Multiple-Purpose Reservoirs And Pollution Control Benefits

The Ohio River basin reservoir program of the U. S. Corps of Engineers with respect to low-flow regulation

Reference Data Publication compiled by

EDGAR W. LANDENBERGER, U. S. Corps of Engineers, and member of the Engineering Committee of the . . .

OHIO RIVER VALLEY WATER SANITATION COMMISSION

To the Chairman and
Members of the Commission

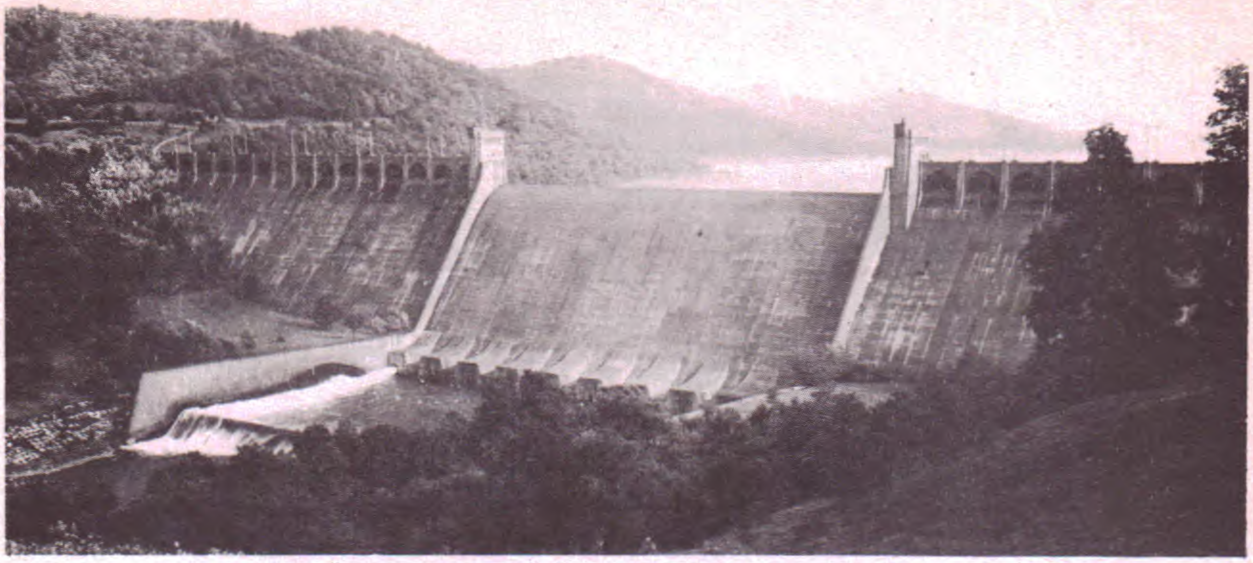
Regulation and augmentation of stream flow are matters of fundamental importance in the conduct of pollution abatement activities. For this reason the Commission is intimately concerned with the reservoir development program in the Ohio River basin, which is under the direction of the Corps of Engineers, U. S. Army. The following report outlines the status of this 80-unit reservoir program with reference to its present and anticipated effects on pollution abatement.

Highlights of the report were presented to the Commission on July 2, 1952, by Commissioner Robert G. West and Mr. Edgar W. Landenberger of the Ohio River Division office of the Corps of Engineers. A background statement prepared by Mr. Landenberger and Mr. Robert K. Horton, Commission staff sanitary engineer, was distributed prior to the meeting. Material from this statement as well as the notes and charts used in the oral presentation have been freely used in the preparation of this report prepared by Mr. Landenberger.

Familiarity with the reservoir program - its purpose and development possibilities - will command continuing attention in the formulation of Commission policies and plans.

