, 152, 161, 170–172, 182, 232, 246, 273, 274). The program consisted of:

1. Immersion Tests.—Spool-type specimen holders, containing specimens of metals and alloys, were suspended in the sumps, main pump discharges, or flumes from pump discharges to receiving streams at four mines.

2. Revolving-Spindle Tests.—Specimens of metals and alloys were spun in mine water from a selected mine to study the effects of velocity on corrosion. Corrosion rates obtained from this part of the study were higher than those from the immersion tests.

Although the immersion tests yielded basic data on the corrosion-resistant qualities of the alloys tested, they did not provide information on the effect of velocity or abrasive particles on these alloys, such as would be experienced in
pump-impeller service; therefore, revolving-spindle tests were made on specimens of alloys by revolving them in the acid mine water to determine the effect of velocity and corrosion on both new types of materials and materials commonly used for their corrosion-resistant properties (92). Five-inch-diameter specimens with three-quarter-inch-diameter mounting holes were attached to the spindles by stainless-steel fastenings. The size and circular shape of the specimens were selected to favor the maximum amount of corrosion loss in the time available and at the same time be acceptable and to obtain data that could be compared with data developed by tests at Kure Beach, N. C. (171, 172).

During the last 2 months of testing, abrasive fines (equal to 10 percent of the weight of the water in the testing tank) were added to simulate severe abrasive conditions on pumps.

The water in the testing tank was sampled three times a week, and the pH, free acidity (methyl-red indicator), total acidity (phenolphthalein indicator), specific conductance at 25° C., and specific resistance were determined.

Although the chemical reactions involved in the formation of acid mine waters are accepted generally, little information is available on the nature of the material called yellow boy precipitated from acid mine waters. Two attempts were made to determine its nature during this study.

Analyses of the yellow boy removed from the specimens after tests showed that it was composed essentially of corrosion products of lead, tin, and copper; virtually all the sulfur was present as sulfate. An unidentified amorphous material in the corrosion product was assumed to be an intermediate and incompletely state in the reaction converting ferrous sulfide to ferrous sulfate.

On the basis of the immersion and revolving-spindle tests, types 302, 303, 304, 316, 410, 430, 446, Armco 17-4 PH, and Armco 17-7 PH stainless steels; cast stainless-steel alloys (Alloy Casting Institute) CE30, CF8M, and HC; and titanium have adequate corrosion resistance to the most severely corrosive acid mine waters in the anthracite region. Specimens of these materials showed no corrosion, although some were in test for 150 days.

The corrosion rate of the 89–2–9 bronze alloy (89 percent copper, 2 percent lead, 9 percent tin) was one-fourth that of the 75–15–10 bronze alloy (75 percent copper, 15 percent lead, 10 percent tin) generally used in the anthracite region to resist corrosion by acid mine water. The weight loss on the 89–2–9 bronze alloy after 30 days' testing was more than 300 times that of the type HC stainless-steel alloy (with the highest average weight loss, 0.1 gram, of the stainless steels) after 150 days of testing. Increasing the lead content of the bronze alloy is detrimental, as it appears to increase the rate of corrosion.

All the aluminum-bronze alloys had corrosion rates equal to or higher than that of the 75–15–10 bronze alloy.

The steel and 5-percent-chromium-steel specimens were dissolved completely during 19 days of testing, indicating that 11 to 12 percent of chromium is necessary to provide adequate resistance to corrosion.

Thin specimens (0.025 inch thick) of type 304 material were tested to determine whether the low chloride content of the water (14–18 p. p. m.) would promote cracking. Stresses exerted by the flowing water on the revolving disk specimens were complex and not readily determined but were sufficiently high to stress the specimens beyond their yield strength. One showed a permanent set of 9° after 4 weeks' testing. Despite these high and possibly alternating stresses, there was no evidence of stress corrosion or corrosion-fatigue cracks on the specimens at the conclusion of the test.

Stainless steels are available in many types, ranging from the chromium stainless steels containing 11 or more percent of chromium and up to 1 percent carbon to the chromium-nickel stainless steels containing up to 30 percent chromium and from 6 to 20 percent nickel. Other elements such as sulfur, selenium, columbium, and molybdenum are sometimes added to give special properties to stainless steels (4, 15, 126, 274).

Each of the 30 standard grades of stainless steels has some specific property different from the other grades (3, 4, 13, 274). Selection of the proper alloy generally depends on the level of corrosion resistance and mechanical properties (tensile strength, yield strength, and ductility), machineability, hardness, scaling resistance, creep strength, and weldability desired. Some of the chromium grades are hardenable by heat treatment; others are not (155, 274). The chromium-nickel grades are not hardenable by heat treatment. The hardenable grades often exhibit their best corrosion resistance in the hardened-and-stress-relieved condition. The nonhardenable grades show their best corrosion resistance in the annealed condition. In this connection it is well to know that the heat treatment or cold working of stainless steels has an important bearing on their mechanical properties and corrosion resistance (155, 274).

The designing engineer should consult with stainless-steel technicians before attempting to solve corrosion problems by using stainless steel. They are familiar with grades, heat treatments, and corrosion resistance of stainless
PROBLEMS CONSIDERED

steels and can furnish information regarding selection of the proper grade of steel to assure long life and economies in maintenance (4, 6, 35, 36, 99, 180, 186, 155, 182, 232, 274).

CORROSION AND EROSION OF CONCRETE STRUCTURES

Although many anthracite-mine-drainage discharges flow directly into comparatively small streams, all the mine drainage in the region, except mine water remaining below sea level, eventually finds its way into the Susquehanna, Lehigh, or Schuylkill Rivers. The major streams in the anthracite region also receive sewage and industrial wastes from large and small towns along their banks and in their drainage basins. As long as the anthracite mines continue to operate, the industry and the State will be confronted with the problems of mine drainage, whether the drainage continues to enter the streams at innumerable points as it does at present or whether the drainage is diverted immediately to other channels and discharged into a receiving stream at a single or a few points.

In diverting the acid mine drainage from surface streams, by means of a system of drainage tunnels and central pumping plants, consideration also must be given to the effect of the water on the concrete lining of the proposed gravity-drainage tunnel because of the chemical characteristics of the water.

The average pH of all mine drainage from the anthracite region, as determined by analyses of samples collected in 1941, is 3.0. The average pH of samples collected in 1946 is 3.2; the pH, therefore, can be said reasonably to range from 3.0 to 3.2 (35, 43, 44, 123).

Some precipitation of yellow boy in the tunnels and possibly some reaction between the acid water and the tunnel lining may be expected although such reaction may be expected to be so slight as to be entirely negligible. A solution of 1 percent sulfuric acid will corrode concrete substantially and noticeably within 1 to 2 months (44, 53, 73), but the acid load in the mine-water discharges from the anthracite mines corresponds to an acid solution of only 0.02 percent strength when based on free-acid load or 0.05 percent when based on total-acid load. Experience in some anthracite mines having concrete dams and many other concrete structures shows that early deposition of yellow boy and other material from acid mine waters forms a thin protective coating on the concrete structures that prevents prolonged reaction of acid and concrete, however mild that reaction may be.

Sulfates of iron, aluminum, magnesium, sodium, potassium, and calcium are stated by some authorities to affect actively unprotected concretes. The stronger the concentration of these inorganic salts, the more active the corrosion. The relative degrees of attack on concrete by sulfates from soils, ground waters, or conveyed water are given in Table 13 (44, 73, 160, 161, 210, 231).

Table 13.—Attack on concrete by soils and waters containing various sulfate concentrations

<table>
<thead>
<tr>
<th>Relative degree of sulfate attack</th>
<th>Water-soluble sulfate (as SO4) in soil samples, percent</th>
<th>Sulfate (as SO4) in water samples, p. p. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>0.00 to 0.10</td>
<td>0 to 150</td>
</tr>
<tr>
<td>Positive</td>
<td>.10 to .20</td>
<td>150 to 1,000</td>
</tr>
<tr>
<td>Considerable</td>
<td>.20 to .50</td>
<td>1,000 to 2,000</td>
</tr>
<tr>
<td>Severe</td>
<td>Over .50</td>
<td>Over 2,000</td>
</tr>
</tbody>
</table>

During 1951 Ash and Miller investigated the effects of natural waters on the concrete lining of tunnels and canals in the Hetch Hetchy aqueduct, San Francisco, Calif.; Mokelumne aqueduct, East Bay Municipal Utility District, East Bay Cities, Calif.; Colorado River aqueduct, Metropolitan Water District, Southern California; Delaware aqueduct, New York City; and the Tennessee Valley Authority, Knoxville, Tenn. (108, 192, 260-268).

Inspections in the Hetch Hetchy Coast Range tunnels, which are probably in the most troublesome formation encountered in the United States, have revealed no failures. These tunnels have been in operation continuously since October 24, 1934 (44, 109, 241). The pH of Hetch Hetchy natural water is 6.5.

Mining is a highly competitive industry in which concrete structures are widely used. It is one in which construction economies are imperative for safety of the workmen and for the structures, as well as for minimum costs of production. Initial investments and subsequent operating and maintenance charges are high.

Concrete is particularly well adapted to use in mines because it has an unusual, high resistance to deterioration under the severest conditions of mine use. Concrete is used for linings of all types of mine passageways, for dams, conduits for water, sumps, storage facilities, and ventilating structures of all kinds. Examples of its use are numerous. Failures of concrete mining structures are not due to the unsuitability of concrete for any type of mining structure under properly designed specifications.

The Lackawanna River conducts water that is comparable to the water likely to be conveyed in the proposed gravity-drainage-tunnel system. This water at times carries a highly abrasive silt load of fines and other abrasive materials,
which would not be present in any tunnels comprising a gravity-drainage-tunnel system.

The physical and chemical effects of the Lackawanna River on concrete structures that come in contact with the river water are of interest.

In June 1955 an investigation was made of 36 bridges that cross the Lackawanna River between Wilson Creek and the confluence with the Susquehanna River near Pittston. Of the 36 bridges, 17 have 1 or more concrete piers in the river; of the 17, 5 are in good condition, 11 showed some signs of wear, and 1 (at Mayfield) showed considerable wear. All the bridges are at least 30 years old, except the more recent State highway bridge at Old Forge, which is about 10 years old. Five bridges have concrete piers above the normal river surface, and 14 have masonry piers.

To obtain some historical information concerning the action of the Lackawanna River on the concrete structures, informed engineers of the Pennsylvania Department of Highways, the Lehigh Valley Railroad, and the city of Scranton were interviewed. No serious damage from the action of the river water is recorded. However, serious damage to concrete piers by the acid river water is unknown, but some of the wear shown on the piers may be partly due to acid mine water.

There has been no noticeable damage to the concrete piers of the Coxtown Bridge, which is at least 30 years old.

For many years bridges and other concrete structures constructed by the Lehigh Valley Railroad throughout the anthracite region have revealed no serious trouble caused by acid mine water in the streams.

There are 13 highway bridges in the city of Scranton; 5 of these bridges are 25 years or more old and have concrete piers in the Lackawanna River, and no serious damage to the concrete is due to the river water.

It must be borne in mind that where the concrete piers show signs of wear at high-water marks the river at such time carried considerable heavy debris that caused some of the wear on the concrete over the years that these piers have been in service. Persons familiar with this area for the last 40 years have never heard of any serious failure of the concrete piers along the Lackawanna River during which time there were a number of instances when this river was in flood stage.

**TREATMENT OF ACID MINE WATER**

The hydrogen-ion concentration of the inland streams of the United States, southern Canada, and northern Mexico, excepting badly polluted portions of these waters, as seen in a review of some 10,000 readings made during the period 1932–37, lies, in general, between pH 6.7 and pH 8.6, with the extreme ranges of pH 6.3 and pH 9.0 in streams for which no specific pollution factor affecting the hydrogen-ion concentration was readily observable. The extreme pH range of flowing waters of inland streams of the United States, both polluted and unpolluted, was pH 3.9 to pH 9.5, although different effluents poured into these same waters were found to have a pH ranging from 1.0 to 11.0 at the point of entrance into the stream. These observations show that dilution and the buffer action of different substances in the river waters do change the pH’s of the extremely acid and extremely alkaline waters rather rapidly to the range of the composite pH 6.3 to pH 9.0 (44, 59, 81, 111, 123, 162).

In a study of survival of 700 goldfish in various concentrations of 11 acids found in industrial wastes, Ellis found that solutions of sulfuric acid in water at pH 4.5 were tolerated by the fish without apparent injury for several days but seemed definitely detrimental to goldfish in exposures longer than 2 weeks. He concluded that other aquatic organisms survived and that the fish escaped cumulative injuries in waters less acid than pH 5.5 (44, 111).

Where mine water only is available for coal washeries, treatment of the water with soda ash, hydrated lime, or limestone often is practiced to reduce corrosion of plant equipment. The expense of neutralization is justified by a saving in the replacement costs of plant equipment (44).

Johnson has discussed the treatment of acid mine water for breaker use in the anthracite region of Pennsylvania (44, 123, 162). Mine water with low acid content is used without treatment in breakers, but in many instances the mine water is highly acid and is treated to protect pipe, pumps, valves, tanks, screens, and the metallic lining of chutes from corrosion.

When only highly acid mine water was available for washery use at breakers, the replacement and labor costs required to maintain coal-preparation equipment at desired capacity were exorbitant. It was not unusual to replace pipe and other equipment after 3 weeks of service. Many companies utilized equipment made of extra-heavy metal. In recent years equipment made of acid-resistant alloys to obtain longer and more efficient wear has been used. During World War II, heavy metals and alloys were difficult to obtain.

To enable the industry to maintain peak production, the treatment of mine water for washery use with lime was begun in 1932; this provided a means by which lightweight materials could be utilized because of less corrosion. Lime is added to the acid mine water at anthra-
PROBLEMS CONSIDERED

Cite breakers by four methods. All methods utilize a concentrated lime-water mixture or slurry that is fed into a storage reservoir or directly into the breaker pumping system (44, 162).

Commercially, the term “lime” includes high-calcium lime that contains 90 percent or more calcium oxide (CaO); magnesium lime containing 5 to 25 percent of magnesia (MgO) and 75 to 95 percent of calcium oxide; and high-magnesia to dolomitic limes containing 25 to 45 percent magnesia and 55 to 75 percent calcium oxide. Chemically, pure lime is calcium oxide (CaO), but the commercial product contains impurities such as alumina, iron oxide, and silica.

Hydrated lime, Ca(OH)₂, is used in the anthracite region. It reacts most effectively when used to treat acid mine water. This lime is purchased in 50-pound paper bags and shipped to the breakers by railroad or truck. In the early experimental stages of treatment, granular limestone and agricultural lime were used, but preliminary tests indicated that they were unsatisfactory.

High-calcium hydrated lime is used at several lime-treating installations, but the total amount used is less than 25 percent of the lime used in the anthracite region.

The reaction rates of high-calcium hydrated lime and of dolomitic lime are very rapid, and it is difficult to distinguish between the two. However, because sulfuric acid tends to form insoluble calcium sulfate, this slightly retards the reaction rate of the high-calcium lime. The formation of calcium sulfate is less when dolomitic lime is present; the magnesium sulfate formed is soluble in water (44, 162).

The desirable pH of the treated water varies with the opinions of those in charge of the lime-treating installations. The initial mine water may test from pH 2.7 to more than pH 7.0, but most treatments are on water having a pH that ranges from 2.7 to 4.0. The final pH ranges from 4.1 to 7.0. Some believe that when the pH ranges from 4.0 to 4.4 the free acid is neutralized, the “sting” or “bite” is removed, and additional treatment is not warranted. The majority believe that the water should be treated until a pH of at least 5.4 or preferably a pH that ranges from 5.8 to 6.0 is attained (44, 123, 162).

At pH 4.4 a leveling effect or buffer action is experienced. This is caused by dissolved iron salts, particularly ferrous sulfate. After all the iron salts have been precipitated, the pH will rise at a uniform rate (44, 162).

The pH of mine water differs from season to season because of change in the water table. During a rainy period, the pH may indicate more acid conditions for a few days because of water running through deposits of sulfur mud (yellow boy). Usually, during low-water periods, the pH of the mine water is low (highly acid), and more lime is required for treatment. A rough estimate used for lime requirements is that 100 pounds of hydrated lime will raise the pH value of 100,000 gallons of water 1 pH. This appears to be excessive but is justifiable where relatively small volumes of water are treated under conditions requiring a short reaction time (44, 65, 125, 162).

It is difficult to refer to the lime treatment of acid mine water as a tangible asset, because appraisals on replacement parts, life of parts, labor costs, maintenance costs, and other related items are not usually kept in mine-cost-account records. Statements by individuals in charge of treatment processes infer that, before the mine water was treated to prevent corrosion, it was necessary either to replace pipe, chute linings, screens, and other metal equipment every few months or to use equipment of expensive acid-resistant alloys or extra-heavy metal.

Breaker equipment receives harsh treatment, primarily from the abrasive action of pulverized coal and rock, from silt in high-pressure water sprays, and from sand where used for preparation. However, equipment made of extra-heavy metals, alloys, rubber, and glass is used to prevent abrasion and corrosion. Where acid mine water is required for coal-preparation purposes, breaker officials have learned from the experience of many breakdowns, frequent and expensive replacements, and the cost of a large maintenance crew that the problem is greatly alleviated by installing a lime-treatment system (44, 162).

Where acid mine water is treated with lime, it has been possible to use steel pipe instead of cast-iron pipe, lightweight metal for chute linings in place of extra-heavy metal linings, and cast iron for parts in pumps, valves, and screens instead of parts made of acid-resistant alloys. Consequently, substantial savings are made by a reduction in the first cost of such mine equipment and the reduced costs resulting from longer and more satisfactory wear.

Methods of neutralizing acid mine water have been known for many years (44, 59, 62, 96, 123, 137, 138, 140, 162) and have been applied to some extent both where mine water is used for mining purposes and where it was offensive as a pollutant (44, 59, 162).

Acid mine water is neutralized by adding alkaline salts to the acid water and then discharging the resultant mixture into streams, with or without settling of the precipitated solids. Quicklime, agricultural lime, granular limestone, and hydrated lime have been utilized in the neutralization of acid mine water. Al-
though hydrated lime costs more than quick-lime, it is the form of lime most commonly used, principally because of its greater neutralizing power and small quantity of sludge (44, 65, 123, 162, 179, 180).

The quantity of hydrated lime required to treat acid mine water depends on the end point sought, the acid content of the mine water, and the quantity of water to be treated (65, 123, 128, 179, 180, 259, 270, 271).

The cost of complete neutralization of the acid mine drainage at four widely separated points selected at random in the anthracite region is itemized as follows:

**Colliery A—Pumping 24,000 g. p. m. having a pH of 3.1:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated lime a day</td>
<td>$703.50</td>
</tr>
<tr>
<td>Labor, 3 shifts at $8</td>
<td>24.00</td>
</tr>
<tr>
<td>Power</td>
<td>10.00</td>
</tr>
<tr>
<td>Chemical supervision</td>
<td>2.00</td>
</tr>
<tr>
<td>Interest and depreciation on plant</td>
<td>16.50</td>
</tr>
<tr>
<td>and equipment</td>
<td></td>
</tr>
<tr>
<td><strong>Total cost a day</strong></td>
<td><strong>846.00</strong></td>
</tr>
</tbody>
</table>

Production at colliery A—1,063 tons a day.
Cost of neutralization per ton of coal—$0.795.

**Colliery B—Pumping 465, 164, 250 gallons per month having a pH of 3.0:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated lime a day</td>
<td>$345.00</td>
</tr>
<tr>
<td>Labor, 3 shifts at $8</td>
<td>24.00</td>
</tr>
<tr>
<td>Power</td>
<td>7.50</td>
</tr>
<tr>
<td>Chemical supervision</td>
<td>2.00</td>
</tr>
<tr>
<td>Interest and depreciation on plant</td>
<td>16.50</td>
</tr>
<tr>
<td>and equipment</td>
<td></td>
</tr>
<tr>
<td><strong>Total cost a day</strong></td>
<td><strong>395.00</strong></td>
</tr>
</tbody>
</table>

No production at colliery B; cost must be charged against tonnage produced at other collieries of the company.

**Colliery C—Pumping 4,500 g. p. m. having a pH of 3.1:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated lime a day</td>
<td>$149.50</td>
</tr>
<tr>
<td>Labor, 3 shifts at $8</td>
<td>24.00</td>
</tr>
<tr>
<td>Power</td>
<td>5.00</td>
</tr>
<tr>
<td>Chemical supervision</td>
<td>2.00</td>
</tr>
<tr>
<td>Interest and depreciation on plant</td>
<td>16.50</td>
</tr>
<tr>
<td>and equipment</td>
<td></td>
</tr>
<tr>
<td><strong>Total cost a day</strong></td>
<td><strong>197.00</strong></td>
</tr>
</tbody>
</table>

Production at colliery C—2,312 tons a day.
Cost of neutralization per ton of coal—$0.09.