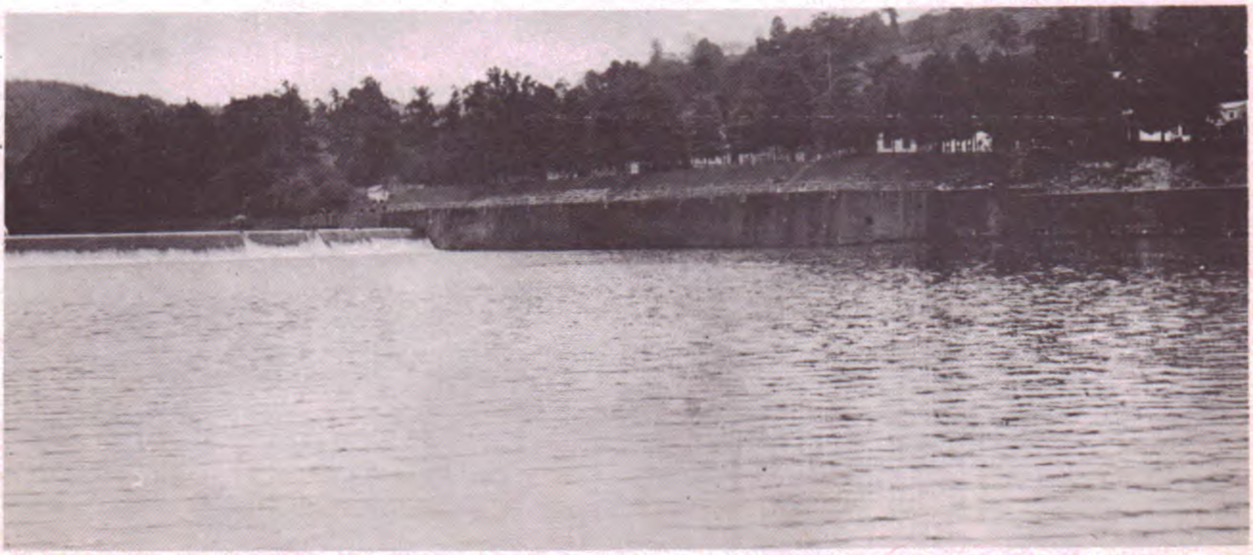
EDWARD J. CLEARY

Executive Director
and Chief Engineer



Tygart Dam on Tygart River, W. Va. Placed in operation in 1938 for flood control and low flow regulation.

Monongahela River below Dam No. 12 during drought of 1930. This was prior to completion of Tygart Dam.



Monongahela River below Dam No. 12 during normal low flow period after completion of Tygart Dam.

MULTIPLE-PURPOSE RESERVOIRS
AND POLLUTION CONTROL BENEFITS

Description and status of the 80-unit
reservoir program of the U. S. Corps of Engineers
in the Ohio River Basin
with reference to its present and anticipated
effects on pollution abatement

A report prepared by
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OHIO RIVER VALLEY
WATER SANITATION COMMISSION

January 1953 *Cincinnati, Ohio*

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INTRODUCTION

In April 1952 the Ohio River Valley Water Sanitation Commission adopted sewage treatment standards for the Huntington - Cincinnati reach of the Ohio River. These provide for seasonal variations in treatment, necessitated in large measure by seasonal variations in stream discharge. Similarly, the Commission's Cincinnati Pool Hearing Committee recognized that primary treatment of sewage discharged to that pool would be adequate during years of average or more than average river flow but that a higher degree of treatment would be required during dry summer periods. This finding was reflected in the sewage treatment standards adopted by the Commission for the Cincinnati pool.

It is significant that determination of sewage treatment requirements for the Huntington - Cincinnati reach and the Cincinnati pool involved recognition of an average increase in summer stream flow of about 1,400 cubic feet per second - over 900 million gallons per day - now available or to be available in the immediate future from reservoir operation.

The reservoirs involved - Tygart, Youghiogheny, East Branch Clarion, Berlin, and Mosquito Creek - are units in the comprehensive program for flood control and allied purposes in the Ohio River basin being prosecuted under the direction of the Corps of Engineers, U. S. Army. Thus, reservoirs provide a means - already in successful use - of modifying the natural regimen of stream discharge in the interest of cleaner streams.