**Colliery D—Draining 12,000 g. p. m. having a pH of 2.9:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated lime a day</td>
<td>$402.50</td>
</tr>
<tr>
<td>Labor, 3 shifts at $8</td>
<td>24.00</td>
</tr>
<tr>
<td>Power</td>
<td>10.00</td>
</tr>
<tr>
<td>Chemical supervision</td>
<td>2.00</td>
</tr>
<tr>
<td>Interest and depreciation on plant</td>
<td>16.50</td>
</tr>
<tr>
<td>and equipment</td>
<td></td>
</tr>
<tr>
<td><strong>Total cost a day</strong></td>
<td><strong>455.00</strong></td>
</tr>
</tbody>
</table>

The foregoing tabulation shows only the cost of neutralization by slaked lime. If complete removal of the acid in mine drainage is to be accomplished, the cost of artificial settling and of separation equipment or the cost of the exca-

vation and periodic cleaning of natural settling basins must be added to the cost of neutralization by slaked lime. In addition, the cost of disposal of the sludge that results from chemically treated water must also be considered and may well become a major factor in any large-scale operation.

Complete neutralization of acid mine drainage in the anthracite region, even if it were possible, would burden the anthracite industry with an exorbitant, if not prohibitive, cost (44, 60, 65, 83, 123, 139, 141, 276).

Pretreatment of industrial wastes is still in its infancy. New and better methods are being constantly devised. Some methods of pretreatment are excessively costly. Some industrial wastes are not susceptible to successful chemical pretreatment (44, 53, 59, 60, 76, 81, 100, 128, 148, 149, 201, 237, 259, 262, 263, 267, 292).

Nearly all pretreatment of industrial wastes falls into one or more of the following patterns:

1. Clarification by sedimentation or flotation.
2. Chemical neutralization, coagulation, or precipitation.
3. Aeration, oxidation, or incineration.
4. Screening.
5. Deodorizing.
6. Decolorizing.
7. Bacterial sterilization.

Of the above-given patterns, chemical neutralization is the only method known or employed at present to prevent excessively acid or alkaline effluents from entering the receiving stream.

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. Any neutralizing treatment to be effective would require continuation of the treatment indefinitely after completion of mining. This does not appear economically feasible (43, 44, 65, 123).

Sealing abandoned mines to reduce the acidity of mine drainage is a controversial subject, and sufficient evidence still is not 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 the average amount of acid produced per year (44, 65, 123).

Low or high pH is often an indication of the deleterious nature of the waste discharge.

Dilution affects pH to some extent but cannot always be resorted to because of needed
capacity in discharge lines or streams. Ordinary tap water is substantially neutral and therefore can have little effect on the pH, even in instances of enormous dilution (36, 44, 53, 59).

If the acid in a stream is neutralized either by natural or artificial means, the organic load of the stream will be disposed of biologically and be offensive during this process. The dilution factor is the important and reliable gage for determining the ability of a stream to dispose of its organic load only when the water, acting as diluent, creates an environment in the combined waters of the receiving stream and the stream discharging into it that is neutral or alkaline and favorable to the development of decay organisms (44, 53, 81).

In discussing industrial-waste problems Van Horn (281) suggests that, where the natural waters in the afflicted areas are alkaline, it might be possible—by regulating the stream discharges by means of dams—to provide enough water in the stream to neutralize the acids to the extent that the aquatic environment would not be seriously affected. It is a fact that the main streams and rivers that flow through the anthracite region, except the Lackawanna and Schuylkill Rivers, are nearly always alkaline at all points within the anthracite region itself; moreover, short distances below the coal measures the rivers are permanently alkaline (36, 44, 128, 287, 288).

Lewis (44, 179) discusses neutralization of acids by lime, considering primarily the pH range covered by the treatment and the minimum time available for the reaction between lime and acid. He points out that dolomitic lime might well be advantageous in treating sulfuric acid wastes because of the lesser sludge problem created by the formation of soluble magnesium sulfates in neutralizing the acid. Aeration of solutions containing ferrous iron salts results in change of ferrous iron to ferric iron and resultant precipitation, so that solutions can be freed of iron and mineral acid without ever passing the neutral point of pH 7.0.

The two fundamentals of raising the pH and the time available for reaction are basic to the choice of a liming material for acid-waste treatment, but there are other factors. One very important factor is the disposal of sludge. The sludge problem may be so acute where cheap land area for lagooning is not available that the dewatering and disposal of sludge outweigh all other considerations; this is one of the reasons why acid-waste treatment processes cannot be standardized but must be tailor-made to fit the occasion (179).

Lewis and Yost (44, 180) have discussed utilization of lime in treating acidic industrial wastes. Lime applied in the form of a water slurry is reacted more quickly and completely than if applied in a dry form. However, within the last few years the procedure of dry liming has been given considerable study. Sludges from dry lime-acid systems have unusual dewatering and settling characteristics; the excellent filtering characteristics of the resulting sludge in dry liming can be an important factor in the final design of an acid-disposal system.

Two of the most common errors made in applying liming materials to waste acids are failure to establish the minimum acceptable efficient pH and failure to provide adequate reaction time between lime and acid to reach such minimum pH. Where large quantities of lime are utilized and reaction time is not thoroughly appreciated, the difference of one pH unit can result in costly waste of lime. Secondary undesirable effects in the treatment operation also result from excess lime dosage (44, 179, 180).

Gehm (128) has reported the success of his experiments in neutralizing acid waste waters consisting mainly of a mixture of nitric and sulfuric acids and neutralizing hydrochloric, nitric, and sulfuric acids singly by upflow through limestone beds. Acids having an initial pH as low as 1.5 were raised to pH's well above 4, and by aeration to remove dissolved CO2 the pH's were raised to 8.0.

The studies indicate that the upflow limestone bed shows promise of providing acid neutralization with little supervision and control at a very low initial equipment cost. The method employs pulverized limestone, one of the least-expensive neutralizing agents. Additional development of the method may prove it to be practicable in treating acid mine waters.

A method of lime treatment of mine water is utilization of pulverized (4- to 6-mesh) limestone. Laboratory tests on the neutralizing power of limestone have been conducted at the Missouri School of Mines and Metallurgy. A solution containing 200 p. p. m. of sulfuric acid was percolated through a bed of minus 4-mesh plus 6-mesh limestone assaying 98 percent calcium carbonate (44, 270).

The treatment of acid mine water with lime for preparing anthracite in the anthracite region has been described (44, 123, 162). Lime or limestone treatment of acid waste is often found to be a practicable means of complying with pollution-abatement requirements (44, 59, 128, 162, 179, 180, 270). Furthermore, it is generally accepted that each treatment plant or process for the disposal of industrial wastes, which include acid mine water, must be made to fit the circumstances under each given set of conditions (44, 179).

Every acid-disposal problem utilizing lime or limestone is concerned with three basic considerations: The pH range over which the treatment is to take place, the minimum time available for
the reaction between the lime or limestone and acid, and the disposal of products formed, of which sludge is of primary importance in the anthracite-mine-water problem.

Braley and coworkers made a comprehensive study of the neutralization of acid mine water at the mine (65). Theoretically, the complete neutralization of 98 pounds of H₂SO₄ requires 100 pounds of CaCO₃ or 74 pounds of Ca(OH)₂. It can be concluded that 1 pound of acid requires approximately 1 pound of powdered limestone.

The findings of the Mellon Institute Fellowship program showed that the onlyhope of preventing the flow of acid draining from a mine is by stopping the formation of acid from sulfuric material on the walls and roof, causing the mine water to leave the mine by the shortest route in the quickest possible time without leaching the acidic substances from the walls and roof or diverting all water from the mine (44, 65).

Most of the recommended practices to treat mine water relate to economy and efficiency in removal of water from operating mines. Of equal importance are procedures to abate stream pollution by the acid discharge. While no method of prevention of acid formation is known, it is the responsibility of every operator to remove the water from his mine in a manner that will prevent pollution insofar as possible. All water should be 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 before water boards who can speak authoritatively in regard to the operator’s practices (35, 43, 44, 65, 123).

WATER CONTROL

Water control in this report intends coordinating the control of ground-water levels and the conservation of water for use in the anthracite region and the densely populated areas along the Atlantic seaboard that utilize water from streams originating in or traversing the anthracite region. The problem of stream pollution has been discussed in previous reports (44, 81, 106, 127, 149, 154, 163, 201, 209, 227).

It is important to realize that the mine water discharged at the portal of the proposed gravity-drainage tunnel may have an average flow of 730 second-feet (327,000 g. p.m.). This water can be a valuable supply of potable water for domestic and industrial use in the coastal cities of Pennsylvania, New Jersey, Delaware, and Maryland (44).

Because it has been stated many times that the treatment of acid mine water at the mine is impracticable and too costly, this should not be construed or considered as closing the door to any treatment for any purpose whatsoever. Treating acid mine water at tidewater in volume of the magnitude stated in this report (pp. 40, 53, 54, and 84) is feasible and comes within the province of conservation of the natural resources of water and of the anthracite reserves of the Nation. The abandonment of anthracite mines will not prevent or reduce the volume of acid mine water from discharging into the streams of the anthracite region of Pennsylvania (12, 44, 61, 64, 69, 81, 82, 106, 146, 209).

Public Law 448, chapter 568, 82d Congress, 2d session, H.R. 6578, provides for the development of practicable low-cost means of producing from sea water, or from other saline waters, water of a quality suitable for agricultural, industrial, municipal, and other beneficial consumptive uses on a scale sufficient to determine the feasibility of the development of such production and distribution on a large-scale basis, for the purposes of conserving and increasing the water resources of the Nation (159).

The Secretary of the Interior, acting through such agencies of the Department of the Interior as he may deem appropriate, is authorized to perform the purposes of Public Law 448 mentioned above (159).

An initial appropriation of $125,000 was made in fiscal year 1953 to start the program, followed by a supplemental appropriation of $50,000 for specific use in awarding research contracts. Congress appropriated $400,000 to finance the program in fiscal year 1954, which amount was originally authorized in Public Law 448 (82 million prorated over a 5-year period). For fiscal year 1955, $400,000 was appropriated by Congress for the work (159).

At the beginning of the Saline Water Conversion Program, the cost of converting sea water to fresh water by the best processes in use was estimated at about $400 to $500 an acre-foot. Accordingly, 2 arbitrary criteria were set for the initial 5-year phase of the program, 1 for water for municipal and similar purposes and 1 for irrigating water. For these criteria no distinction is made as to whether the water to be converted is sea or brackish water. These goals were $125 and $40 per acre-foot (38 and 12 cents per 1,000 gallons), respectively, and they were believed, on the basis of data then available, to be the maximum
that could be borne by these types of use. It was thought that if these goals could be approached during the initial 5-year phase, further reduction could be justified in a second phase. Increased emphasis is being placed on the potential use of demineralized water for industrial purposes, and a survey of such uses is also being started (159).

In discussions concerning the treatment of acid mine water the complete neutralization of such water is stressed (59, 61–63, 65, 81, 95, 123, 136, 140, 161, 174, 184, 198, 222). The complete neutralization is by no means necessary, because the degree of neutralization will depend entirely on the final place of disposal and use for which the treated water is intended (44, 95, 162, 281, 292). Acid mine water having a pH of 5.5 (7 is neutral) would contain less than 10 p.p.m. (0.001 percent) H₂SO₄. It is generally known that freshly distilled water often has a pH of 5.5.

A comparison of chemical analyses of a typical sample of the raw feed saline water being investigated by the Department of the Interior (159, p. 60) and a sample of highly acid anthracite mine water (35) shows that there is ample justification for Federal participation by the Department of the Interior for developing an acceptable method for treating the acid mine water discharged in the anthracite region of Pennsylvania when collected as recommended in this report (p. 50) and in the original reports (36–39). Chemical analyses of samples of sea water and acid anthracite mine water are shown in table 14.

Bradley and coworkers (63) discuss the cost of complete neutralization of acid mine water. The cost (1950 prices) of the lime required to neutralize the acid in 1,440,000 gallons of mine water having a total acidity (phenolphthalein indicator) of 1,000 p.p.m. as H₂SO₄ was $55.75 or $0.0408 per 1,000 gallons, exclusive of freight charges. Manpower for continuous operation, cost of equipment removal, and disposal of sludge are items to be considered in addition to the cost of the lime or limestone.

Although the use of limestone or hydrated lime to neutralize acid mine drainage produces hard water, to soften this hard water is not a problem that cannot be accomplished economically. The Metropolitan Water District of Southern California supplies water for domestic, industrial, and agricultural uses for Los Angeles and neighboring cities and farming areas by means of the Colorado River aqueduct. The rated volume of this aqueduct is 1,605 second-feet. This natural water is hard (pH 8.1) and is softened after being conveyed through 92 miles of concrete-lined tunnels by canal and by pumping plants (44, 192). Before softening, it has a total hardness as CaCO₃ of 361 p.p.m., of

<table>
<thead>
<tr>
<th>Item</th>
<th>Sea water, p.p.m.</th>
<th>Acid anthracite mine water, p.p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids</td>
<td>31,248</td>
<td>2,066</td>
</tr>
<tr>
<td>Organic solids</td>
<td>5,400</td>
<td></td>
</tr>
<tr>
<td>Mineral solids</td>
<td>25,839</td>
<td></td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>4</td>
<td>31</td>
</tr>
<tr>
<td>Total iron (Fe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferrous iron (Fe)</td>
<td>64</td>
<td>0.5</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>442</td>
<td>155</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>6,209</td>
<td></td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻)</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>15,760</td>
<td>14</td>
</tr>
<tr>
<td>Sulfate (SO₄²⁻)</td>
<td>2,190</td>
<td>1,540</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td></td>
<td>124</td>
</tr>
<tr>
<td>Total acid</td>
<td></td>
<td>1,032</td>
</tr>
<tr>
<td>Free acid</td>
<td></td>
<td>450</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

1 Sample collected Oct. 3, 1954.
2 Sample collected Feb. 10, 1933.
3 In parts per million (p.p.m.), except pH.
4 Iron and aluminum oxide as Fe₂O₃.
5 As sodium.
6 As H₂SO₄ phenolphthalein indicator.
7 As H₂SO₄ methyl-red indicator.

which the noncarbonate hardness is 255 p.p.m. Pertinent chemical constituents are calcium (Ca), 192 p.p.m.; magnesium (Mg), 32 p.p.m.; sodium (Na) and potassium (K), 129 p.p.m.; bicarbonate (HCO₃⁻), 129 p.p.m.; sulfate (SO₄²⁻), 380 p.p.m.; chloride (Cl), 100 p.p.m.; and dissolved solids, 802 p.p.m. (44, 192).

The need for water in the anthracite region and Atlantic coastal cities will increase greatly with the continued development of the entire area. Until the need for fresh water has been satisfied, only the irredendable minimum of anthracite mine water that cannot be treated and conserved should be discharged to coastal waters to be lost to the area for useful purposes (73, 79, 154, 159).

**Preservation of Fish and Wildlife**

The Susquehanna River and the Delaware River Drainage Basins were originally one of the greatest natural habitats for fish, birds, and game on the North American Continent. The Fish and Wildlife Service of the Department of the Interior has investigated the possibilities of preserving the fish and game resources of this area. Further investigation by this Department will reveal that the fish resources, in particular, can be restored by a controlled mine-drainage system. As stated in this report the proposed mine-drainage system will aid rather than pollute the streams of the anthracite region (106).
COMPREHENSIVE PLAN

The Federal Government has recognized its responsibility to preserve the anthracite industry and the economic potential it represents by conducting an engineering survey of the mine-water problem. This study established the facts of the problem, and the collected data were presented in numerous reports (16-26, 29-48), several of which outlined definite recommendations for a solution of the problem, based on sound engineering principles (22, 35-39).

Many varieties of plans and suggestions to solve the anthracite-mine-water problem were thoroughly investigated, evaluated, and discussed with management and labor representatives of the anthracite industry and the Secretary of Mines of Pennsylvania (113, 215), with whom close contact was maintained at all times.

Of all the plans and ideas considered, the comprehensive plan appears to be the most logical, because it provides the maximum in relief to all fields for an unlimited period with a minimum of maintenance and operating costs. This plan provides immediate and permanent solution of the mine-drainage problem by means of a gravity-drainage-tunnel system, consisting of a main tunnel and two or more main central pumping plants for emergency use, discharging at tidewater.

PRELIMINARY STUDIES AND PLANS

Studies of the anthracite-mine-water problem have been conducted by mine operators and State and Federal organizations for over 60 years. The advantages of drainage tunnels to relieve pumping loads have long been recognized. In 1889 a lease was negotiated by C. B. Markle & Co. for a Jeddo tunnel to drain flooded mines in the Eastern Middle field. Although originally driven only 3 miles in length, it was extended at various times, so that by 1935 the Jeddo tunnel system included 8 miles of tunnels draining 25 square miles of the Eastern Middle field (47). In 1912 a 4-mile tunnel was driven at the eastern end of the Southern field. In 1915 consideration was given to a drainage system for the Lackawanna Basin to prevent future flooding of the Wyoming Basin, but little interest could be aroused in the project. Many short tunnels have been driven in the anthracite region, each offering a temporary solution to some local pumping problem (37).

In January 1939, in response to a request from the President of the United States, the Natural Resources Committee submitted a report (113), Energy Resources and National Policy, which included the following suggestions:

Thus, in one district, a large or long drainage tunnel might be necessary or desirable to recover all the coal, but the initial cost of such a drainage tunnel might be beyond the resources of any or all the companies operating in that district at the time or in the future.

Adequate planning should take into account and plan for the recovery of all coal under the ground, even though much of the coal may not be reached for a long time.

In 1940 the Bureau of Mines was represented on the Delaware Drainage Basin and the Susquehanna Drainage Basin Committees of the National Resources Planning Board (37, 110). One of the functions of the Drainage Basin Committees was to assist in planning a sound program of public works. More than 30 proposals for Works Progress Administration projects, bearing on the water problem in the anthracite region, were brought to the attention of the committee members. The outstanding request was for assistance in an engineering and cost-finding survey to solve the water problem in the anthracite mines. A meeting of the Susquehanna Drainage Committee was held on July 12, 1940, with a representative from each of the four fields of the region who presented the problem from the practical standpoint of the mine operators. Proposals were considered to construct two 22-mile tunnels, 1 from the Susquehanna River eastward along the Western Middle field and 1 from the Schuylkill River to Frackville, with 14 miles of tunnel along the Western Middle field. A request for State and Federal funds for a survey and study of the project was set aside. The project was considered too limited in scope, as only the Western Middle field would receive the main benefit of this project (37).

During 1940 and 1941 the Bureau of Mines was engaged in a survey of the acid mine water in the entire anthracite region (16, 43, 123). Acid drainage from mining operations in the anthracite region of Pennsylvania is a problem in stream sanitation confronting communities along the banks of the receiving streams and
scattered over their drainage basins both inside and outside of the anthracite region. It is, therefore, one of the principal factors to be considered in the conduct of any anthracite mine flood-prevention program (44, 45).

During the 4 years ending July 1948, studies were made of mining subsidence and backfilling of anthracite reserves, protective methods employed to handle acid mine water, and the buried valley of the Susquehanna River; factual data were obtained on underground and surface water pools in anthracite mines, acid mine water in the anthracite region, and the method of establishing barrier pillars between mines. The data gathered emphasized the importance of the mine-water problem and its seriousness (24, 33, 43, 122, 123).

From the studies and work done, it was apparent that a tremendous amount of engineering data was available in the mine offices throughout the region, but no effort had been made to coordinate this material with regard to the mine-water problem for the region as a whole. The Federal Geological Survey and the Geological Survey of Pennsylvania had prepared excellent topographic and geologic maps and cross sections of the entire region, with careful correlation of the beds in the coal measures of each field and the region. Without these maps and data much of the present engineering survey would have been impossible within the time available. For an engineering survey of the mine-water problem, data had to be collected and assembled on mine pumping, the condition of barrier pillars, and surface seepage. To get factual information on the magnitude of the pumping problem and the amount of water to be considered in designing central pumping plants or drainage tunnels, it was necessary to collect the records of every known pumping plant in the region (37, 42, 43). With data thus collected, it was possible to study seasonal variations in pumping loads and methods used to control inflow from flash floods. Every mine had maps of workings adjacent to barrier pillars in its own property, but little had been done to correlate the maps, even with those of adjoining properties in some cases. Because the flow of water from one mine into another was dependent on the condition of the barrier pillars between the mines, a careful review was made of individual mine maps, and a study was made of each barrier pillar (23–25, 34, 46).

To evaluate the effectiveness of surface diversion projects, a study was made of water seepage into the mines from streams and the surface of the ground (26, 31, 41, 48). The direct correlation between seepage and pumping was found to be extremely difficult to determine, which made recommendations for the expenditure of large sums for surface diversion projects questionable.

Information on the types of pumps in use in the anthracite region was gathered as a background for consideration in connection with possible central pumping plants (177, 178). The huge pumps used by the Metropolitan Water District of Southern California and the Bureau of Reclamation on water supply and irrigation projects were examined, and consultations were held with the engineering office of the Bureau of Reclamation regarding their use in central pumping plants. The hydraulic properties and extremely low operating costs of these large pumps suggest their application to this problem as the feasible and appropriate means of handling the huge volume of mine water and reducing pumping costs (154, 192, 286).

As factual data were accumulated on all phases of the mine-water problem, the feasibility of each drainage and pumping scheme suggested in the past was carefully reviewed. From Pittston to Harrisburg, Pa., a distance of 121 miles, the Susquehanna River has a fall of only 2.0 feet per mile, or 0.04 percent. It was readily apparent that the short tunnels already driven into the hillsides from the river by individual mining companies were almost as effective as a longer tunnel to the Northern field from any point on the Susquehanna River between Pittston and Harrisburg. Mining in the Moosic saddle between the Wyoming and Lackawanna Basins of the Northern field had so weakened the ground because of subsidence that the flow of water from the mined coal measures of the Lackawanna Basin into the coal measures of the Wyoming Basin could not be prevented by a short diversion tunnel to the Susquehanna River (29, 37). When mining is completed in the Lackawanna Basin, arrangements must be made to continue pumping from abandoned mines in this basin or to pump this extra water from operating mines of the Wyoming Basin, unless some solution is found for this problem.

One suggested proposal that was considered combined a short tunnel with a central pumping plant to pump 60,000 gallons of water per minute, with a lift of 100 feet into the Susquehanna River at Coxton, during the life of the Wyoming Basin.

The suggestion in 1915 for a 60-mile tunnel from the Delaware River to the Lackawanna Basin indicates that these conditions were recognized by some engineers over 40 years ago. Such a tunnel offered little advantage to operating mines in the Lackawanna Basin, and its main purpose was future protection for the Wyoming Basin. The physical difficulties connected with the construction and maintenance of a tunnel under the Pocono Mountains, as well
as other disadvantages, make this tunnel scheme almost as undesirable today as then, even though this particular problem is now imminent (37).

One modification of this plan has been a suggestion to construct the tunnel from the Delaware River to the Wyoming Basin, so that the pumping load in the Wyoming Basin could be decreased in addition to draining water from an abandoned Lackawanna Basin. Even with this modification, this plan would require the construction of 60 or more miles of tunnel for the benefit of just 1 of the 4 anthracite fields, with no consideration for the problems in the other fields (37).

A suggestion was made for a gravity-drainage tunnel from the New Jersey coast to Wilkes-Barre in the Wyoming Basin, but such a plan contained all the objectionable features of the Delaware River tunnels, as well as other new ones, without enough compensating advantages to offset the extra 40 miles of tunnel. The New Jersey coastline is a highly industrialized area and does not lend itself to economic tunnel construction, although the demand for water could justify it (37).

The plans suggested in 1940 to the Susquehanna Drainage Committee for tunnels from the Susquehanna and Schuylkill Rivers to the Western Middle field included 58 miles of tunnels but provided for drainage mainly from the Western Middle field. Data on water pools and barrier pillars in the Southern field indicated that a tunnel from the Schuylkill River through the Southern field to Frackville in the Western Middle field would encounter difficulties in the vicinity of St. Clair in the middle of the Southern field. Even if the plans were modified to permit the tunnel from the Schuylkill River to pass through the less-mined part of the field between Middletown and Brockton, it is doubtful whether old caved mine workings could be avoided. The scope of this project could be increased to include drainage from more mines in the Southern field, but the mileage of necessary tunnels would be increased out of proportion to the benefits. Conditions in the Western Middle and Southern fields have not changed enough since 1940 to make these plans any more desirable or urgent now than they were at that time (36–39).

Several plans for short tunnels from a neighboring creek to one property or another were discarded as being entirely local problems of individual companies, as the benefit from such projects was too limited for consideration as a solution of the water problem for the region.

It was concluded from the review of former suggestions on drainage tunnels that although limited advantages were offered by each plan, none could be considered as a satisfactory solution of the mine-water problem for the anthracite region.

It was evident that any short drainage tunnel could not be expected to give more than temporary relief to a small section of one field or basin.

Suggestions for central pumping plants to relieve the pumping burden on operating companies were reviewed without much favor. Most suggestions consisted of the reestablishment of typical mine pumping plans in abandoned mines to maintain pools in these mines at depths considered safe for the men in adjoining mines and to prevent seepage into the operating mines. This would be an expansion of the temporary assistance given by the State to some Lackawanna mines in 1936. Projects of this sort will not solve the mine-water problem and do not reduce pumping costs but merely transfer part of the annual cost from the operating mines to some State or Federal agency (37).

DIVISION OF COMPREHENSIVE PLAN INTO CONSTRUCTION PROJECTS

The seriousness of the water problem is not uniform throughout the anthracite region. In some basins water may be of little consequence in 1 or 2 mines, while other mines are being abandoned because of their inability to handle the inflow of water. To meet the most urgent situations as quickly as possible, it is recommended that the construction of parts of the comprehensive plan be undertaken.

The comprehensive plan is divided into five construction projects: Project No. 1 (Lackawanna), Project No. 2, Project No. 3 (Wyoming), and Projects Nos. 4 and 5. Project No. 1 (Lackawanna) will provide relief for the most urgent problem of the Lackawanna Basin as soon as possible, and the others can be constructed whenever desired or when the necessity arises.

Reports have been issued that contain specific and detailed data on the proposed construction projects (36–39).

Figures 1 and 2 (pp. 8 and 9) show the geographical positions of the projects comprising the comprehensive plan. These positions are defined in the original reports (36–39). Additional information on each project is given later in this report.

GRAVITY-DRAINAGE TUNNEL FROM TIDEWATER TO EDDY CREEK, PA.

The sum total of all studies made shows conclusively that the best overall solution of the problem is a gravity-drainage-tunnel system extending either from tidewater in the Delaware River at Marcus Hook, Pa., or from tidewater in the Susquehanna River just below the Conowingo Dam in Maryland to near Eddy Creek, Pa., in the Northern field (22, 35–39).
ADVANTAGES OF TUNNELING

It is not within the scope of this report to discuss the economics of tunneling. However, investigations of a number of first lines of handling mine drainage considered main pumping facilities exclusively, all tunneling and no main pumping facilities, and combinations of these two. Popular opinion among hydraulic engineers and others naturally favors a gravity-drainage-tunnel system. Several gravity schemes and pumping schemes for handling mine drainage were studied.

Many factors affect the economic value of tunnels (27, 40, 235). No doubt, the rapid rise and importance of aerial warfare and the bonding of vital utility services, such as pumping plants, canals, conduits, flumes, and power plants, have added an intangible value to deep gravity tunnels in comparison with vulnerable central pumping plants. Moreover, pumping water having a pH of 3.0 presents a problem of pumping acid mine water; this in itself, in a long-range program, favors a gravity-tunnel system that assures optimum protection against inundation and replacements, because of possible corrosion of large pumps and the stability of tunnels compared with pumps. Tunnels are adaptable to plants in one or a few places for treating acid mine water for domestic and industrial purposes.

Costs of Land and Other Damages for Pressure Tunnel.—The construction of a gravity-drainage tunnel designed as a pressure tunnel requires the purchase of no land except the comparatively few acres at the shafts. A right-of-way must be leased or acquired but at cost much less than for construction at the surface of the ground. During construction little annoyance is offered residents along the route traversed, and this only at the sites of construction shafts.

Costs of land and other damages required for the tunnel will be small in comparison with the total cost of the tunnel, and the cost estimates in this report have considered such land costs and damages as are included in the conservative estimates of construction costs as given later in this report (36–39, 225).

Pressure Tunnels Versus Other Methods for Conveying Water.—A single aqueduct to convey large volumes of water great distances, that could ultimately transmit water for the domestic and industrial needs of the large coastal cities, must be carefully designed. Safety, continuous use, long life, durability of all materials of construction, and soundness of workmanship are factors to be given the greatest consideration. It would be a great disaster if some facilities should be deprived of water.

In a long-range program the use of lined pressure tunnels deep in ledge rock is invaluable for conducting the upland source of water supply to the large coastal cities, as such a conduit possesses advantages over any other type as concerns service, freedom from maintenance cost, maximum protection against sabotage or earthquake shock, and continuation of high initial carrying capacity.

New York City adopted pressure tunnels for construction of the Delaware aqueduct about 1938, taking in consideration experience in construction and operation of the Catskill aqueduct completed about 40 years ago, which in large part employed other types of construction; this is pertinent, as topography and geological formations along the route from the anthracite region to tidewater are very similar to those on the route of New York’s Delaware aqueduct. Some of the pressure tunnels of the New York system have been in service for over 40 years and never has it been necessary to unwater them.

During the last few years great advances have been made in methods of driving deep tunnels (192, 225, 235). Some of the Delaware aqueduct tunnel contracts were completed years ahead of the contract time allowed; and the average rate of progress on several contracts, measured in terms of tunnel completed per month, was nearly 3 times the best rate attained in construction of tunnel sections of the Catskill aqueduct some 25 years earlier.

Tunneling consists of a definite cycle of operations, developed from ideas that are crystallized and translated into action programs through various engineering phases that begin with the first preliminary survey and do not end until the job is completed. Once the line of the bore is established and a time is set for the completion of the work, the face must advance according to estimates prepared before work is begun. This schedule must be followed in regular sequence from the moment the drills start against a new face of rock until they are ready again to drill the succeeding face, constituting a round.

SELECTING ROUTE OF MAIN TUNNEL

In general, the route of the main tunnel can be fairly well established because of the hundreds of miles of mine workings comprising the anthracite mines, the altitudes of drainage horizons of the present mine workings and depth of the coal measures, the natural features of topography and convenience of entrance and egress of the tunnel to tidewater, the possibility of obtaining rights-of-way or easements under private property, and the effect of mine discharges on the receiving body of water.

The economy of construction and the convenience of the contractor must be considered.
The contractor will require room for shafts, surface plant, and spoil banks.

Tidewater Route.—The Northern field is so situated that airline distances from the Wyoming Basin to tidewater on the New Jersey coast and in the Delaware and Susquehanna Rivers are nearly equal.

Preliminary investigations had shown that the route to the New Jersey coast was undesirable. A direct route to tidewater in the Delaware River at Marcus Hook, Pa., from the Northern field would pass through the Southern field, thereby making it possible to drain the water from 2 fields instead of 1, but still retaining most of the undesirable features of other Delaware River tunnels. However, by driving the tunnel from No. 9A shaft to tidewater at Marcus Hook, the distance and costs are virtually the same. (See figs. 1 and 2.) There is much to recommend this route (36).

The route from the Northern field to tidewater in the Susquehanna River just below the Conowingo Dam would pass under the Eastern and Western Middle fields and through the Southern field at a point of shallow mining. (See fig. 2.) Such a route presented the opportunity of drainage from the four fields without additional tunnels outside the coal measures and without seriously altering the drainage in the Susquehanna and Delaware River Basins. A reconnaissance survey of this route showed that there were no cities or streams of any size along the route. The surface between Conowingo, Md., and Middleport, Pa., at the Southern field is uniformly rolling country without high mountains; this also applies to the Marcus Hook route (36). Even between the Eastern Middle and the Northern fields along this route, creeks form valleys from which construction shafts of reasonable depth could be sunk. A review of the geological data available did not indicate the presence of the badly shattered formations, which had caused extreme difficulties with aqueducts along the Delaware River near Stroudsburg. This route offered all the advantages of any other plan studied, without the disadvantages that made many of them impractical, and added the possibility of optimum drainage by having the tunnel discharge at nearly sea level. Preliminary diamond drilling along this route from the surface to nearly sea-level depths encountered no large underground streams, and core recovery indicated favorable rock for tunneling at the points drilled (37, 40, 48).

The core-drilling and geological reports indicate that the rock formations and the frequency of unknown faults that may be encountered by a tunnel on the route and at the depths selected would be generally comparable to conditions encountered during construction and successful completion of the Delaware aqueduct by the Board of Water Supply of the City of New York. There appears no reason to believe that there would be any unusual construction difficulties or excessive costs (37, 40, 48, 176, 223, 225).

Considering the above-mentioned factors, the tentative route of the proposed main tunnel (Conowingo tunnel) begins in the vicinity of Eddy Creek, Pa., and extends south 135 miles to Conowingo, Md., where the mine water will discharge into the Susquehanna River immediately downstream from the Conowingo Dam; this route follows closely and lies nearly parallel to the 76th meridian (36, 40).

Conclusions drawn from preliminary studies of available data indicate that, although some problems may arise by the proposed changing of the present situation of discharging mine water into the Susquehanna River at many points along its course to discharging it at one single place below the Conowingo Dam, these problems are not unsurmountable. They require, however, further studies by other State and Federal agencies, such as the United States Public Health Service and the Fish and Wildlife Service and Bureau of Reclamation, United States Department of the Interior.

The Susquehanna River does not always supply potable water for the communities below the Conowingo Dam that use the river water as their source of supply. This is not attributable to acid mine water, which would neutralize excess salinity. Serious consideration should be given to obtain a better supply, 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 (Marcus Hook tunnel) could be constructed that would discharge the mine water into the Delaware River at a point between Chester and Marcus Hook, Pa.

The length of such a tunnel and its diameter and gradient would remain unchanged from the design for the Conowingo tunnel. Figure 2 shows the alignment of this alternate tunnel, which would be constructed in its entirety within the boundaries of the Commonwealth of Pennsylvania.

HYDRAULICS OF TUNNEL

The hydraulic elements establishing the design of a transmission water conduit are the difference in altitude between the inlet and outlet works, the length of the tunnel, the cross-
sectional area of the tunnel, the smoothness of the surface in contact with the water, and the volume of water to be conveyed (191, 225).

Choice of Grade.—From a study of the pumping records of individual pumping stations in the 4 anthracite fields (37, 45, 205), it was evident that any tunnel connecting to the Southern and Western Middle fields below an altitude of 400 feet would make appreciable savings in present pumping costs in these fields. However, the sum of the pumping costs in these fields represented only 29 percent of the total cost of the region, and the Northern field, representing 68 percent of the $10 million annual pumping cost in the anthracite region, became the principal consideration in determining the economic grade for a drainage tunnel from tidewater to the Wyoming Basin.

Only 7 percent of the water pumped from the Lackawanna Basin is collected below an altitude of 200 feet. Although the lowest pump in the Wyoming Basin is 863 feet below sea level, 50 percent of the present pumping plants in this basin are handling water collected between 200 feet above and 100 feet below sea level. From the present costs of pumping in the Wyoming Basin, it was determined that over a period of 50 years $15 million could be saved in pumping costs for each decrease of 50 feet of vertical height, with a drainage tunnel connecting to the basin between altitudes 250 and 100 feet.

In the preliminary consideration of most proposals, it had been assumed that the grades of drainage tunnels would be similar to that of the Jeddó (Pa.) tunnel system, 0.25 percent or 13 feet rise per mile of tunnel (37, 47, 228). The hydraulic characteristics of concrete-lined tunnels are quite different from those of unlined rock tunnels, such as the Jeddó system, and grades of ½ to 3 feet per mile are not unusual in concrete-lined aqueducts. The Susquehanna River provides as good or better drainage from the Northern field than any possible unlined tunnel at a grade of 5 feet or more per mile. Because over 66 percent of the water pumped in the anthracite region is pumped in the Northern field, any effective drainage system for the anthracite region must provide relief for the pumping in that field. Consideration was therefore given to long concrete-lined tunnels at grades of less than 5 feet per mile.

The Colorado River aqueduct utilizes 62 miles of concrete-lined canal subjected to desert conditions. No evidence of concrete destruction caused by chemical constituents of the water or otherwise is reported. Because of the desirability of utilizing as small a gradient as possible for tunnels that may be employed to handle anthracite mine water, it is interesting to note that this concrete-lined canal has the following hydraulic properties:

\[
\begin{align*}
A &= 360.57 \text{ sq. ft.} \\
T &= 6.35 \text{ ft.} \\
S &= 0.00015 \\
V &= 4.45 \text{ ft. per sec.} \\
Q &= 1,605 \text{ c. f. s.}
\end{align*}
\]

The slope of 0.00015 (0.792 foot per mile) is steeper than the theoretically economic gradient for that project but was considered necessary to provide ample velocity of flow (4.45 feet per second) to move sand that might blow into the stream to the sand traps. Lined canal was found to be lowest in cost per linear foot to construct any aqueduct section on the project. It requires the least slope for its operation (44, 192, 286).

From pumping records (37, 46) and making allowance for flash floods and reasonable sump capacity in the mines, it was determined that the design of a gravity-flow drainage tunnel should be based on a maximum flow of 280,000 g. p. m. Four sizes of circular, lined tunnels, 14, 15, 16, and 18 feet in diameter at grades of 2, 1½, 1, and ¾ feet per mile, respectively, met this condition. Starting from Conowingo, Md., or from Marcus Hook, Pa., tunnels at these 4 grades would connect to the Wyoming Basin at 250, 200, 150, and 100 feet above sea level, respectively. The total cost of construction of such tunnels increased in proportion to the size and would increase $7 million as the size increased from 14 to 15 feet in diameter, or from 15 to 16 feet in diameter, but would increase $20 million as the size increased from 16 to 18 feet in diameter. Increasing the size of the tunnel to 16 feet in diameter and decreasing the vertical pumping head from 250 to 150 feet showed greater savings in future pumping costs than the increased cost of construction, but beyond these figures the increase in construction costs would be greater than the saving in pumping costs. The 16-foot diameter tunnel at 1-foot-per-mile grade was selected as the most desirable under these conditions. The velocity of flow in this size tunnel would range from 4 feet per second during low water periods to 4.38 feet per second at maximum flow, well within recognized, good-hydraulic practice of velocities greater than 2 feet per second to prevent silt from settling and less than 8 feet per second to prevent undue wear on concrete lining (36-39).

Design of Tunnel Sections.—Because of the great length of the proposed gravity-drainage tunnel, a variation of cross-sectional area or gradient would affect the amount of money required in the overall picture. Because the tunnel will operate generally as a gravity tunnel, its section could be the typical horseshoe type.

The choice of a circular section was made because of the permanence of this type of structure and the utilization of the tunnel as a pressure tunnel (37, 109, 114, 241). The only known failures in water tunnels have occurred
where horseshoe sections were employed and had to be replaced with circular sections to withstand hydrostatic and ground pressure. The desirability of a tunnel free from possible interruptions due to failure dictated the choice of a circular section. The tunnel from the Southern field to Conowingo or Marcus Hook will pass under farmlands, and both shafts and tunnel must be able to withstand hydrostatic pressure of ground water to prevent seepage from surface springs. The tunnel must serve for the life of the anthracite industry. Although the anthracite reserves have been estimated to be adequate for over a hundred years, 75 years have been taken as the basis for calculations, although a much longer life is expected (37, 192).

A circular section offers an additional advantage of a maximum velocity during periods of minimum flow.

The intervals at which the proposed tunnel diameter is increased have been determined by the estimated increments contributed by the lateral and sublateral tunnels joining the main bore at points along the tunnel alignment.

No lateral tunnels are planned for the Eastern Middle field. The lowest points of the coal basins in this field are several hundred feet above the altitude of the proposed drainage tunnel, and most of these basins are already drained by local tunnels. The coal reserves of the Eastern Middle field are nearly exhausted and do not justify the expense of any extensive additional mine-drainage scheme in this field. If it is advisable in the future to drain the water contained in the pools of the Eastern Middle field, for any reason, connections to the proposed drainage tunnel can be effected by large-diameter boroholes (22, 36, 47).

The depth of the proposed tunnel and known conditions of the rock formations indicate that reinforcing steel will be generally unnecessary in the concrete lining.

Rock cover is believed adequate to provide structural strength. If faulted or disintegrated ground is encountered during construction the necessary steel reinforcing can be placed.

Friction losses in the tunnel were computed by Manning's formula (191):

\[ V = \frac{1.486}{n} r^{1/2} S^{1/2} \]

Where \( V \) is the velocity in feet per second (f. p. s.), \( n \) is the coefficient of friction (assumed as 0.013), \( r \) is the hydraulic radius in feet, and \( S \) is the hydraulic slope expressed as the tangent of the slope angle.

The concrete lining is designed for a minimum effective thickness of 5 inches to the “B” line (within which no rock or timber is permitted). The actual thickness of the lining is 10 inches to the “B” line in the supported section. If rock conditions require it, the thickness of the lining can be readily increased by varying the “A” line.

Figures 4, 5, and 6 show the construction details and hydraulic properties of the tunnel sections at different conditions of flow.

When the rock is fractured and requires support during excavation, provisions can be made for supporting the roof and sides with either steel arch ribs and lagging or with roof bolts. Typical designs of steel arch ribs are shown in figures 4 to 7. Figure 8 shows a typical unsupported tunnel section. Several variations in design permit a selection to suit the varying conditions generally encountered in tunnels. An estimate of the amount of steel required has been made and incorporated in the general estimate of costs.

An important requisite in the design and construction of some tunnels is cement grouting. It is proposed to utilize cement grout at pressures ranging from 200 to 1,000 p. s. i. to consolidate and stabilize the surrounding rock. Only by grouting at the correct pressure is it possible to construct a tunnel capable of preventing seepage out of or into a tunnel (27, 109, 192, 203, 225, 235, 241, 268, 286).