The Corps of Engineers has completed or essentially completed thirty-two reservoirs for flood control and allied purposes in the Ohio River basin, three other reservoirs are under construction at this time, and forty-five additional reservoirs are included in the comprehensive plan approved by Congress. The total cost of the eighty reservoirs in the approved comprehensive program will be in the order of one and a quarter billion dollars. Sound economic practice dictates that the maximum possible public benefit be realized from the investment of such a sum. Correlation of the reservoir program with the pollution abatement program of the Commission will assist in the attainment of this objective.

HOW IT STARTED. Basic authorization for the comprehensive program for flood control and allied purposes being prosecuted in the Ohio River basin is found in federal flood control legislation. The Flood Control Act of 22 June 1936 defines fundamental federal flood control policy as follows:

> "It is hereby recognized that destructive floods upon the rivers of the United States, upsetting orderly processes and causing loss of life and property, including the erosion of lands, and impairing and obstructing navigation, highways, railroads, and other channels of commerce between the States, constitute a menace to national welfare; that it is the sense of Congress that flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with States, their political subdivisions, and localities thereof; that investigations and improvements of rivers and other waterways, including watersheds thereof, for flood control purposes are in the interest of the general welfare; that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected."

Actually, the Ohio River basin program had its genesis in the great flood of 1913, following which Congress recognized the national aspect of the basin's flood problem in the adoption of legislation calling on the Corps of Engineers for preliminary study of the situation. Although a report favorable to a detailed investigation was submitted, no further action was taken by Congress until surveys of the Ohio River and its tributaries in the interest of navigation, flood control, and power development were authorized by the River and Harbor Act of 21 January 1927, in accordance with House Document No. 308, 69th Congress, 1st Session. The Ohio River "308" report (HD 306/74/1) was made under that authority and was the basis upon which Congress authorized initiation of a comprehensive plan for alleviation of floods on the main stream. Development of this plan was underway when the great floods of 1936 and 1937 occurred.

Review of the "308" plan in the light of new flood experience resulted in the formulation of the general comprehensive plan for flood control and other purposes in the Ohio River basin adopted by the Flood Control Act of 28 June 1938. Subsequent investigations have provided the background for modification and expansion of the program into its present form.

WHAT IT INCLUDES. At this time the program comprises eighty reservoirs and two hundred and thirty-nine local flood protection projects. It is designed to provide a high degree of flood protection and related benefits throughout the basin at minimum overall cost. Thus, along most of the Ohio River, principal reliance for flood control is placed on local protection works supplemented by reservoirs, since it is not economically feasible to provide protection by reservoirs alone. On the other hand, flood protection at Pittsburgh and along the Ohio River immediately below Pittsburgh can be provided most economically by reservoirs alone. Similar situations exist in the tributary basins. For example, valuable flood protection can be provided for many acres of agricultural land in the Wabash River basin at lowest cost by means of levees of moderate height; whereas, in the Muskingum basin, it has been found advisable to construct an extensive reservoir system supplemented by relatively few local flood protection projects. Considerations of this sort have resulted in the formulation of a physically and economically balanced flood control program, the current construction status of which is as follows:

Construction Status	Reservoirs	Local flood protection projects
Completed or essentially completed	32	39
Under construction	3	8
Authorized, but not yet started	45	192
Total	80	239

The program is under continuing investigation to insure that it will best serve the needs of the Ohio River basin.

While the comprehensive flood control program is of general interest, and water supply and waste treatment facilities frequently are benefited by local flood protection works, it is the reservoir portion of the program which is of primary importance in relation to the Ohio River Valley Water Sanitation Commission's objective of stream betterment.

The locations of the eighty reservoirs in the authorized program are indicated on the map on the following page and pertinent reservoir data are tabulated in the appendix.