**EMERGENCY PUMPING PLANTS**

Although the design of the main drainage tunnel in the comprehensive plan contemplate some reserve sump capacity in each field to provide for the sudden increase of inflow of water into the mines due to flash floods, drainage from the mines must be maintained at all times. Any tunnel as long as the proposed main gravity-drainage tunnel is subject to interruption from accidental causes. Although such interruptions will occur rarely, if ever, as shown by the experience of existing aqueducts, it is necessary to provide for such a contingency. Three emergency pumping plants, 1 for the Northern field, 1 for the Western Middle and Southern fields, and 1, which can be classed as temporary, for the Lackawanna Basin are included in the comprehensive plan to allow inspection or repair of the drainage tunnel and to provide adequate additional capacity during periods of high water when the amount of mine water to be handled might be beyond the capacity of the drainage tunnel (36–39).

**CENTRAL PUMPING PLANTS**

Central pumping plants to be effective must have some provision for getting water from a number of mines to a pumping station. In the long, relatively narrow fields of the anthracite region, tunnels serving as channels for collecting water become a major part of the expense
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- FPS</th>
<th>R- 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>88.35</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>76.95</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>66.36</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>31.81</td>
</tr>
</tbody>
</table>

Figure 4.—Hydraulic Properties of Tunnel Sections (50 Percent Full).
HYDRAULIC PROPERTIES OF TUNNEL SECTIONS (92% FULL)

<table>
<thead>
<tr>
<th>TUNNEL DIA. - D</th>
<th>S 1 FOOT PER MILE</th>
<th>Q - DISCHARGE</th>
<th>V - EPS. VELOCITY</th>
<th>R - FT HYD. RAD.</th>
<th>A - SQ.FT. CROSS-SECTION AREA</th>
<th>η - FRICTION COEFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>16' - 0&quot;</td>
<td>0.000189</td>
<td>848</td>
<td>381,000</td>
<td>4.38</td>
<td>4.71</td>
<td>193.56</td>
</tr>
<tr>
<td>15' - 0&quot;</td>
<td>0.000189</td>
<td>713</td>
<td>320,000</td>
<td>4.19</td>
<td>4.42</td>
<td>170.12</td>
</tr>
<tr>
<td>14' - 0&quot;</td>
<td>0.000189</td>
<td>593</td>
<td>266,000</td>
<td>4.00</td>
<td>4.12</td>
<td>148.20</td>
</tr>
<tr>
<td>13' - 0&quot;</td>
<td>0.000189</td>
<td>487</td>
<td>219,000</td>
<td>3.81</td>
<td>3.83</td>
<td>127.78</td>
</tr>
<tr>
<td>12' - 0&quot;</td>
<td>0.000189</td>
<td>394</td>
<td>177,000</td>
<td>3.62</td>
<td>3.53</td>
<td>108.86</td>
</tr>
<tr>
<td>11' - 0&quot;</td>
<td>0.000189</td>
<td>312</td>
<td>140,000</td>
<td>3.42</td>
<td>3.24</td>
<td>91.48</td>
</tr>
<tr>
<td>10' - 0&quot;</td>
<td>0.000189</td>
<td>244</td>
<td>110,000</td>
<td>3.23</td>
<td>2.94</td>
<td>75.61</td>
</tr>
<tr>
<td>9' - 0&quot;</td>
<td>0.000189</td>
<td>186</td>
<td>84,000</td>
<td>3.04</td>
<td>2.65</td>
<td>61.25</td>
</tr>
</tbody>
</table>

Figure 5.— Hydraulic Properties of Tunnel Sections (92 Percent Full).
**CIRCULAR TUNNEL SECTIONS SUPPORTED 180°**

- Grout pipes as directed
- Remove timber spreaders before placing concrete
- Tie bolts between ribs
- Lagging
- Wall plate
- Wooden posts
- 6" H-beam
- "B" line
- "A" line
- D

### 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</th>
<th>F - FT</th>
<th>A - SQ.FT</th>
<th>N - FRICTION COEFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>16'-0&quot;</td>
<td>16 FT.</td>
<td>.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>.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>.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>.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>.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>.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>.000189</td>
<td>456</td>
<td>208,000</td>
<td>3.44</td>
<td>3.25</td>
<td>132.73</td>
</tr>
<tr>
<td>12'-0&quot;</td>
<td></td>
<td>.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>.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>.000189</td>
<td>229</td>
<td>103,000</td>
<td>2.92</td>
<td>2.5</td>
<td>76.54</td>
</tr>
<tr>
<td>9'-0&quot;</td>
<td></td>
<td>.000189</td>
<td>175</td>
<td>78,000</td>
<td>2.75</td>
<td>2.25</td>
<td>63.82</td>
</tr>
</tbody>
</table>

**Figure 6.**—Hydraulic Properties of Tunnel Sections (Full).
CIRCULAR TUNNEL SECTIONS
SUPPORTED 280°

Remove timber spreaders before placing concrete

CIRCULAR TUNNEL SECTIONS
UNSupported

Figure 7.—Circular Tunnel Sections (Supported 280°).

Figure 8.—Circular Tunnel Sections (Unsupported).
of central pumping installations. Unless such collecting tunnels are constructed with more than consideration of local conditions, the cost of pumping at these installations may be a continuous expense for the life of the industry. Because the comprehensive plan tunnel system is designed to give optimum drainage from all fields, any part of the plan may be constructed at any time with the assurance that in the future it can be connected to the completed plan without loss of efficiency or duplication. Thus, central pumping plants in parts of this plan may be designed to provide immediate relief in critical areas but can be removed as the plan is expanded. Such pumping plants should be classed as temporary, to be used only until the comprehensive plan is completed (36–39).

TECHNICAL ASPECTS OF EMERGENCY PUMPING PLANTS

The technical advice of the Bureau of Reclamation, particularly that of I. A. Winter, chief, Hydraulic Machinery Branch, and staff, Denver, Colo., was utilized in preparing specifications of large pumps for the emergency pumping plants.

Each emergency pumping plant would consist of pumps of 200 c. f. s. capacity (90,000 g. p. m.) each. These pumps have characteristic pumping costs less than 50 percent of that of the average mine pump.

Pumping plants of the size required, 200,000 to 300,000 g. p. m. capacity, are used efficiently in water-supply systems but are unknown in mining operations. Ease of operation and control, as well as low maintenance expense, has been demonstrated by successful operation of plants along the Colorado aqueduct supplying water for Los Angeles.

Although pumps of the above-mentioned size are unknown in mining operations, they are not classed as a large pump for some purposes. Winter considers that centrifugal pumps delivering 1,000 to 5,000 c. f. s. for irrigation purposes and requiring motors of 20,000 to 100,000 hp. may be classified as large units (154). Physical limitations, so far as pump design is concerned, do not appear to be important either for underground or for surface installations. The limits on size are imposed by the shop facilities and the available metals or alloys (35, 154).

Investigations by the authors indicate that the size of the impeller may be too great for bronze, brass, and some other alloy castings. Stainless steel, which can be repaired in place, is not only preferred but necessary if noncorrosive surfaces are desired. Users of pumps are paying much more attention to reliability and cost these days than they once did, and exceptions to some common practices are sometimes utilized (77). Many users are participating in development and testing programs, whereas in earlier days these were primarily the function of the manufacturer (35, 44, 45, 77, 154, 272).

Corrosion relating to anthracite mine waters and noncorrosive metals and alloys is discussed under Corrosive and Erosive Effects of Acid Mine Waters (p. 40) and in detail in the original report (35).

Studies have shown that the electrical system supplying power to the driving motors of pumps, particularly of the size contemplated in the comprehensive plan, is not a limiting factor where four or more motors of equal capacity are supplied from a common substation (107).

Projects Containing Pumping Plants.—For geographic and practical reasons the comprehensive tunnel plan is divided into 5 projects, of which 3 contain pumping plants; these are described generally in the original reports—Project No. 1 (Lackawanna), Northern Field (37); Project No. 2, Western Middle and Southern Fields (38); and Project No. 3 (Wyoming), Northern Field (39).

Location of Pumping Plants.—The three pumping plants proposed in the comprehensive plan are (a) a permanent emergency pumping plant at No. 15 shaft in the western end of the Northern field near Glen Lyon, Pa.; (b) a permanent emergency pumping plant at No. 9A shaft near Brockton, Pa., in the Southern field; and (c) a temporary pumping plant at Old Forge No. 2 shaft in the Northern field. Both permanent pumping plants will be required to operate when the tunnels are being inspected or repaired or when the water to be drained is in excess of the capacity of the tunnels. The temporary pumping plant at Old Forge No. 2 shaft can be abandoned when the gravity-drainage tunnel is completed or conditions do not require it. The pumps in it, after making slight changes in the impellers, could be used in the permanent pumping plant at No. 15 shaft (36–39).
**PUMPS**

**Capacities.**—Exhaustive studies on the mine pumping plants (45) indicate that the average flow of water to the pumping plants is as follows:

<table>
<thead>
<tr>
<th>Pumping plants</th>
<th>Projects</th>
<th>Average flow of water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>G. p. m.</td>
</tr>
<tr>
<td>Old Forge No. 2 shaft</td>
<td>No. 1</td>
<td>70,000</td>
</tr>
<tr>
<td>Old Forge No. 2 shaft</td>
<td>No. 2</td>
<td>121,000</td>
</tr>
<tr>
<td>No. 9A shaft, near Brockton, Pa.</td>
<td>No. 3</td>
<td>196,000</td>
</tr>
<tr>
<td>No. 15 shaft, near Glen Lyon, Pa.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 From Western Middle and Southern fields.

The maximum flow of water feasible, without developing an excessive pressure head in the tunnels supplying water to the pumping plants, will be attained when they are filled to 92 percent of full capacity; under these conditions the pumping capacity required in each station will be as follows:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Projects</th>
<th>Pumping capacity required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>G. p. m.</td>
</tr>
<tr>
<td>Old Forge No. 2</td>
<td>No. 1</td>
<td>84,000</td>
</tr>
<tr>
<td>No. 9A, near Brockton, Pa.</td>
<td>No. 2</td>
<td>219,000</td>
</tr>
<tr>
<td>No. 15, near Glen Lyon, Pa.</td>
<td>No. 3</td>
<td>266,000</td>
</tr>
</tbody>
</table>

1 From Western Middle and Southern fields with no flow from Northern field.

The foregoing data indicate that the number and capacities of pumps required for emergency or temporary pumping are as follows:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Projects</th>
<th>Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G. p. m.</td>
</tr>
<tr>
<td>Old Forge No. 2</td>
<td>No. 1</td>
<td>2</td>
</tr>
<tr>
<td>Old Forge No. 2</td>
<td>No. 2</td>
<td>4</td>
</tr>
<tr>
<td>No. 9A</td>
<td>No. 3</td>
<td>3</td>
</tr>
</tbody>
</table>

Based on the altitudes of the center lines of tunnels that will supply water to the pumps and on their points of discharge, the static pumping heads on the pumps will be as follows:

<table>
<thead>
<tr>
<th>Shaft</th>
<th>Project</th>
<th>Pumping head, feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Forge No. 2</td>
<td>No. 1</td>
<td>467</td>
</tr>
<tr>
<td>No. 9A</td>
<td>No. 2</td>
<td>657</td>
</tr>
<tr>
<td>No. 15</td>
<td>No. 3</td>
<td>411</td>
</tr>
</tbody>
</table>

A study of the capacities and heads at which the pumps in Old Forge No. 2 shaft pumping plant and the pumps in No. 15 shaft pumping plant (near Glen Lyon) will operate indicates that, with certain changes in the impeller, the pumps could be made interchangeable between the two plants. If and when the pumps are no longer required in Old Forge No. 2 shaft pumping plant, they may be transferred to the permanent pumping plant at No. 15 shaft near Glen Lyon.

The water from the pumping plants will be discharged into the following rivers:

**Rivers**

Old Forge No. 2 shaft

No. 9A shaft, near Brockton, Pa.

No. 15 shaft, near Glen Lyon, Pa.

**Susquehanna**

**Type.**—The type of pump recommended is similar to that used by the Metropolitan Water District of Southern California, the Bureau of Reclamation, and many municipalities. For capacities of 25,000 g. p. m. or greater, the type found to be the most economical is the vertical-shaft, single-stage, single-bottom-suction, volute pump. Figure 9 shows the design of pumps having a capacity of 200 c. f. s. against a head of 444 feet as used by the Metropolitan Water District of Southern California in the Eagle Mountain and Hayfield pumping plants of the Colorado River aqueduct. The pumps in these plants are placed so there is a positive suction head on each; this solves the priming problem and generally makes possible the adoption of a higher rotative speed than when pumps are operated under a suction lift (57–39, 154, 192, 286).

Inasmuch as it is recommended that the pumps not be throttled to reduce pumping capacity, the question of single-volute or double-volute casings is not too important. The 770-c. f. s., 197-foot (total head) pumps in the Tracy pumping plant of the Bureau of Reclamation, Tracy, Calif., are the double-volute type. The 200-c. f. s., 444-foot (total head) pumps at the Eagle Mountain and Hayfield pumping plants (fig. 9) are the single-volute type (153, 192, 286).
Figure 9.—Section of 200-c. f. s., 444-Foot (Total Head) Pumps in Eagle Mountain and Hayfield Plants, Metropolitan Water District of Southern California.
(Courtesy, Worthington Co.)
Variable Duty and Operating Characteristics.—Because the volume of water flowing to each pumping plant will vary, it is necessary to decide on the proper method of reducing capacities of the pumps to suit a reduced flow of water. There are three methods of controlling the flow to the pumps: (a) Throttling the pump or pumps in operation so that the water pumped by them equals the water flowing into the sumps or allowing the level of water in the sumps to fall; this will produce the same effect as throttling the discharge by means of a valve; (b) reducing the speed of the pumps and thereby reducing the volume of water pumped; and (c) starting or stopping one or more pumps so that the level of water in the sumps and the tunnel is kept within a certain range.

The first method by which the discharge head is increased by throttling is not desirable because it reduces the efficiency of the pump and increases the power cost correspondingly. For example, at 75 percent rated capacity the increase in power cost would be approximately 15 percent more than at the rated pump capacity, and at 50 percent of rated capacity the power cost would be approximately 30 to 35 percent more than at rated capacity.

The second method by which the speed of the pump is varied would show a small gain in operating cost, but the cost of the necessary control of the motor would be increased excessively.

The method recommended to match pumping rates and flow of water into the sumps is to cut the pumps in and out of service as the water level rises or falls in the sumps. This method is the most economical, as the pumps are operated near their rated capacity and head and, therefore, at maximum efficiency. It requires adequate sump capacity, but this is available in the tunnels as designed to supply water to the sumps.

Calculations indicate that the pumps in Old Forge No. 2 shaft pumping plant would be required, under the start and stop method of control, to start and stop more frequently than those in the other two stations. Considering only water in the tunnels, without water in the sump, and on a basis of one 200-c. f. s. pump in operation, the most frequent starting would be once every 3.35 hours at a flow of 62,800 g. p. m. At flows approaching rated pump capacity the time that the pump would be shut down would be relatively short (around 18 minutes). Figure 10 shows a graphic analysis and supporting data on which the above calculations are based.

The total head at which pumps operate depends on the difference between the altitude of the water level in a sump and the altitude of the point of discharge, the friction losses in the piping and valves, and the friction loss in the discharge pipe. Variations in the head at which the pumps would operate would be only a small percentage of the total head; consequently, differences in the pump capacities would be small, irrespective of whether the pumps had a steep-head- or a flat-head-capacity characteristic. The flat-head-capacity characteristic is preferred for the pumps because the decrease in pump capacity would be slightly greater as the water level lowered in the sumps.

The pumps should be installed so that they would have a suction head of not less than 4 feet. Under these conditions, charts by the Hydraulic Institute indicate that a pump having a capacity of 90,000 g. p. m. against a total head of 413 feet should not have a rotative speed of over 483 r. p. m. This suggests utilizing a motor having a rotative speed of 450 r. p. m., the next lower synchronous speed (153).

The maximum flow to Old Forge No. 2 shaft pumping plant (without the 9-foot tunnel running full with a considerable upstream head) would be 84,000 g. p. m., and the rated total head 474 feet. It is feasible to design a pump having the characteristics shown in figure 11 that meet the hydraulic properties required for the pumps for No. 15 shaft pumping plant; these pumps have a larger impeller that has the characteristics shown in figure 12. The pumps in Old Forge No. 2 shaft pumping plant, designed as stated, could be used later in No. 15 shaft pumping plant by having their impellers reduced slightly in diameter.

In No. 9A shaft pumping plant, the total pumping head ranges from 660 to 670 feet. It is feasible to build single-stage centrifugal pumps to operate at that head, but they would be of a lower specific type and less efficient than the pumps for No. 15 shaft pumping plant. Furthermore, the large size of the pumps and the high-water pressures that they would work against would present difficult problems in design, development research, and manufacture. It is therefore desirable to pump the water in two steps or stages with pumps having equal heads, with half of them installed at the bottom of the shaft and the other half installed at the midway point. The pumps at the lower altitude would discharge water into a manifold, from which it would flow through a single discharge line into a suction manifold and the suction pipes of three pumps installed in the upper-level pumproom. The discharge line from the pumps would be connected to a common discharge manifold, from which water would be discharged to the surface through a separate discharge line. A common manifold would also be provided to which suction lines from the pumps in the lower pumping station
Figure 10.—Graphic Analysis of Storage Volume and Pumping Cycle on Start and Stop Control of Pumping at Old Forge No. 2 Shaft Pumping Plant, Based on 84,000-g. p. m. Pumping Capacity.
Figure 11.—Characteristics of (Approximately) 90,000-g. p. m., 450-r. p. m. Pump for Conditions Expected at No. 15 Shaft Pumping Plant.

Figure 12.—Pump Characteristics Obtainable From 90,000-g. p. m., 450-r. p. m. No. 15 Shaft Pumps, With Larger Impeller To Suit Old Forge No. 2 Shaft Pumping Plant Conditions.
would be connected. To standardize pumping equipment, half of the total head should be developed by each pump, and the position of the higher pumps should be such that water from the pumps on the tunnel level would enter the suction inlet of those on the upper level under a positive suction head. The general arrangement of the foregoing plan is shown in figure 22 of the original publication (38). To provide a surge tank and a vent to the surface, a 24-inch pipe would be carried from the pumps on the tunnel level to the surface. The foregoing type of pump installation is used successfully at the Colorado River aqueduct of the Metropolitan Water District of Southern California and in many oil-pumping plants.

For the heads considered in the plans designed for the pumping plants at No. 9A and No. 15 shafts (38, 39), the individual pumps for No. 9A shaft plant will be the same as those for No. 15 shaft plant, except that they would operate at 400 r. p. m., whereas those for the No. 15 shaft plant would operate at 450 r. p. m.

If a pump having the characteristics shown in figure 12 is operated at 400 r. p. m. instead of 450 r. p. m., its total head at 80,000 g. p. m. would be 365 feet, with an efficiency of 88 percent being obtained. A pump with characteristics shown in figure 11 would develop a total head of 326 feet at 80,000 g. p. m. and also have an efficiency of 88 percent. Figure 13 shows the resultant full characteristics of the pumps in No. 15 shaft plant when operated at 400 r. p. m.

All pumps in the pumping plants should operate satisfactorily under the variable heads of water. The differences in head will not be enough to affect the pumping costs or the high efficiency of the pumps. Because the pumps must handle acid mine water, the pump manufacturers should aim for reliability in operation, a corrosive-resistant design, and a reasonable base efficiency. Corrosion and corrosive-resistant metals and alloys are discussed in this report (p. 40) and in the original report (35).

Motors and Starters.—Synchronous motors are recommended to drive the pumps. They should be the vertical type, with thrust bearings designed to carry the total weight of all rotating parts. The torque of the motors must be adequate to meet all requirements of the pumps under all starting conditions. Equipment for full-voltage starting would be less expensive than for reduced-voltage starting and should be used if local conditions permit.

General Recommendations.—The burden of conducting research on pumps has been mostly in the hands of manufacturers of pumps, except that necessary for large pumps such as those discussed in this report and in other reports (37-39, 154, 192, 286). The Bureau of Reclamation of the United States Department of the Interior is in a class by itself in this respect (154). It is urgently recommended that at such time as definite project reports may be prepared the Bureau of Reclamation be assigned the problem of recommending pumps,
motors, and all electrical accessories. Moreover, all metals and alloys selected for pumping equipment for anthracite mine water should be selected on the basis of the recommendations and definitions in this report and in the original report on corrosion (35), and the Bureau of Reclamation should approve the selection.

PUMP CHAMBERS

The typical pump chamber, as designed, is 46 feet wide, 93 feet long, and 105 feet high (maximum) from the sump to the arched roof. The roof and side walls are concrete-lined. A compact layout of pumping equipment requires minimum excavation, yet enough room for removing pumping and electric equipment. Traveling cranes are provided for handling the heavy equipment. Pressure doors at accessible control points permit isolating the pump chamber from the main tunnel in emergencies.

There are many subsurface structures in this country and abroad that are larger than those designed for the underground pumping plant; the construction of such chambers presents no unusual problems.

An interesting comparison can be made with the recently completed underground powerhouse of the Nechako-Kitimat Project of the Aluminum Company of Canada; this powerhouse is 700 feet long, 83 feet wide, and 140 feet high; it will house 8 turbines. Ultimately, it will be 1,100 feet long. This project was constructed with no serious incidents under conditions far more difficult than those likely to be in the proposed comprehensive plan.

The proposed pump chambers have been adequately described in the original reports on the projects (37–39); they will be excavated in rock and lined with concrete. A careful study was made to assure mobility of equipment. A control room is provided adjacent to the pump-room. Automatic controls permit the pumps to be cut in or out as conditions of flow require.

When the existing reserves of anthracite in the Lackawanna Basin are exhausted it is feasible to utilize the available head of water that could be impounded by the Moosic saddle for generating power at Old Forge No. 2 shaft pumping plant. The design of the pump chamber and controls have, therefore, been developed with this purpose in mind.

It is proposed to use Dickson shaft as a control shaft; this shaft would be constructed so that water could be drawn off at several desired altitudes and be discharged into the main tunnel at suitable pressures. At Old Forge No. 2 shaft, the original pump chamber could be converted into a power-generating station. A single generating unit would be installed in place of the pumps. The available head and quantity of water would be adequate for generating a nearly uniform capacity of 4,500 hp.

PROJECT NO. 1 (LACKAWANNA)

The critical area in the anthracite region that needs an immediate solution of the anthracite-mine-water problem, from the study made by the Bureau of Mines engineers, is between the city of Pittston and the borough of Peckville in the Northern field. The western part of this area is in the Wyoming Basin, Luzerne County, and the eastern part is in the Lackawanna Basin, Lackawanna County. Because of the number of active mines, the large number of people employed, the large tonnage of current anthracite production, and the large tonnage of anthracite reserves affected by a shutdown of local mines owing to the mine-water problem, Project No. 1 (Lackawanna) is selected to serve the area (37).

The mine-water problem has become critical recently in a part of the area in the Wyoming Basin because a number of mines have become inactive, especially those on the northern limb of the basin. The pumps have been removed, and the underground workings have filled with water, which has progressively encroached to such an extent that more active mines are threatened with the handling of additional water, along with that they now have to handle, and possibly the eventual shutdown of these mines (37, 183).

The mine-water problem in Lackawanna County has been critical for a number of years, and, under present conditions, mining would have to stop in a few years. The economic life of this area could be extended to 25 years if adequate steps were taken to solve the drainage problem. Furthermore, failure to solve this problem in the Lackawanna Basin would shortly result in overflow into the Wyoming Basin, thus aggravating the condition in that area and even creating dangers from subsidence and inundation, which could result in a disaster.

For many years subsidence of land surfaces has been occurring at a number of places in the anthracite region, varying from a few hundredths of a foot to over 20 feet, as measured over a period of years. The subsiding areas that have received the most attention are those where appreciable damage has been done to homes, streets, utilities, agricultural lands, or engineering structures, and where several feet of sinking has been noted in the last few years. This is not a problem peculiar to the anthracite region but is known to many other parts of the world (21, 29, 70, 117, 135, 143, 193, 195, 196, 240).

The mines in the area covered by the original report produced 12 percent of the total anthra-
cited tonnage in 1951 and employed 14 percent of the total persons in the anthracite industry.

The problem is to keep active mines in this area in the same status and to reëxamine certain mines, if feasible, now inundated. The plan submitted by Bureau of Mines engineers as Project No. 1 (Lackawanna) is designed to accomplish the above objectives (37).

Project No. 1 (Lackawanna) of the comprehensive drainage tunnel plan consists of the following:

1. Drainage tunnel.
2. Shafts:
   (a) Dickson.
   (b) Dodge.
   (c) Old Forge No. 2.
3. Temporary pumping plant at Old Forge No. 2 shaft.
5. Construction schedule.

The length of the main drainage tunnel in Project No. 1 is 11.89 miles, including 5.68 miles of 9-foot-diameter tunnel and 6.21 miles of 10-foot-diameter tunnel. The northern end of the tunnel has an altitude of 159 feet at the invert. The tunnel alignment has a minimum rock interval of 70 feet between the top of the drainage tunnel and the bottom anthracite bed—a safe interval from water impounded in the mines. (See fig. 6, ref. 37.) All water in the mines in this area, except that in a few small local pools below tunnel grade, can be drained by gravity, but to be fully effective Project No. 1 would require a few sublaterals and several additional connections between mines.

Project No. 1 is planned as the first phase of the entire drainage-tunnel scheme and is necessary to provide a temporary pumping plant capable of handling all mine water in the Lackawanna Basin at all times until an extension of the tunnel to another pumping plant and ultimately to the portal at tidewater is accomplished. An arrangement can be made whereby the water can be discharged by gravity into the Susquehanna River on completion of Project No. 3. (See fig. 14 and ref. 39.)

Project No. 1 is described in detail in a report of the Bureau of Mines (37). This project is a self-contained unit that will be of unimpaired value to the Lackawanna Basin if the other four projects are never realized or are completed at some later date (35–39).

PROJECT NO. 2

Project No. 2 is in the Schuylkill and Northumberland Counties. Its southern end is 3.84 miles south of the No. 9A shaft, which is 0.6 mile southwest of the village of Brockton, and its northern end is 2.6 miles north of the No. 11 shaft, which is 2½ miles east of Mahanoy City. The overall length of this project along the main tunnel is 11.48 miles. Included in this project are parts of the Lansford, Lykens, and Trevorton lateral tunnels. The main tunnel considered is aligned nearly at right angles to the main mountain ranges and valleys, as follows: Tumbling Run Valley, Sharp Mountain, Schuylkill Valley, Locust Mountain, Locust Valley, Rush Valley, Vulcan Hill, Mahanoy Valley, and Broad Mountain. The Lansford lateral, which is turned off from the No. 9A shaft, follows the Schuylkill Valley in an easterly direction; the Lykens lateral, which is turned off from the No. 9A shaft, follows Broad Mountain in a westerly direction; and the Trevorton lateral, which is turned off from the No. 11 shaft, follows Mahanoy Valley in a westerly direction (38).

The project covers the construction of these lateral tunnels for the following distances, measured from the point where they branch off the main tunnel:

<table>
<thead>
<tr>
<th>Lateral</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lansford</td>
<td>1</td>
</tr>
<tr>
<td>Lykens</td>
<td>10.56</td>
</tr>
<tr>
<td>Trevorton</td>
<td>20</td>
</tr>
</tbody>
</table>

Project No. 2 of the comprehensive plan, when extended to its ultimate limit and supplemented with the necessary tributary tunnels, will serve the mines in the Western Middle and Southern fields. It will be the means to remove the water that at present inundates and makes inaccessible over 80 percent of the total anthracite reserves in the ground (estimated at 7 billion tons) which could be recovered from these fields under present mining practice. The project, as proposed in the original report, will permit the removal of over 3 billion tons of water (38).

In the event of a national emergency and if the demand for anthracite became urgent, it would be impossible to increase the production from these fields unless the water in the mines was removed and the mines kept unwatered.

From the early 1920's to 1952, the abandonment of mines resulted in the flooding of 34 percent of the Southern field and over 60 percent of the Western Middle field. Since 1952 many more mines have been abandoned in both fields.

The Western Middle and Southern fields produced nearly 50 percent of the total anthracite tonnage in 1951, when approximately 40 percent of the persons in the anthracite industry were employed in these fields.

The problem is to keep producing mines active in the Western Middle and Southern fields and to make available, when the demand arises, the large tonnage of anthracite that is now inaccessible. Project No. 2 is designed to accomplish these objectives.

The pumping plant proposed at No. 9A shaft
is designed primarily as an emergency pumping plant for function in the completed tunnel system when the flow of water in the main tunnel has to be interrupted for inspecting or repairing the tunnel. Until the portion of the main tunnel from the southern limit of Project No. 2 to the portal at Conowingo, Md., or Marcus Hook, Pa., is driven or if that part of the project is never executed, No. 9A shaft pumping plant can be considered and utilized as a central pumping plant (36).

The average or normal flow from the present active mines and standing pools, which can be drained by the facilities provided by Project No. 2, amounts to 70,000 g. p. m. This volume can be handled by the proposed central pumping plant at an annual saving in pumping costs estimated at $1.1 million over the alternate method of individual pumping plants for individual mines. This saving can be further increased when the lateral tunnels, as provided by Project No. 2, are extended to their ultimate limits and more mines and water pools included in the system. The pumping plant has been designed for this ultimate service.

The monetary advantage from such a central pumping plant by reducing pumping costs, however, is outweighed many times by the physical benefits created. The proposed pumping plant has a capacity of nearly four times the normal drainage from the area to be served by it, thus making it unlikely that any abnormal inflow of water into the underground workings will result in future flooding of mines because of the inability to handle the volume.

The large capacity of the central pumping plant will also permit the greatest possible flexibility in draining existing pools while handling drainage from operating mines.

Project No. 2 (Western Middle and Southern fields) of the comprehensive plan consists of the following:

1. Drainage tunnel.
2. Shafts:
   (a) No. 9A.
   (b) No. 11.
   (c) Broad Mountain, Lykens lateral.
   (d) Mine Hill, Lykens lateral.
   (e) Boston Run, Trevorton lateral.
   (f) Girardville, Trevorton lateral.
3. Slopes:
   (a) Locustdale, Trevorton lateral.
   (b) Helfenstein, Trevorton lateral.
4. Permanent pumping plant at No. 9A shaft.

The tunnel portion of the comprehensive plan in Project No. 2 consists of the following:

1. Main tunnel.
2. Turning off the Lansford lateral.
3. Lykens lateral.
4. Trevorton lateral.

Flood relief for the Southern and Western Middle fields is considered nearly as urgent as that for the Lackawanna Basin in the Northern field, although inundation of present active mines, except by the abandonment of some of them, is not as imminent as in the Lackawanna Basin. Project No. 2 is described in detail in a report of the Bureau of Mines (38). It is a self-contained unit, like Project No. 1 (37), that is intended to be joined with other portions of the comprehensive plan into a complete mine-drainage system, but which will be effective in the area it serves whether or not the other projects are completed (35–39).

PROJECT NO. 3 (WYOMING)

Project No. 3 of the comprehensive plan contains a main tunnel system, which, when extended to its ultimate limit and supplemented with the necessary tributary tunnels, will serve the mines in the Wyoming Basin of the Northern field between Pittston City and Glen Lyon Borough. This tunnel can relieve the operating mines of handling water from abandoned properties. This condition will become worse as more mines are abandoned. The majority of the reserve tonnage in the Wyoming Basin lies below sea level, and the comprehensive plan, when completed, will reduce the head against which the water must be pumped in this area by an average of 440 feet, which should reduce annual pumping costs by at least $3.4 million (39).

Project No. 3 (Wyoming) of the comprehensive plan consists of the following:

1. Tunnels:
   (a) Main tunnel.
   (b) North Wyoming lateral.
2. Shafts:
   (a) No. 15.
   (b) No. 15 water-discharge shaft and discharge tunnel to Susquehanna River.
   (c) Alden.
   (d) Sugar Notch.
   (e) Baltimore No. 2.
   (f) Laffin.
3. Pumping plant:
   (a) Permanent pumping plant at No. 15 shaft.

The tunnel portion in Project No. 3 consists of (1) the main tunnel and (2) turning off the North Wyoming lateral.

The southern limit of this project is 101.95 miles from the portal at Conowingo, Md., or Marcus Hook, Pa.; the eastern limit near Laffin would connect with Project No. 1 (Lackawanna) (36, 37).

The main tunnel from No. 15 shaft northward parallels the southern side of the Wyoming Basin and will make the following mine-drainage areas tributary to the tunnel: Wanamie and Alden; Truesdale and Bliss; Sugar Notch, Huber, and Franklin; Hollenback, Stanton-Empire, and Baltimore; Mineral Spring, Pine Ridge-Delaware, Prospect, Dorrance, and Henry; and No. 14, Ewen, Schooley, Exeter, Stevens, Laffin, and Packer.
When completed, Project No. 3 will have a number of sublaterals and additional connections between mines (39). Construction of surface ditches and flumes and backfilling strip-pings can temporarily prevent or reduce some surface seepage if the work is properly engineered and judiciously executed. However, stripping and underground mining continually create new surface openings and seepage courses. Unless a program of this nature also is continuing, the benefits derived are temporary and eventually are destroyed (26, 31, 41, 48).

Underground watercourses and dams are merely a means of conducting or confining water to a definite pool and have little effect in preventing flooding of mines. They are in fact adjuncts to pumping plants, which are part of the mine plant, and must be considered the financial and operational responsibility of the owner or mine operator and not of the Federal Government.

The main tunnel is to be circular, concrete-lined, and on a gradient of 1 foot per mile. The altitudes of the roof of the tunnel at its southern and eastern ends are 132.95 and 156.1 feet, respectively.

The main tunnel eventually can be utilized, if desired, to drain by gravity only the overflow from an abandoned Lackawanna Basin into the Susquehanna River. The size and depth of the tunnel would allow this smaller quantity of water to flow through the tunnel into the Susquehanna River at Shickshinny without causing the water level in the Lackawanna Basin to rise above the broken strata at Moosic “saddle” (37, 39). To make this possible, all connections to the Wyoming Basin would have to be closed and pumping resumed at some individual mines utilizing the tunnel at that time in the Wyoming Basin.

The graphic analysis of conditions permitting free flow of water from the Lackawanna Basin into the Susquehanna River below No. 15 shaft is shown in figure 14, which illustrates the head for free flow of water (156 sec.-ft.) from Dickson shaft to the Susquehanna River below No. 15 shaft.

The North Wyoming lateral is to be driven from the main tunnel at No. 15 shaft for a distance of 1 mile and is to be 9 feet in diameter, circular, concrete-lined, and on a gradient of 1 foot per mile.

Five shafts are required in this project: (a) No. 15 shaft near Glen Lyon (which will be a new, circular, concrete-lined, permanent shaft, and the necessary surface plant will be installed; (b) Alden shaft at Alden; (c) Sugar shaft Notch at Sugar Notch; (d) Baltimore No. 2 shaft at Wilkes-Barre; and (e) Laffin shaft at Laffin. The last four shafts originally were part of active mining operations but now are inactive, except the Sugar Notch, and they will be used as construction shafts for driving the drainage tunnel.

The pumping plant at No. 15 shaft will pump water from the area of Project No. 3 until the main tunnel is completed from No. 15 shaft to Conowingo, Md., or Marcus Hook, Pa., after which this plant will become a standby plant, to be used if inflow requires it or to handle the water to allow inspection of the main tunnel below No. 15 shaft. This pumping plant (with three 200-sec.-ft.-capacity pumps) will also handle the water from the area of Project No. 1 (Lackawanna) when Project No. 3 connects to it, thereby permitting the abandonment of Old Forge No. 2 pumping plant, if desired. (See section on Technical Aspects of Emergency Pumping Plants, p. 61.)

The project, as outlined, is a self-contained drainage unit that will permit unwatering inundated mines and safeguarding active mines in the Wyoming Basin of the Northern field and also will handle the water in the Lackawanna Basin. Project No. 3 is described in detail in the original report (39).

The pumping plant provided in Project No. 3 at No. 15 shaft will discharge into the Susquehanna River all the mine water of the Northern field gravitating from above the pumping plant and that pumped from lower altitudes to the proposed tunnel system. This arrangement permits pumping against the lowest obtainable hydraulic head and will be continued until the extension of the main tunnel to the portal either below Conowingo Dam on the Susquehanna River or at Marcus Hook on the Delaware River is completed and the gravity flow is established.

**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) (38). Its northern end is 1.0 mile south of No. 15 shaft near Glen Lyon (Project No. 3) (38). Project No. 4 will connect with Project No. 3 (Wyoming) and with Project No. 2 (Western Middle and Southern fields) (36, 38, 39). The line of the tunnel proposed in Project No. 4 runs nearly due north and south and at right angles to the mountain ranges (36).

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
HEAD FOR FREE FLOW OF WATER (156 SEC.-FT.) FROM DICKSON SHAFT TO SUSQUEHANNA RIVER BELOW NO. 15 SHAFT

FRICION HEAD, FEET

12-FT. DIA... 2.50 MI. LONG... 0.6
13-FT. DIA... 15.76 MI. LONG... 2.5
11-FT. DIA... 6.41 MI. LONG... 2.2
10-FT. DIA... 6.21 MI. LONG... 3.4
9-FT. DIA... 3.14 MI. TO DICKSON SHAFT... 2.9
TOTAL HEAD... 11.6

FLOOD STAGE

ALTS 518 FT.

2 1/2 MI. OF TUNNEL

MOSIE SADDLE BARRIER

ALT. 545 FT.

FREE-RUNNING DISCHARGE FROM LACKAWANNA BASIN 70,000 G.P.M. (156 SEC.-FT.)

ALT. 530 FT.

ALT. 156.5 FT.

PROJECT NO. 3

22.17 MI.

PROJECT NO. 1

11.89 MI.

HORIZONTAL SCALE, MILES

FIGURE 14.—Graphic Analysis of Conditions Permitting Free Flow of Water From Lackawanna Basin Into Susquehanna River Below No. 15 Shaft.
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 (47). 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, Nos. 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.

The strata overlying the proposed drainage tunnel in Project No. 4 have 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 (38, 40).

To safeguard the drainage tunnel from possible failure if critical internal or external pressure, or both, are 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 (36, 38, 40).

The tunnels as provided in Projects Nos. 4 and 5 will not tap water from any mines (36). 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 (37–39).

Project No. 1 proposes construction of a tunnel and related facilities to drain effectively the Lackawanna Basin, Project No. 2 the Western Middle and Southern fields, and Project No. 3 the Wyoming Basin. Project No. 3 provides for connection to the works proposed in Project No. 1, and Project No. 4 provides for connection to 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 is described in detail in the original report (36).

**PROJECT NO. 5**

The discharge end of the comprehensive plan is a part of Project No. 5 (36). 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 anthracite 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 Octararo Creek and the Susquehanna River below the Conowingo Dam at an altitude of 15 feet, or at a point on the Delaware River between Chester and Marcus Hook, Pa. (36).

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 Mine 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 will be in Cecil County, Md., if that route is selected.

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 rights-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 the original report, which describes Project No. 5 in detail (36).

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 (40, 48).

The portal section of the proposed tunnel, if in Maryland, 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 mouth or portal of the tunnel could be near the junction of Octararo 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 (36).

**ALTERNATE ROUTE, MAIN TUNNEL**

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 (Marcus Hook tunnel) could be constructed 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 in the original report (36) shows the alignment of this alternate tunnel, which would be constructed entirely within the boundaries of Pennsylvania.

In this instance, Projects Nos. 1, 2, 3, and 4, as discussed earlier in this report, would remain unchanged. In Project No. 5 only the alignment of the tunnel would have to be altered. The estimate of construction costs and construction schedule is fully applicable to the alternate tunnel location without important changes (36–39).

**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 mines is entering the Susquehanna River (21–23, 36, 54, 36, 39, 41, 43–46). The acidity of this mine water is neutralized, and the soluble salts are carried to the mouth of the river under present conditions (31, 43–45, 123, 216). The changes that will result if the mine water is collected and discharged at one point must be given careful study (36, 65, 123, 216).

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 its average flow, whereas the mine pumping decreases only to two-thirds the average pumping load (31, 45).

The admixture of different waters at the confluence of the Lackawanna River and the North Branch of the Susquehanna River 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 at one place into either the Susquehanna River or the Delaware River (36, 43–45, 123, 216).

The North Branch of the Susquehanna River is alkaline (pH 7.5) at Pittston where it enters the Wyoming Basin of the Northern field and receives the acid Lackawanna River water. The discharge of the Susquehanna River at this point is more than 10 times that of the Lackawanna River. Because of the volume and the alkalinity of the Susquehanna River, the acidity of the Lackawanna River is completely neutralized where it discharges into the Susquehanna River. At this confluence of the rivers, the alkalinity as CaCO$_3$ (methyl-red indicator) of the Susquehanna River is 58 p. p. m., and the alkalinity as CaCO$_3$ (phenolphthalein indicator) is 55 p. p. m. The free acidity as H$_2$SO$_4$ (methyl-red indicator) of the Lackawanna River is 81 p. p. m., and the total acidity as H$_2$SO$_4$ (phenolphthalein indicator) is 240 p. p. m.

The relation between stream flows in the Lackawanna and Susquehanna Rivers during 1944 shows a range of dilution ratios from 1 to 11 in dry seasons to 1 to 23 during flood seasons. Similarly, the relation between mine pumping and flow in the Lackawanna River ranged from a probable 1 to 2 in dry seasons to 1 to 15 during flood conditions. The facts are that the dilution factors have always been such as to neutralize the Lackawanna River water at the confluence. However, combining the foregoing figures indicates that a dilution factor as low as 1 to 20 has resulted in a satisfactory neutralization of mine water from the Lackawanna Basin in the Susquehanna River. During average flow conditions and during flood conditions this dilution factor increases to 1 to 50 and 1 to 300, respectively.

Although much additional acid mine water from mines in the Wyoming Basin and Eastern Middle field is discharged into the Susquehanna River between Pittston and Danville, a distance of 59 miles, the alkalinity of the Susquehanna River is enough to neutralize the acid. Moreover, extensive sampling of the Susquehanna River at Danville during a period of several years shows that river to have a pH of 6.9 to 7.0. The bicarbonate content of the Susquehanna River shows a decrease from 6 p. p. m. at Falls, Pa., before entering the anthracite region
to 37 p. m. at Danville. The sulfate content of the river shows an increase from 17 p. m. at Falls to 72 p. m. at Danville (44, 123, 217).

Between Danville and Harrisburg four creeks carrying acid mine water from the Western Middle and Southern fields flow into the Susquehanna River but are neutralized by the alkaline water in the Susquehanna and its tributaries entering from the area west of the river. At Harrisburg the river samples over a period of several years show a pH between 6.8 and 7.2. The bicarbonate content of the river shows an increase to 53 p. m. and the sulfate content a decrease to 24 p. m. (44). The change in sulfate content of the Susquehanna River cannot be directly related to any particular source because even the alkaline tributaries between Sunbury and Harrisburg contain much more sulfate (p. p. m.) than the main river (217).

The Lehigh River receives acid mine waters in creeks from the Eastern Middle and Southern fields between Rockfort and Mauch Chunk. The river at Rockfort has a pH of 6.0 to 7.3 but is slightly alkaline (44). After receiving the inflow of three creeks containing acid mine water (pH 3.1 to 3.9) the Lehigh River appears slightly acid (pH 4.5) at Lehighport. This acid is neutralized by alkaline water from tributaries of the Lehigh River below Lehighport so that samples collected at Catassuqua and Bethlehem show slightly alkaline water having a pH of 6.6 to 7.6 (44, 123).

The Little Schuylkill River has its source in the Southern field, and all samples taken in the river show it to be acid from its source at Tamaqua to its confluence with the Schuylkill at Port Clinton (123, 289).

The Schuylkill River rises in the Southern field at Tuscarora and receives acid mine water from mine-pump discharges and creeks until it leaves the field at Cressona. Samples of the river show it to have a pH of 3.2 to 4.6 throughout this distance. It continues to be acid until Maiden Creek enters the river just below Leesport. This alkaline stream (pH 7.0 to 8.0) neutralizes the acid in the river. From Leesport to Pottstown, the river water becomes more alkaline. The flow in the Schuylkill River at Leesport ranges from 114 to 1,700 sec.-ft., and the flow in Maiden Creek ranges from 39 to 675 sec.-ft. (44, 123, 289).

Studies by the Mellon Institute of Industrial Research (36, 65) indicate that a flow of 14,600 sec.-ft. in the Susquehanna River would neutralize the entire drainage from the mines in all the fields. This indicates a dilution factor of 1 to 22 that is corroborated by the experience at Pittston. The average flow in the Susquehanna River at Harrisburg is 40,000 sec.-ft. (44, 123, 216). Under average flood conditions, the inflow of mine water into the Susquehanna River at any point would not be expected to make any particular change in the character of the river water entering the Chesapeake Bay. However, two factors must be considered in regard to the flow in the Susquehanna River. In an extremely dry season (summer of 1930) the flow in the river dropped to 2,000 sec.-ft. (272), and in recent years it has dropped to 40,000 sec.-ft. several times (123). The second factor is the presence of dams in the river below Harrisburg. Whenever the flow in the river is less than 8,000 sec.-ft., the flow is regulated by the power plant at the York Haven Dam. In times of less than average flow, the power plant at the Conowingo Dam is operated on a part-time basis, taking advantage of the storage capacity behind the dam to operate at full capacity as many hours per day as the water supply will permit (272). This results in periods when no water flows 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 Port Deposit and Havre de Grace in Maryland.

The salinity in the Chesapeake Bay at the mouth of the Susquehanna River is usually about 1 gram per liter, and the water standing in the river is virtually river water (36). This is supported by the fact that drinking water is taken out of the river at Port 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 sec.-ft. and a high of 875,000 sec.-ft. dwarf the significance of the 180 sec.-ft. 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.

Flows of 100,000 to 875,000 sec.-ft., 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 (36).

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 United States Public Health Service and the Fish and Wildlife Service and the Bureau of Reclamation of the United States Department of the Interior. The Susquehanna River at present does not always supply potable water from the communi-
ties below Conowingo Dam, and a better source of water for these communities should be considered in this connection.

If the data obtained from unbiased investigations by competent agencies prove that mine water from the proposed anthracite drainage tunnel should not be discharged into the Chesapeake Bay, the comprehensive plan for mine drainage as proposed in this report can be altered accordingly. A similar tunnel can be constructed to discharge the mine water into the Delaware River at a point between Chester and Marcus Hook (36).

SUMMARY OF COST

The construction-cost estimates of the comprehensive plan, described in the preceding paragraphs and in the original reports (36–39), are summarized in table 15.

CONSTRUCTION PROGRAM

The comprehensive plan is a long-range plan for the control of mine water in the anthracite region of Pennsylvania, and the conservation of 95 percent of the anthracite reserves of the Nation should be started at the earliest possible date, as the need for flood protection and conservation of anthracite is urgent. If and when the plan is authorized by the Congress, future progress in its accomplishment will depend equally on congressional appropriations for planning and construction and on prompt action by local interests in providing the cooperation required of them.

Assuming, however, that adequate appropriations were made by the Congress and that requirements of local cooperation were met, the entire comprehensive development could be completed under an orderly and efficient plan in a maximum period of 10 years. The total time required for completion of the entire project will depend on whether the five projects are undertaken simultaneously or in sequence. If all projects are conducted simultaneously, the entire program could be completed in about 5 years. If the projects are conducted in sequence, they are so planned as to provide relief first in the areas where it is needed most urgently. It is considered, however, that completion of certain parts of the plan should be deferred beyond this period, as the need for such features will depend on progressive development of the areas.

All features set up as parts of the comprehensive plan are considered necessary and economically justified. It is impracticable to establish definite priorities at this time for construction of individual items. Some parts of the plan, however, such as those required for protection of human life and conservation of the anthracite economy are obviously more urgently needed than the longer range features of the plan. In addition, engineering considerations will require an order of development that would produce, step by step, construction of the works that can be operated from the beginning with the greatest efficiency and would obtain progressively, from the beginning, the benefits that the plan is designed to produce. With such practical considerations in mind, it appears that logical construction should be as outlined below and in the five projects described in detail in the original reports (36–39).

Most anthracite mines now operating have pumping plants of adequate capacity to handle maximum seepage, although the continued pumping burden may contribute to premature cessation of some operations. Any construction plan that proposes that as additional mines are

<p>| Table 15.—Summary of construction-cost estimates for Projects Nos. 1 to 5 of the comprehensive plan |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th></th>
<th>Project No. 1 (Lackawannas)</th>
<th>Project No. 2 (Southern and Western Middle fields)</th>
<th>Project No. 3 (Wyoming)</th>
<th>Project No. 4 (facilities connecting Projects Nos. 2 and 3)</th>
<th>Project No. 5 (drainage facilities to tidewater)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnels</td>
<td>$13,167,112</td>
<td>$53,469,440</td>
<td>$30,419,617</td>
<td>$26,374,914</td>
<td>$107,203,259</td>
<td>$230,633,330</td>
</tr>
<tr>
<td>Shafts</td>
<td>$885,357</td>
<td>$4,624,964</td>
<td>$2,876,359</td>
<td>$1,479,100</td>
<td>$3,835,300</td>
<td>$13,900,777</td>
</tr>
<tr>
<td>Slopes</td>
<td></td>
<td>$864,240</td>
<td></td>
<td></td>
<td>$249,490</td>
<td>$1,113,730</td>
</tr>
<tr>
<td>Pumping plants (including tunnels, etc.)</td>
<td>$44,457</td>
<td>$5,500,855</td>
<td>$5,471,604</td>
<td>$10,800</td>
<td>$65,750</td>
<td>$14,242,825</td>
</tr>
<tr>
<td>Access roads</td>
<td></td>
<td>$194,890</td>
<td>$8,645</td>
<td>$10,800</td>
<td></td>
<td>$220,345</td>
</tr>
<tr>
<td>Diamond drilling to tap water</td>
<td>$20,400</td>
<td>$55,000</td>
<td>$6,815</td>
<td></td>
<td></td>
<td>$27,215</td>
</tr>
<tr>
<td>Diamond drilling to prove geology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$27,215</td>
</tr>
<tr>
<td>Pumping during construction</td>
<td>$78,047</td>
<td>$86,528</td>
<td>$8,116</td>
<td>$222,573</td>
<td>$741,910</td>
<td>$1,715,522</td>
</tr>
<tr>
<td>Acquiring property and right-of-way</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1,112,561</td>
</tr>
<tr>
<td>Surface excavation, buildings, and sewage</td>
<td>$114,000</td>
<td>$344,000</td>
<td>$190,000</td>
<td>$114,000</td>
<td>$418,000</td>
<td>$1,140,000</td>
</tr>
<tr>
<td>Powerlines and substations</td>
<td>$185,000</td>
<td>$325,000</td>
<td>$275,000</td>
<td>$250,000</td>
<td>$1,004,000</td>
<td>$1,959,000</td>
</tr>
<tr>
<td>Chlorination</td>
<td>$9,000</td>
<td>$40,000</td>
<td>$25,000</td>
<td>$15,000</td>
<td>$55,000</td>
<td>$144,000</td>
</tr>
<tr>
<td>Total</td>
<td>$17,822,234</td>
<td>$60,211,067</td>
<td>$39,554,325</td>
<td>$28,689,653</td>
<td>$114,657,638</td>
<td>$295,944,917</td>
</tr>
<tr>
<td>Contingencies and engineering</td>
<td>$891,612</td>
<td>$3,316,553</td>
<td>$1,677,716</td>
<td>$1,494,652</td>
<td>$2,723,882</td>
<td>$13,347,246</td>
</tr>
<tr>
<td>Grand total</td>
<td>$18,713,846</td>
<td>$63,527,620</td>
<td>$41,231,041</td>
<td>$30,184,305</td>
<td>$137,381,520</td>
<td>$319,327,163</td>
</tr>
</tbody>
</table>
abandoned the pumps taken out of service in private mines be replaced with equipment purchased out of the appropriation and that other pumping plants be modernized at public expense is only temporary relief and benefits only individual private operators at public expense; this is not the proper domain of Federal funds.

Any such general program must be flexible enough to permit such changes as would become desirable in the prosecution of a project of the magnitude of the comprehensive plan and its development. For example, if lands and rights-of-way and other necessary assurances of local cooperation are made available by local interests for any feature of the plan and that feature can be constructed and operated in accordance with the overall purposes of the plan, it should not be delayed pending commencing other features.

The scope of work constituting Project No. 1 (Lackawanna) (37) covers the following separate construction items:

1. Reconditioning:
   (a) Dickson shaft, 474 feet.
   (b) Dodge shaft, 512 feet.
   (c) Old Forge No. 2 shaft, 198 feet.

2. Equip the three shafts with suitable hoists and alter the existing headframes to provide adequate dumping facilities.

3. Excavate shafts 40 feet below respective tunnel level as follows:
   (a) Dickson shaft, 139 feet.
   (b) Dodge shaft, 197 feet.
   (c) Old Forge No. 2 shaft, 356 feet.

4. Excavate tunnel bore from each of the three shafts in opposite directions, to meet approximately halfway between the shafts.

5. Construct pumproom at foot of Old Forge No. 2 shaft.

6. Construct control arrangement at foot of Dickson shaft.

7. Install electric cables, control, and motors in Old Forge No. 2 shaft and in pumproom.

8. Install pumps, valves, and pipes in Old Forge No. 2 pumproom.

9. Install tunnel control gates and bulkhead doors at bottom of all three shafts.

10. Construct discharge tunnel from top of Old Forge No. 2 shaft to the Lackawanna River.

The time schedule for the construction program outlined above is given in graphic form in figure 31 of the original report, which describes the project in detail (37). The diagram is based on the following estimated work progress:

3 feet per operating day 1 for shaft sinking.
30 feet per operating day 1 for tunnel-face advance.
60 feet per operating day 1 for tunnel concreting.

1 All work scheduled for regular 5-day week.

For the first year, an estimated allocation of $3 million is necessary for project engineering, for reconditioning and deepening existing construction shafts (Dickson, Dodge, and Old Forge No. 2), and for commencing tunnel excavation in the second half of the first year.

For the second year, an estimated allocation of $7.5 million is necessary for tunnel excavation and pumproom construction.

For the third year, an allocation of $6.5 million is required for tunnel excavation, concrete lining the tunnel, and installing pumps, motors, and control equipment in the pumproom. The balance of the estimated total cost for Project No. 1 (Lackawanna), amounting to $1,723,846, is to be made available for the fourth year and will be expended in the first 6 months when the Lackawanna project is to be completed.

The scope of work constituting Project No. 2 (Western Middle and Southern fields) (38) covers the following separate construction items:

1. Construct the following shafts:

<table>
<thead>
<tr>
<th>Shaft</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 9A</td>
<td>705</td>
</tr>
<tr>
<td>No. 9A water discharge</td>
<td>755</td>
</tr>
<tr>
<td>No. 11 shaft</td>
<td>1,207</td>
</tr>
<tr>
<td>Broad Mountain</td>
<td>1,074</td>
</tr>
<tr>
<td>Mine Hill</td>
<td>1,050</td>
</tr>
<tr>
<td>Boston Run</td>
<td>1,139</td>
</tr>
<tr>
<td>Girardville</td>
<td>1,554</td>
</tr>
</tbody>
</table>

2. Construct the following slopes:

<table>
<thead>
<tr>
<th>Slope</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locustdale</td>
<td>2,236</td>
</tr>
<tr>
<td>Helfenstein</td>
<td>2,404</td>
</tr>
</tbody>
</table>

3. Construct the following tunnels from shafts and slopes:

<table>
<thead>
<tr>
<th>Shafs</th>
<th>Slopes</th>
<th>Tunnels</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 9A</td>
<td>South</td>
<td>3.84</td>
<td></td>
</tr>
</tbody>
</table>
<pre><code>        | Do | North | 2.52 |
        | Do | Lansford lateral | 2.00 |
        | Do | Lykens lateral | 2.50 |
</code></pre>
<p>| No. 11 | South | 2.52 |
| Do | North | 2.60 |
| Do | Trevorton lateral | 2.50 |
| Broad Mountain | | 2.50 |
| Do | West | 2.00 |
| Mine Hill | East | 2.60 |
| Do | West | 1.56 |
| Boston Run | East | 2.50 |
| Do | West | 2.50 |
| Girardville | East | 2.50 |
| Do | West | 2.50 |
| | Helfenstein | East | 2.50 |
| | Do | West | 2.50 |</p>

4. Construct pump chambers at No. 9A shaft.
5. Construct gate-control arrangement at foot of No. 11 shaft.
6. Install electric cables and controls in No. 9A shaft.
7. Install pumps, motors, valves, and pipes in pump chambers in No. 9A shaft.
8. Install tunnel control gates and bulkhead doors at bottom of Nos. 9A and 11 shafts.
9. Construct water-discharge channel from top of No. 9A water shaft to the Schuylkill River.

The time schedule for the construction program outlined above is given in graphic form in figure 35 of the original report, which describes the project in detail (38). The diagram is based on the following estimated work progress:

- 3 feet per operating day \(^1\) for shaft sinking.
- 5 feet per operating day \(^1\) for slope sinking.
- 30 feet per operating day \(^1\) for tunnel-face advance.
- 60 feet per operating day \(^1\) for tunnel concreting.

\(^1\) All work is scheduled for a regular 5-day week.

The work schedule for Project No. 2 (38), covering an estimated period of 5 years, requires a varied allocation of funds for each year, determined by the nature of the work, as follows:

- The first year an estimated allocation of $4.5 million is required for project engineering and to sink the shafts (Nos. 9A and 11, Broad Mountain, Mine Hill, Boston Run, and Girardville) and slopes (Locustdale and Helfenstein).
- The second year an estimated allocation of $0.6 million is required to finish sinking the shafts and slopes, except for the No. 9A water shaft, and for tunnel excavation.
- The third year an allocation of $22.5 million is required to finish sinking the No. 9A water shaft and the various tunnel excavations and concreting.
- The fourth year an allocation of $20.3 million is required for tunnel excavation, concrete lining the tunnel, and pumproom construction.
- The fifth year an allocation of $12,621,620 is required for concrete lining of tunnels, construction of pumproom, installation of pumps, motors, and control equipment, and miscellaneous items to complete the project.

The scope of work constituting Project No. 3 (Wyoming) (39) covers the following separate construction items:

1. Reconditioning:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alden</td>
<td>540</td>
</tr>
<tr>
<td>Baltimore No. 2</td>
<td>595</td>
</tr>
</tbody>
</table>

2. Equip the above shafts and the Sugar Notch and Laflin shafts with suitable hoisting equipment and headframes designed to provide adequate dumping facilities.

3. Excavate shafts 40 feet below their respective tunnel level, as follows:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 15 (new)</td>
<td>883</td>
</tr>
<tr>
<td>No. 15 water discharge</td>
<td>422</td>
</tr>
<tr>
<td>Sugar Notch</td>
<td>284</td>
</tr>
<tr>
<td>Alden</td>
<td>0</td>
</tr>
<tr>
<td>Baltimore No. 2</td>
<td>403</td>
</tr>
</tbody>
</table>

4. Construct the following tunnels from shafts:

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Tunnels</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 15</td>
<td>South</td>
<td>1.00</td>
</tr>
<tr>
<td>Do.</td>
<td>East</td>
<td>2.24</td>
</tr>
<tr>
<td>Do.</td>
<td>North Wyoming lateral</td>
<td>1.00</td>
</tr>
<tr>
<td>Do.</td>
<td>Water discharge to river</td>
<td>2.40</td>
</tr>
<tr>
<td>Sugar Notch</td>
<td>Tunnel to main tunnel</td>
<td>1.10</td>
</tr>
<tr>
<td>Do.</td>
<td>West</td>
<td>2.47</td>
</tr>
<tr>
<td>Do.</td>
<td>East</td>
<td>2.58</td>
</tr>
<tr>
<td>Alden</td>
<td>Tunnel to main tunnel</td>
<td>3.32</td>
</tr>
<tr>
<td>Do.</td>
<td>West</td>
<td>2.24</td>
</tr>
<tr>
<td>Do.</td>
<td>East</td>
<td>2.47</td>
</tr>
<tr>
<td>Baltimore No. 2</td>
<td>Tunnel to main tunnel</td>
<td>4.46</td>
</tr>
<tr>
<td>Do.</td>
<td>West</td>
<td>2.58</td>
</tr>
<tr>
<td>Do.</td>
<td>East</td>
<td>2.06</td>
</tr>
<tr>
<td>Laflin</td>
<td>West</td>
<td>2.07</td>
</tr>
<tr>
<td>Do.</td>
<td>East</td>
<td>3.46</td>
</tr>
</tbody>
</table>

5. Construct pump chambers at No. 15 shaft.
6. Install electric cables and controls in No. 15 shaft.
7. Install pumps, motor, valves, and pipes in pump chamber in No. 15 shaft.
8. Construct water-discharge channel from portal of water-discharge tunnel to Susquehanna River.

The time schedule for the construction program outlined is given in graphic form in figure 28 of the original report, which describes the project in detail (39). This diagram is based on the following estimated work progress:

- 5 feet per operating day \(^1\) for reconditioning shafts.
- 3 feet per operating day \(^1\) for sinking shafts.
- 30 feet per operating day \(^1\) for advancing tunnel face.
- 60 feet per operating day \(^1\) for concreting tunnel.

\(^1\) All work is scheduled for a regular 5-day week.

The work schedule for Project No. 3 (Wyoming) (39) covers an estimated period of 5 years and requires a varied allocation of funds for each year, determined by the nature of the work as follows:

For the first year, an estimated allocation of $4.1 million is necessary for project engineering, to sink the No. 15 shaft, to deepen the Sugar Notch shaft, to unwater and deepen the Alden shaft, to recondition Baltimore No. 2 shaft, to unwater and deepen the Laflin shaft, and to commence tunnel excavation.

For the second year, an allocation of $9.4 million is required to finish sinking the shaft and to continue excavating the tunnel.

For the third year, an allocation of $11.7 million is required for tunnel excavation, to concrete line the tunnel, and to construct the pumproom.

For the fourth year, an allocation of $10.3 million is required to continue the tunnel excavation, to concrete line the tunnel, and to install pumps, motors, and control equipment in the pumproom.
The balance of the estimated cost for Project No. 3 ($6,032,041) will be expended in the forepart of the fifth year to complete the tunnel work and to finish the project.

The work contemplated in Project No. 4 (36) covers the following items of construction:

1. Excavate and construct the following shafts to the depths indicated:

<table>
<thead>
<tr>
<th>Shfts:</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 12</td>
<td>1,089</td>
</tr>
<tr>
<td>No. 13</td>
<td>795</td>
</tr>
<tr>
<td>No. 14</td>
<td>523</td>
</tr>
</tbody>
</table>

2. Construct the following tunnels from shafts:

<table>
<thead>
<tr>
<th>Shfts</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>No. 13</td>
<td>South</td>
<td>3.84</td>
</tr>
<tr>
<td>No. 14</td>
<td>South</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>2.42</td>
</tr>
</tbody>
</table>

The time schedule for the construction program outlined is given in graphic form in figure 15 of the original report, which describes the project in detail (36).

The schedule is based on the following work progress:

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

All work is scheduled for a regular 5-day week.

The work schedule for Project No. 4 (36) covers an estimated construction period of 5½ years. Because 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 $1,690,000 will be required for engineering and shaft construction.

The second year will require an allocation of $5,985,000 to finish sinking the shafts and to 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 (36) covers the following separate items of construction:

1. Construct the following shafts to the depths indicated:

<table>
<thead>
<tr>
<th>Shfts</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>835</td>
</tr>
<tr>
<td>No. 3A</td>
<td>440</td>
</tr>
<tr>
<td>No. 4</td>
<td>350</td>
</tr>
<tr>
<td>No. 5</td>
<td>606</td>
</tr>
<tr>
<td>No. 6</td>
<td>540</td>
</tr>
<tr>
<td>No. 7</td>
<td>472</td>
</tr>
<tr>
<td>No. 8</td>
<td>565</td>
</tr>
<tr>
<td>No. 8A</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>Shfts</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portal to Shaft No. 1</td>
<td>6.50</td>
</tr>
<tr>
<td>Shaft No. 1 to Shaft No. 2</td>
<td>6.50</td>
</tr>
<tr>
<td>Shaft No. 2 to Shaft No. 3</td>
<td>6.50</td>
</tr>
<tr>
<td>Shaft No. 3 to Shaft No. 3A</td>
<td>6.50</td>
</tr>
<tr>
<td>Shaft No. 3A to Shaft No. 4</td>
<td>6.67</td>
</tr>
<tr>
<td>Shaft No. 4 to Shaft No. 5</td>
<td>6.68</td>
</tr>
<tr>
<td>Shaft No. 5 to Shaft No. 6</td>
<td>6.30</td>
</tr>
<tr>
<td>Shaft No. 6 to Shaft No. 7</td>
<td>7.10</td>
</tr>
<tr>
<td>Shaft No. 7 to Shaft No. 8</td>
<td>6.70</td>
</tr>
<tr>
<td>Shaft No. 8 to Shaft No. 8A</td>
<td>7.67</td>
</tr>
<tr>
<td>Shaft No. 8A to northern limit of project</td>
<td>3.84</td>
</tr>
</tbody>
</table>

The schedule for the construction program is shown in graphic form in figure 16 of the original report, which describes the project in detail (36).

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.
- 30 feet per operating day for advancing tunnel face.
- 60 feet per operating day for concreting tunnel.

All work is scheduled for a regular 5-day week.

It is anticipated that Project No. 5 (36) 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 years 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 balance of the estimated cost of the project ($2,400,520) will be expended during the first half of the sixth year to complete all work.
ECONOMIC ANALYSIS

Four separate reports covering Projects Nos. 1, 2, 3, and 4 and 5, of a series of five projects, have been published by the Federal Bureau of Mines. The economic analysis of the mine-water problem is inseparable from the economics of the region, discussed under Economic Development (p. 8) and in the original reports (37–39).

The flood protection and mine-water control provided by Project No. 1 (Lackawanna) of the proposed comprehensive plan will not only benefit the Lackawanna area but also the Wyoming area, as it will prevent mine water from the Lackawanna Basin from flowing over the Moosic saddle and endangering the active mines in the Wyoming Basin.

The latter has by far the greater coal reserves and is much more vulnerable to mine flooding and excessive pumping costs because of the greater depth of the mine workings, reaching 1,500 feet below sea level at its deepest point. This demonstrates that the Lackawanna and Wyoming Basins must be considered as a unit in relation to flood-prevention problems.

The benefits to be expected can best be stated in a negative manner, that is, stating what losses will occur to the industry and community interests, as well as to State and Federal Governments, if no flood relief is provided.

The Northern field carries the highest pumping load per ton of anthracite mined of all the four fields. In 1951 the mines in the Northern field pumped an average of 32.3 tons of water for every ton of coal hoisted.

The proposed tunnel project (Project No. 1), with a temporary pumping plant at Old Forge No. 2 shaft, would not reduce the total volume of water to be pumped but would materially lessen the cost of pumping, owing to the concentration of pumping in a plant with higher efficiency and the lowest pumping head available. When the entire tunnel is driven, virtually all mine water of the Lackawanna Basin can flow by gravity to tidewater, removing all pumping costs, except for small local pools below the tunnel and having almost negligible inflow. On the other hand, if a tunnel and the temporary pumping plant are not provided in due time, some mines will not only have to pump their own mine water against considerably higher pumping heads than other mines but will also have to pump water from adjacent abandoned and flooded mines to keep the hydrostatic pressure against the barrier pillars to a safe limit. Such a situation may force one mine after another to cease operation, thus compounding the problem to the point that ultimately all mines will be inundated because of excessive pumping costs or physical inability to cope with such large volumes of water. When this happens, most of the people in this area will lose their means of livelihood, and the once prosperous anthracite region will be for many years an economic-distress area (37).

In 1952 the Northern field, of which the Lackawanna Basin is an integral and inseparable part in respect to overall economy and mine flooding problems, produced 13,775,000 marketable tons of anthracite, providing work and a livelihood for 38,229 employees. Of this production, 77.5 percent was deep-mined, which accounts for the comparatively large labor force employed and also emphasizes the economic importance of anthracite mining in the Northern field. The income value of this production to the anthracite producers was approximately $210 million and, in addition, produced a railroad and truck freight revenue of approximately $66 million (37).

The expenditure of an estimated $18,723,846 for a mine flood project, designed not only to make possible the continuation of mining in the Lackawanna Basin but to remove the hazard to the Wyoming Basin from flood waters from the Lackawanna Basin, cannot be disputed, neither from a mathematical nor an economic viewpoint (37).

The flood protection and mine-water control provided by Project No. 2 will benefit the Western Middle and Southern fields, not only in reducing, and in some instances removing, present pumping costs but also in removing water pools over coal reserves in idle mines (38).

The Southern field has the largest coal reserves of the region, thus making it the major producing area for the future. Consequently, remedial measures that will drain the water pools from above these untapped reserves will be of incalculable value.

While the benefits to be derived from the proposed mine flood-prevention project cannot be evaluated in exact monetary terms, it is, nevertheless, apparent that failure to provide such
preventive means will bring about an early and untimely end of anthracite mining in these fields. Furthermore, failure to remedy this situation may make it physically and economically impossible to develop these large reserves of a valuable fuel whenever the need for it will arise, particularly if a national emergency will require anthracite to play again the important role in the fuel economy of the Nation, which it did during the last two great wars (38, 39).

The flooding of mines in the Western Middle and Southern fields has already reached such proportions that the present active mines could not produce their share of the total anthracite production if the coal had to be mined from underground workings (38, 39).

The 1952 production from the five-county area—Carbon, Schuylkill, Columbia, Northumberland, and Dauphin Counties—comprising the Western Middle and Southern fields is reported by the Pennsylvania Department of Mines to be as follows:

<table>
<thead>
<tr>
<th>Source</th>
<th>Production, tons</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep-mined</td>
<td>9,529,386</td>
<td>45.40</td>
</tr>
<tr>
<td>Stripping</td>
<td>7,433,384</td>
<td>35.50</td>
</tr>
<tr>
<td>Refuse and silt banks</td>
<td>4,001,838</td>
<td>19.10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20,964,608</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

Stripping and bank-recovery operations, by their very nature, have a short life and cannot provide anthracite beyond a period of about 5 years to meet future demand. Underground operations, on the other hand, will not be able to take up the slack unless inundated mines are drained of water and are reactivated (38, 39).

The flood protection and mine-water control provided by Project No. 3 (Wyoming) (39) of the proposed comprehensive plan is to be considered as supplementary to that provided by Project No. 1 (Lackawanna), which will handle the mine water in the Lackawanna Basin (37).

Facilities to be provided by Project No. 3 are designed primarily to collect water from operating and inundated mines in the Wyoming Basin by discharging it into the tunnel system by gravity where feasible, otherwise by pumping from altitudes below tunnel elevation. The pumping plant to be installed at No. 15 shaft is designed to function primarily as an emergency pumping station when the tunnel system is completed. In the interim, No. 15 shaft pumping station will pump the mine water flowing in the tunnel serving the Northern field, including the Lackawanna Basin. When No. 15 shaft pumping station is operating and the tunnel system of Projects Nos. 1 and 3 are connected, the pumping plant at Old Forge No. 2 shaft, provided by Project No. 1, can be taken out of service and the pumps transferred to either of the pumping plants at Nos. 9A or 15 shafts (39).

The Wyoming Basin contains most of the remaining coal reserves of the Northern field, but they are in the deepest part of the basin, which, at its lowest point, reaches an altitude of 1,500 feet below sea level. Consequently, the remaining reserves could sustain mining operations at the present rate of production for well over 100 years, but they are particularly vulnerable to inundation and eventual abandonment because of the physical impossibility of handling the mine water under existing drainage practice if the basin is inundated.

The facilities provided by Project No. 3 would reduce considerably the pumping head of most operating mines in the Wyoming Basin and drain, by gravity, many underground pools in abandoned mines that are endangering adjoining active mines and increasing their drainage costs. Water in abandoned or idle mines does not flow to the surface but, due to natural conditions, must be pumped by operating mines to keep the hydrostatic pressure against the barrier pillars within a safe limit (39).

The financial burden and physical layout of the mines may force one mine after another to cease operating, thus compounding the problem to the point that ultimately all mines will be abandoned.

A report (36), the fourth of a 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, known as the comprehensive plan, provides facilities for collecting the mine waters from the three major anthracite fields of Pennsylvania and for their discharge by gravity to tidewater (36–39).

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 (37–39).

The proposed comprehensive plan is sound engineering. It is based on data and facts obtained in the only comprehensive study ever made of the anthracite-mine-water problem. The five component projects of the plan constitute both a short-range program to afford immediate relief in those areas where relief is needed most urgently and a long-range program to benefit the whole anthracite industry and the region, the State, and the Nation. The comprehensive plan provides an immediate and
permanent solution to the mine-drainage problem in the sequence of the five proposed projects throughout the entire region; it not only will prevent further decline of the industry and additional loss of anthracite reserves because of inundation but will make it possible to revitalize the industry and insure the conservation of additional reserves for the future welfare of the Nation.

The cost of the comprehensive program is large, but its benefits will be larger. The $500 million of new wealth created by the anthracite industry in 1954, its most depressed year, is almost twice the estimated cost of the comprehensive plan. Unless a comprehensive flood-control program becomes an action program in the near future, the anthracite industry faces extinction. The savings realized by averting loss of the industry, based on the poorest year in its history, refutes any contention that benefits derived from the comprehensive plan would not warrant the capital expenditure.
LOCAL COOPERATION

LANDS, EASEMENTS, AND RIGHTS-OF-WAY

In the accomplishment of flood-control projects, such as levees, control works, diversion channels, and major drainage tunnels, as are proposed in the comprehensive plan, it has been found that local interests are best qualified to furnish necessary lands, easements, and rights-of-way. Moreover, present flood-control laws of surface waters require that local interests furnish such lands, easements, and rights-of-way for local flood-protection projects. (See table 15.)

The completion of Project No. 1 (Lackawanna) (37) as a part of the comprehensive plan, as set forth in the original report, would result in large benefits that would accrue not only to the anthracite operators but to local, State, and national interests as well.

To accomplish the proposed project, the anthracite companies most interested and deriving the most benefits would be required, and they have indicated their willingness, to deed to a mine-drainage authority all necessary surface and coal lands, easements, and rights-of-way for construction, operation, and maintenance of the facilities comprising the tunnel project.

The Hudson Coal Co. is expected to deed the Dickson shaft, which is no longer used in their mining operations, with enough surface area surrounding Dickson shaft for all construction and maintenance incidental to deepening the shaft from its present bottom to reach the necessary altitude of the tunnel, as well as for driving the tunnel toward its eastern terminal and westerly part way toward Dodge shaft. Dickson shaft will remain an important control station in the tunnel scheme and must remain accessible indefinitely. It is, therefore, imperative that it shall not be damaged by any future mining, which can be assured by reserving to the mine-drainage authority (37) an adequate shaft safety pillar surrounding it.

The Moffat Coal Co. is expected to make available Dodge shaft, which no longer is used for ingress or egress in active mining, for deepening to tunnel altitude and for driving the tunnel easterly part way toward Dodge shaft and westerly toward Old Forge No. 2 shaft. Enough surface lands adjacent to the shaft must also be made available for disposal of the tunnel spoil. Dodge shaft will also be used as a control station in regulating the discharge from surrounding mines into the tunnel; therefore, it must also be permanently protected by reserving the coal pillars surrounding it to the mine-drainage authority (37).

Old Forge No. 2 shaft is the key facility in the tunnel plan for the Lackawanna project. It is the property of the Pennsylvania Coal Co. and is still used as a water shaft. For the purpose of the tunnel project, it can and must be made available for driving the tunnel and for the installation of the proposed temporary pumping plant. For this reason the Pennsylvania Coal Co. is expected to deed to the mine-drainage authority Old Forge No. 2 shaft, with all appurtenances and sufficient surface for disposal of all spoil from shaft extension, tunnel, and pumproom excavation. Maintenance of the shaft as a permanent access to the pumping station requires that the coal within the shaft reservation be deeded or reserved to the mine-drainage authority (37).

As the proposed tunnel is designed to drain the Leadville mine, it also becomes necessary that an understanding is reached for an easement or right-of-way to permit effective control of the flow from the inundated mine or mines into the tunnel.

To obtain some comprehension of the contribution of the coal companies toward the total cost of the project set forth in this report, the following evaluation of the above-cited contributions is stated as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market value of surface lands</td>
<td>$50,000</td>
</tr>
<tr>
<td>Value of coal in shaft reservations</td>
<td>$135,000</td>
</tr>
<tr>
<td>Value of existing shafts, exclusive of headframes and buildings, 1,184 feet at $600 per foot</td>
<td>$710,400</td>
</tr>
<tr>
<td>Value of headframes, buildings, etc</td>
<td>$140,000</td>
</tr>
<tr>
<td>Estimated value of contributions</td>
<td>$1,035,400</td>
</tr>
</tbody>
</table>

The anthracite-producing or anthracite-holding companies operating in the area to be serviced by the facilities provided under Project No. 2 would be required to deed to the mine-drainage authority all necessary surface and coal lands, easements, rights-of-way for construction, and operation and maintenance of the works undertaken (38).

Preliminary studies do not indicate that existing shafts or slopes, which are not now used by the coal companies, can be incorporated into the
scheme; shafts and slopes must be sunk in or below the outcrop of the lowest workable coal bed. The respective owners or lessees of such locations will be required to make available enough surface land for sinking operations, spoil disposal, and proper access from public highways. They will also be required to deed to the mine-drainage authority, whose rights and duties are outlined in Project No. 1, sufficient coal over, under, and adjoining such shafts, slopes, or tunnels as will be deemed necessary to safeguard the facility from damage due to mining (37, 38).

The monetary value of such contributions by the coal companies and interested local political units of the area obviously cannot be accurately estimated, but it may approach a million dollars (38).

To accomplish Project No. 3 (39), the anthracite-mining companies most interested and deriving the most benefits would be required to deed to a mine-drainage authority all necessary surface and coal lands, easements, and rights-of-way for construction, operation, and maintenance of the facilities comprising the work outlined in this project. Consequently, it is specifically required that the owners of the Alden No. 1, Sugar Notch, Baltimore No. 2, and Laflin shafts—all of which are idle and, from information available, are not expected to be used again for active mining operation—cede these shafts to the mine-drainage authority (37–39). The quitclaim deeds should include enough surface area for all purposes of construction and maintenance, access to public roads, and a shaft safety pillar adequate in size to prevent damage to shafts or tunnels from future mining (39).

It is impossible to place a firm estimate on the value of past and future contributions by the mining companies or on the facilities to be made available temporarily or permanently by county or municipal authorities. An assumed estimate would be near a million dollars (39).

The coal companies have furnished maps and data necessary to plan the facilities for Project No. 3; they have cooperated by making available their engineering personnel for consultation and review of plans before reaching their final form (39).

The facilities provided by Projects Nos. 4 and 5 (36) 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 uses 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, the tunnel can remove acidic mine water from the river and its tributaries and place the water where it can be treated, if necessary, or dispose of it 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 (36).

**RELOCATIONS AND ALTERATIONS**

Local interests in the anthracite region and the Commonwealth of Pennsylvania should be required to bear the cost of all relocations and alterations of highways and public utilities, including those of highway bridges, that may be required for the construction of the comprehensive plan and to bear the cost of lands required for such relocations and changes. The cost of relocations and alterations of railroad bridges should be borne by the Federal Government.

**MAINTENANCE AND OPERATION**

Coordinated operation of the major features of the comprehensive development are essential if the estimated benefits are to be obtained. This operation would affect nine Pennsylvania counties (93), the industrial and agricultural communities of organized subdrainage districts, and the urban areas along the east coast (22). It would also involve a great variety of engineering works and require continuous study and improvement of operative procedures. In view of these considerations it is believed that a local anthracite mine-drainage authority should maintain and operate all facilities of the comprehensive plan after completion of each project, including pumping plants and control works, in cooperation with the appropriate State and local agencies; and local interests should pay the cost, determined by the anthracite mine-drainage authority, which is defined later, as well as in the original reports (22, 36–39).

The average annual cost of maintenance and operation of either of the five projects when the project is complete would be zero at the beginning of the construction period, gradually increasing to the full amount as features of the project are completed, and continue thereafter for the life of the project (22, 36–39).

**DIVISION OF COST**

The flood-prevention work and relief facilities constituting the comprehensive plan will result
in benefits that will accrue not only to the anthracite region but to local, State, and national interests as well. Consequently, a proper division of cost for the project between the Federal Government, the Commonwealth of Pennsylvania, county and municipal authorities, and the mining companies is required. This has been discussed in the original reports (36–39) (See table 15.)

The anthracite industry admittedly is suffering an economic depression, which, in fact, is one of the compelling reasons in support of the proposed comprehensive plan. The industry must recognize the necessity of investing in its own future if it is to survive, and initial contributions by the industry to the proposed comprehensive plan consist essentially of grants of rights-of-way and property that represent real economic value but require no cash expenditures.

**METHOD OF FINANCING**

Although it is recommended that the Federal Government appropriate a Federal grant of $247,496,837 as its share of the comprehensive plan, the financing of projects as outlined in detail in the original reports (36–39) suggests a number of problems and differences of opinion not ordinarily encountered in public works. The problem here is more than just an ordinary one to benefit the public. The conservation of an important, irreplaceable natural resource, the livelihood of a large segment of our people, and the rehabilitation of an economy are at stake. It requires a plan of financing that is more than a mere subsidy to an industry.

The value of this natural resource, of which 5 billion tons can be conservatively recovered, is $50 billion at present prices at the mine. At an annual production of 25 million tons this would last at least 200 years. An annual payment of $1,641,140 for 75 years at only 6.5 cents a ton by the industry, if it must assume that cost, would amortize the total cost ($280,292,163) of the comprehensive plan if financed by an allocation, interest-free, from the Federal Government as a sinking fund invested at 2 percent interest. This period (75 years) is far less than one-half the expected life of the anthracite reserves of Pennsylvania.

Ordinarily, public improvements by municipalities or States are financed either on a sinking-fund basis or by the issuance of serial bonds.

A sinking fund is a fund into which an amount is deposited yearly, which, if invested, will on the maturity of the obligation be sufficient to meet in full the total obligation. A typical rate of investment in the past has been 3 percent. An example of such financing would be the issuance of a $1 million bond issue maturing in 50 years. Such a bond issue would require setting aside $8,865.50 each year into a sinking fund, which is invested at 3 percent interest. In 50 years the accrued interest and sinking fund would be enough to pay off the outstanding obligation.

A serial bond, on the other hand, requires an annual payment of fixed proportion of the principal plus interest on the balance of the outstanding obligation. Thus, a $1 million serial bond, maturing in 50 years, would be redeemable in equal annual payments of $20,000 plus interest annually.

For the ordinary public-works projects, such as highways or aqueducts, the sinking-fund basis would appear to be the least burdensome, although it may be shown that the serial bond permits a substantial saving of some obligations by the end of the period.

The proposed comprehensive plan presents some problems not ordinarily encountered in public-works assistance programs. In the usual Government project for the development or conservation of resources, it is the practice for the Federal Government to allocate funds outright for the construction work. Thus, many huge reclamation developments in the Middle and Far West and numerous flood-control and harbor-improvement projects throughout the country have been financed entirely by the Federal Government. The proposed comprehensive plan, however, is more than merely a conservation measure of a natural resource; it is also a proposal for the conservation of an entire economy as well and the rehabilitation of a private industry. Therefore, it may be believed that certain features of ordinary public financing should be modified to permit eventual self-liquidation over a period of years.

One method would be for the Federal Government to allocate the necessary funds, interest-free, to be reimbursed by a local mine-drainage authority over a period of 75 years. The authority would then be empowered to levy a minimum tax on each ton of coal produced. This money would be placed in a sinking fund, which, if properly invested at a conservative rate of interest (2 percent) would be adequate to discharge the obligation at the end of the 75-year period.

The calculation of the annual payment to amortize the $42 million (the cost of Project No. 3) is shown as an example. The $42 million would be allocated to the authority, which could then proceed with the construction as described in the original report (39). The authority, chartered by the State Legislature, would be empowered to levy a tax on each ton of coal produced in an amount that would pay current operating costs plus the minimum annual amount to be set aside at 2
percent interest to accumulate as a sinking fund (229).

The annual payment can be determined by using the fundamental relation (229) for the annual payment of an annuity that 1 will purchase as follows:

\[ R = K \left( \frac{1}{a_{ni}} - i \right) \]

where

- \( a_{ni} \) denotes the present value of an annuity of 1 per annum for \( n \) years, the total payment of 1 being made in one installment at the end of the year,
- \( R \) = Annual payment,
- \( K \) = Total amount of indebtedness, $42 million,
- \( i \) = Interest at 2 percent, expressed as a decimal fraction,
- \( n \) = 75 years.

From Putnam’s annuity tables (229)

\[ \frac{1}{a_{ni}} = 0.0258551, \]

and

\[
R = \frac{42,000,000(0.0258551 - 0.02)}{0.0258551},
\]

\[
R = \frac{42,000,000 \times 0.0058551}{0.0258551},
\]

\[
R = 245,914.20,
\]

which is the annual payment required to amortize the $42 million (\( K \)) over a period of 75 years. The sum of $245,914.20, plus annual operating costs, determined by the authority, will be levied against the industry.

An analysis of amortization of mine-drainage cost in 75 years at 2 percent sinking fund is:

\[ [R = K(0.0058551)] \]

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Total cost of project (( K ))</th>
<th>Annual payment (( R ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$18,723,846</td>
<td>$109,629.99</td>
</tr>
<tr>
<td>2</td>
<td>1 69,531,620</td>
<td>407,056.04</td>
</tr>
<tr>
<td>3</td>
<td>41,531,041</td>
<td>243,174.25</td>
</tr>
<tr>
<td>4</td>
<td>30,124,136</td>
<td>176,379.83</td>
</tr>
<tr>
<td>5</td>
<td>120,390,520</td>
<td>704,898.52</td>
</tr>
<tr>
<td>Total</td>
<td>1 280,292,163</td>
<td>1,641,138.64</td>
</tr>
</tbody>
</table>

1 $327,936,336 provided by Commonwealth of Pennsylvania (98).

In making economic studies of the need and justification for the desired works and determining the methods of financing and repayment, the engineer’s responsibility varies widely, depending on whether the work or project is for an individual, a business or industry, a public utility, or a government agency. The authors realize that the engineer may have little to do with the need for the works, the financial arrangements, the final design of the work, or the supervision of its construction. When engaged by a government agency, the engineer’s economic functions will vary widely, depending on the extent to which legislators and administrators confine themselves to major policy-making and allow the engineer to act broadly within the terms of applicable laws and the policies based thereon. There usually is wide variation in the engineer’s economic functions in planning works for city, county, and State agencies. In Federal government agencies the engineer’s economic responsibility varies in accordance with guiding policies and concepts based on existing laws.

It should not be a matter of undue concern that several Federal agencies employ different economic approaches in evaluating public works and, consequently, cannot agree readily with one another when engaged in joint or comprehensive planning.

A pertinent example is the policy of subsidizing reclamation in the western States; this policy has paid off, as evidenced by the development there from 50 years of reclamation. The search, in recent years, for more uniform economic evaluation procedures for Federal agencies and moves for closer cooperation between those agencies should not be allowed to create the illusion that confusion, waste of taxpayers’ money, and lack of purpose have occurred in the past.

Substantial progress is being made toward more uniform legislative and administrative measures to insure comprehensive planning for the conservation of the Nation’s natural resources (79, 95, 113, 220).

ASSURANCE OF LOCAL COOPERATION

Because of the seriousness of the anthracite-mine-water problem, it has been necessary to complete a report for the comprehensive plan as expeditiously as possible. Consequently, it has been impracticable for the State or other local interests to develop an organization with the authority necessary to furnish firm assurances of cooperation for inclusion in the report. Existing agencies of the State appear to lack authority to underwrite a program of the scope proposed under the comprehensive plan of improvement. This situation can be rectified by action of the State Legislature, or by cooperative action of groups of local interests before the time when construction may be started. The comprehensive plan set forth in the original reports has been discussed with representatives of the State of Pennsylvania and with officials of counties, cities, and other local organizations. Many such officials and organizations have indicated their concurrence in and desire to support the plan of improvement. The wide local interest and the attitude of local interests are evidenced by the resolutions and communications. It is felt, therefore, that
action leading to adequate assurances of local cooperation may be anticipated (22, 36–39).

Maryland or New Jersey and Delaware (if the Marcus Hook route is selected) are expected to cooperate with Pennsylvania and with the mine-drainage authority that will have charge of planning, engineering, and executing the projects comprising the comprehensive plan. 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 (22, 36–39).

The procedure to be followed by local interests in providing the required local cooperation may be developed in detail by future negotiations. This might take the form of action by the State to form a new agency to obtain by taxation the necessary funds to pay for relocations and for acquisition of lands, easements, and rights-of-way and to provide annually the sums required as contribution to first cost and for maintenance and operation. In any event it is considered that there should be established, preferably by the Commonwealth of Pennsylvania, a single local agency with which the Federal Government can deal on all matters of local cooperation for this subject (22, 36–39).
COORDINATION WITH GOVERNMENT AND OTHER AGENCIES

The interests of different Federal and local agencies in the area under consideration are summarized briefly in previous paragraphs and in the original reports (19, 20, 22, 24, 29, 35–39, 74, 81, 93, 96, 104, 110, 117, 135, 166, 221, 222, 237, 260, 277–279, 288, 289). The comprehensive plan has been developed with full consideration of the functions of those agencies.

FEDERAL AGENCIES

Because of subsidence and floods, the Corps of Engineers of the United States Army has a continuous problem in the matter of levees and surface flood control. This is of vital importance to the region, and there is a constant use and exchange for the data prepared by the Bureau of Mines in current problems and covered in the comprehensive plan (21, 29).

The Soil Conservation Service of the United States Department of Agriculture has studied soil and water control in the anthracite region.

The comprehensive plan presented in this report will contribute important particulars in any plan of improvement considered necessary by that service (110, 125).


The utilization of the services of the Bureau of Reclamation and of the Fish and Wildlife Service has been mentioned in this report. The recommendations of the Hydraulic Machinery Branch, Bureau of Reclamation, and the Fish and Wildlife Service on the comprehensive plan should be met on all essential points.

The National Water Pollution Control Act of 1948 reflects the national interest in water pollution. Hollis (44, 148) discusses water-pollution abatement in the United States and explains the national policy embodied in the National Water Pollution Control Act of 1948.

The United States Public Health Service believes that the policy established by the Congress will work. The success of cooperative action depends largely on strong State programs. Historically, the policy of the Public Health Service has been to aid the States to that end.

The present law limits Federal activities to interstate problems with the consent of the State in which the problem originates. The burden of making this cooperative procedure work rests on the States and the Public Health Service. The act, in recognizing the primary rights of the States, sets up the means whereby the Federal Government can give the States financial and technical aid and strengthen the overall program through measures applying to interstate waters.

It is believed that the Federal Government, through the United States Public Health Service, can contribute to the work and should engage in an active attack, in close coordination with other agencies, on the problem of stream pollution by the mine water discharging at tidewater. When satisfactory answers are found, there will be little need to be unduly concerned as to the method of correction, because the importance of removal, control, or treatment measures will lead to a reasonable solution through the self-interest of each State involved.

Carey has summarized the various steps that have been proposed or taken toward the goal of comprehensive planning and the conservation of natural resources in the United States (79).

LOCAL AGENCIES

There have been full coordination and consultation with agencies of the Commonwealth of Pennsylvania, such as the Pennsylvania Department of Mines and Pennsylvania Department of Forests and Waters, as well as with affected counties and other interested local agencies. Resolutions and statements from many of these agencies are given in the original reports (35–39) or reports listed in their bibliographies.

The United Mine Workers of America at all times took an active interest in the progress of the engineering study and the proposal for a solution to the mine-water problem. The presidents of the UMWA districts comprising the anthracite region were members of the Anthracite Advisory Board Engineering Committee.
CONCLUSIONS AND RECOMMENDATIONS

DISCUSSION

The chief motive for comprehensive planning originally was to open up the country for development (79). Today the dominating motive is to insure continuing prosperity by conserving the natural resources and determining and utilizing those resources for the greatest good for the greatest number, thereby conserving the national strength (22).

The anthracite fields have contributed heavily to our country's fuel requirements and are of primary importance to our national economy. Five billion tons of anthracite has been mined and marketed from a relatively small area in northeastern Pennsylvania during the past 150 years, yet the extraction of this vast amount has not exhausted the reserves. Estimates indicate that enough coal remains to support current production for more than 200 years. It is with these thoughts in mind that the program for anthracite is conducted (22, 33, 55–39, 51, 78, 93).

The problems of mine flood control in the anthracite region are complex. They range from protection of life and property, menaced by sudden collapse of barrier pillars surrounding inundated mines or strata between mines and the surface waters, to easing the financial and physical burden of pumping vast quantities of water now plaguing the industry and threatening to curtail its natural economic life by making inaccessible or otherwise destroying billions of tons of an irreplaceable natural resource. The comprehensive plan presented in this report has been prepared after full consideration of these varied problems (55–39).

The preparation of this report has been greatly facilitated by information and assistance furnished by the anthracite-mining companies and by the full cooperation of their management and engineering personnel. The comprehensive plan is not a panacea for all the economic difficulties inherent in the development of the anthracite region. No feasible plan of improvement within the realm of economic justification could completely banish flooding of all mines in this area or insure that potable water supplies could be restored to all anthracite streams.

When completed, the comprehensive plan would provide the maximum degree of flood protection and conservation of the anthracite reserves of the Nation as well as the water resources of the region. A long-range plan of this kind for the purposes stated is urgently needed now so that a healthy economy can be restored to the region and its development proceed in an orderly manner that will preserve its resources of anthracite, water, and land for future generations. An analysis of economics shows that the projects contemplated in the comprehensive plan as a whole are justified by a wide margin (36–39). Construction and subsequent operation of the comprehensive development to insure that its purposes are obtained would require the best efforts and continued cooperation of Federal, State, and local agencies (22, 37).

The comprehensive plan (project) being designed is a long-range plan for the control and solution of the anthracite mine-drainage problem, conservation of a basic industry, and economy of a vital area. It should be started at the earliest possible date, as the need for flood protection, mine-water control, and conservation of anthracite is urgent. If and when a plan is authorized by the Congress, future progress in its accomplishment will depend equally on Congressional appropriations for planning and construction and on prompt action by local interests (State and industry) in providing the cooperation required of them.

Assuming, however, that adequate appropriations were made by the Congress and that requirements of local cooperation were met, the entire comprehensive development (5 projects) could be completed under an orderly and efficient construction program within a maximum period of 10 years. (See page 76.) Some integral parts (2 projects) of the plan, however, such as those required for the protection of human life and well-being of the Lackawanna Basin (Project No. 1) and the Western Middle and Southern fields (Project No. 2), are obviously more urgently needed than some longer range features of the plan (36–39).

There is ample justification, both economic and social, for the approval of a comprehensive project for anthracite mine-drainage control as outlined in this report and in the original reports on the comprehensive plan (36–39). Any authorization should, however, provide latitude for changes, even major ones, should the advis-
ability of such changes develop in the final planning stages. Because construction of the proposed comprehensive project will take place over an extended period, many features of the plan will require further detailed study before the beginning of the construction.

Early in 1949 there were 228 completed flood-control projects in the United States. These finished works, consisting of local-protection projects, small detention dams, debris dams, large multiple-purpose reservoirs, channel-improvement works, major drainage projects, and levees, had been in operation from 1 to 10 years. The total cost of all projects to the American taxpayer was $483 million. The amount of flood damages prevented by these completed works during their very brief periods of service to that date was $500 million. In other words, these projects have more than paid back to the people of the United States the entire cost of their construction. All benefits that they may produce since 1949 and in the future represent a further profit to the United States. The service records of a few typical projects emphasize the soundness of the Nation's flood control investment (22, 127).

The anthracite mines of Pennsylvania produce nearly $500 million of new wealth to the Nation in 1 year, based on the value of 1 year's normal production at the breaker. The cost of projects to avert disaster and premature extinction of this major industry is trivial as compared with the savings they will effect. The loss of this valuable resource for only 1 year will cost the Nation more than the total cost of flood-control projects in the United States during the above-mentioned 10-year period (22, 37).

CONCLUSIONS

The comprehensive plan, particularly the first phase of it as outlined in this report, provides for the most feasible and economical solution of mine flood control and related water problems besetting the anthracite industry and threatening to destroy it. The plan should be adopted to provide the flood protection now urgently needed. The cost will necessarily be large, but its benefits will be larger, and its ultimate development is essential to the welfare of the affected area and the Nation for the conservation of a valuable energy resource and to the stabilization of the economy of both the anthracite industry and the region as a whole (36-39).

Project No. 1 (Lackawanna) (37) was selected as the first phase of the larger project because operating mines in this area pump such a disproportionate tonnage of water for each ton of coal hoisted that the continuation of mining on an economical and competitive basis is doubtful. If mining in the Lackawanna Basin would cease, pumping would be stopped, and the entire basin would be filled with water to an altitude of approximately 540 feet. When this altitude is reached, the water will spill over the Moosic saddle and flow into the mines in the Wyoming Basin. As nearly all barrier pillars between individual mines in the Wyoming Basin are either punctured or weak at varying altitudes, it follows that one mine after another would have to handle this onrush of water, which under existent physical conditions is impossible and beyond the financial capacity of any mine or group of mines.

Because immense coal reserves, which must be exploited in the future if the anthracite industry is to remain a vital economic factor locally, as well as in the State and national economy, are submerged under great pools of water in the Western Middle and Southern fields, it is imperative that these pools be drained and remain drained. Only when this is done will it be economically feasible to mine the large reserves of virgin coal at lower depths, which characterize the Western Middle and Southern fields, for which Project No. 2 is designed (38).

About 60 percent of the production of anthracite from the Western Middle and Southern fields comes from surface stripings, reclamation of refuse banks, or from small outcrop workings. They all have a very limited life, probably not in excess of 5 years at the present volume of production. As the supply becomes exhausted, the industry will have to turn more and more to deep mining to produce coal for market; however, the industry will be able to mine such coal at competitive costs only if the large bodies of water now overlying the reserves are drained and kept drained by economical means.

Unless relief is forthcoming in the form of the proposed tunnel, which will carry the water away from the overlying pools, anthracite mining in the Western Middle and Southern fields will decline at an increasing rate and will more or less cease altogether in about 10 years.

The impact of such a rapid decline of the basic industry is certain to have a catastrophic effect on the economic and cultural life of the region. Furthermore, the inundated coal reserves (more than 7 billion tons) will no longer be available on short notice to aid the national economy in time of critical need. The flood-control facilities applicable to the Western Middle and Southern fields are covered in detail in the original report (38).

The flood-control facilities comprising Project No. 3 are covered in detail in the original report (39). They are supplemental to or an extension of those recommended in Project No. 1 (Lackawanna) (37). When the flood-control units of
that project and Project No. 3 (Wyoming) are joined, the temporary pumping plant at Old Forge No. 2 shaft can be taken out of service and the pumps transferred to either of Nos. 9A or 15 shaft pumping plants (38, 39). No. 15 shaft pumping plant will handle all water flowing in the tunnel system serving the Northern field and will discharge it into the Susquehanna River over the lowest static pumping head obtainable in the Northern field. This arrangement will result in a considerable saving in pumping costs, based on low head and high efficiency; furthermore, it will reduce the danger from uncontrollable flooding of active mines by the sudden collapse of barrier pillars or accidental tapping of water-bearing strata of the buried valley.

When the entire comprehensive plan is completed, the pumping plant at No. 15 shaft will become inactive but will remain in service as an emergency pumping plant only when the tunnel south of No. 15 shaft is to be inspected or repaired or if the volume of mine water coming from the Northern field is in excess of the tunnel capacity.

Projects Nos. 1, 2, and 3 deal 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 water, particularly acid mine water. Circular, concrete-lined tunnels, which will neither permit mine water to seep into surrounding strata nor permit ground water to enter the tunnel, are considered the proper medium to conduct the mine water to the mouth of the Susquehanna River or to the Delaware River, where it would be neutralized in a comparatively short distance by the river water, which is known to be alkaline enough in either river for this purpose.

Problems arising from possible effects of acid mine water entering the Delaware River at Marcus Hook or the Susquehanna River below Conowingo Dam on fish and waterfowl and on the suitability of the river water as a water supply for municipalities located 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 United States Public Health Service and the Fish and Wildlife Service of the United States 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.

The proposed comprehensive plan will benefit all anthracite fields fully and equally so that each field can maintain its competitive position within the industry. It will provide the most economical and most effective means of draining inundated mines that form a constant threat to adjoining mines in all the anthracite fields. It will also reduce considerably the hydrostatic pumping head for most mines, and for some it will dispense with pumping entirely (36–39).

RECOMMENDATIONS

It is recommended that an anthracite mine-drainage authority be created by appropriate legislation by the Commonwealth of Pennsylvania, defining duties and constitutional limitations of such authority. The anthracite mine-drainage authority shall have the power to perform the following functions:

1. To purchase, lease, or otherwise acquire any land, mine, shaft, and works for utilization in such manner as is deemed necessary.
2. To purchase, lease, erect, utilize, and maintain such buildings, machinery, and plants and execute such works as are considered necessary on or in any land, mine, or shaft belonging to or occupied by the drainage authority.
3. To sell, let, or abandon any property belonging to the drainage authority, which in its opinion is not needed or has proved unsuitable for the purpose for which it was acquired.
4. To enter at all reasonable times or have officers of the drainage authority or other duly authorized persons enter any mine or works to make inspections and surveys as may be necessary and inspect any plans of workings, sections, and any books or records relating to output or drainage.
5. To appoint a general manager, secretary, chief engineer, and other officers and employees that are deemed necessary.
6. To formulate and apply directives designed to coordinate and assist to unwater inundated mines and to protect active mines from damage by water.
7. To formulate and apply directives designed to protect all elements of the project from damage due to mining.

It is recommended—

That to defray the expenses under this scheme, the mine-drainage authority shall levy drainage rates payable by the mine owners on the basis of benefits derived. To this end, a survey shall be made yearly for the determination of drainage rates for the ensuing year. Each year the mine owners or operators shall furnish to the authority a statement of production and other pertinent data required for determination of fair and equitable drainage rates.
That the authority shall be liable to pay compensation to mine owners or operators who suffer injury, loss, or damage by reason of any act done by the authority. All questions as to liability and the amount of compensation shall, in default of agreement, be settled by arbitration.

It is further recommended—

That the Commonwealth of Pennsylvania create and finance the personnel and offices of the authority, which will be charged with the design, construction, operation, and maintenance of the comprehensive plan described in this report;

That the Federal Government, through the Department of the Interior, provide funds and other services for the comprehensive plan as outlined in this report and in the original reports on each of the five projects (36–39);

That the comprehensive plan be considered as one for flood control and related purposes, and that its further consideration be under the provisions of the mining laws and flood-control laws.

That there be authorized to be appropriated by the Congress annual sums adequate for completing the comprehensive plan in a logical step-by-step manner as described in this report and in the original reports (38–39).

Specifically, it is recommended—

That the Federal Government appropriate for the first phase of the plan, known as Project No. 1 (Laickawanna), a Federal grant of $18,723,846. Out of this sum are to be defrayed the engineering costs for the entire project, the execution of all work, and the furnishing of all equipment described in the original report (37).

That for Project No. 2, Western Middle and Southern fields, the Federal Government grant $36,726,294 and the Commonwealth of Pennsylvania grant $32,795,326, within which amounts will be defrayed engineering costs, the execution of all work, and the furnishing of all equipment described in the original report (38).

That for Project No. 3 (Wyoming) the Federal Government make a grant of $41,532,041 to defray expenditures for engineering, executing all work, and installing all equipment described in the original report (39).

That for Projects Nos. 4 and 5 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 the original report (36).

That the works described in this report, after construction, shall be maintained and operated by the mine-drainage authority.

It is further recommended—

That at such time as definite project reports may be prepared the Hydraulic Machinery Branch, Federal Bureau of Reclamation, be assigned the problem of recommending pumps, motors, and all electrical accessories, and those recommendations should be met on all essential points.

That all metals and alloys selected for pumping equipment recommended in the comprehensive plan for anthracite mine water be selected on the basis of recommendations and definitions in this report and in the original report (39) on corrosion, and that the Bureau of Reclamation approve the selection.

That the Federal Government, through the United States Public Health Service and the Fish and Wildlife Service, engage in an active attack in close coordination with other agencies on the problem of stream pollution by discharging the mine water at tidewater.

That no money shall be appropriated by the Federal Government for the prosecution of features of the comprehensive plan until an anthracite mine-drainage authority has been 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 subdivisions 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.

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 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.
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