RESERVOIRS — AUTHORIZED BUT NOT STARTED

1 ALLEGHENY
2 FRENCH CREEK
3 RED BANK
4 WEST FORK MONONGAHELA
5 TURTLE CREEK
6 SHENANGO
7 EAGLE CREEK
8 MILLERSBURG
9 FRAZEYSBURG
10 BURNSVILLE
11 STEER CREEK
12 WEST FORK
13 LOGAN
14 MOORES FERRY
15 BIG BEND
16 SUMMERSVILLE
17 BIRCH
18 POCA
19 MUD RIVER
20 EAST LYNN
21 HAYSI
22 CLINTWOOD
23 FISHTRAP
24 BIG DARBY
25 DEER CREEK
26 PAINT CREEK
27 ROCKY FORK
28 CAESAR CREEK
29 EAST FORK
30 CAVE RUN
31 FALMOUTH
32 BROOKVILLE
33 METAMORA
34 BUCKHORN
35 BOONEVILLE
36 JESSAMINE
37 NO.2 GREEN RIVER
38 NOLIN RIVER
39 NO.2 BARREN
40 MINING CITY
41 ROUGH RIVER
42 MANSFIELD
43 STEWARTS FERRY
44 THREE ISLANDS
45 ROSSVIEW

OHIO RIVER BASIN

COMPREHENSIVE RESERVOIR PLAN

THE RESERVOIR PROGRAM

The intensive development of the Ohio River basin which has resulted in both the need and economic justification for flood control reservoirs and in the need for such an organization as the Ohio River Valley Water Sanitation Commission has created many water use problems. These problems, all of which are capable of solution either wholly or in part by use of reservoirs, include as the most important those related to navigation, floods, hydroelectric power production, domestic and industrial water supplies, waste disposal, recreation, and fish and wildlife conservation.

The same development which created the water use problems has placed a limitation on the number of usable reservoir sites in the basin. Obviously consideration must be given to developments in potential reservoir areas - agriculture, industry, railroads, highways, urban areas, and so on - as well as to the availability of suitable damsites, if reservoirs are to be provided within the framework of economic justification established by flood control legislation. It may be stated categorically that economical and fully effective basin-wide reservoir systems cannot be developed separately in the Ohio Valley for all purposes such as flood control, hydroelectric power production, and low water regulation. Fortunately, however, many of the reservoir sites in the basin plan present opportunity for economical multiple-purpose development and thus opportunity for provision of a functionally balanced reservoir program.

ITS RELATION TO POLLUTION PROBLEMS. Low flow regulation is the reservoir function of most value in relation to the Ohio River Valley Water Sanitation Commission's program for stream betterment. Described in the simplest terms it comprises impoundment of excess water during periods of high flow for later, controlled release during periods of low flow. It is not acceptable as a substitute for waste treatment. Instead, its value lies in supplementation of waste treatment. In a broad sense this value can be measured in terms of the dilution water provided. In many cases results which are possible through supplemental use of low flow regulation cannot be obtained by conventional waste treatment alone, as for example in a case where the stream to which treatment plant effluents are discharged does not furnish adequate natural flow to permit maintenance of satisfactory stream conditions even after a high degree of waste treatment has been provided. In other applications low flow regulation may provide dilution sufficient to reduce the degree of waste treatment required to meet desired objectives, with attendant savings in treatment costs.

The value of dilution as a pollution abatement measure is recognized by sanitary engineers. In general, undesirable stream characteristics which vary in concentration in inverse relation to stream discharge are subject to betterment by dilution and, hence, to betterment by low flow regulation. In order to indicate the general applicability of low flow regulation to stream polution problems, Figure 1 has been prepared to show certain pollution - discharge relationships as follows:

Curve A, indicates a hardness - discharge relationship for the Monongahela River at Pittsburgh, based on water treatment plant and stream flow records. The characteristic inverse form is conducive to the beneficial softening effect now being obtained by reservoir operation in the Monongahela River basin, as described in more detail later.

Curve B, adapted from the Commission's report on Pollution Patterns in the Ohio River - 1950, illustrates an approximate chloride - discharge relationship for the Ohio River near Haverhill, Ohio. The inverse form of the curve indicates the possibility of reducing chloride concentration by means of low flow regulation.

Curve C, adapted from the 1943 report on the Ohio River Pollution Survey made by the Public Health Service and the Corps of Engineers (HD 266/78/1) indicates a relationship between dissolved oxygen deficiency and discharge in the Mahoning River at Lowellville, Ohio. The value of dilution water in a situation such as is defined by the curve is obvious.

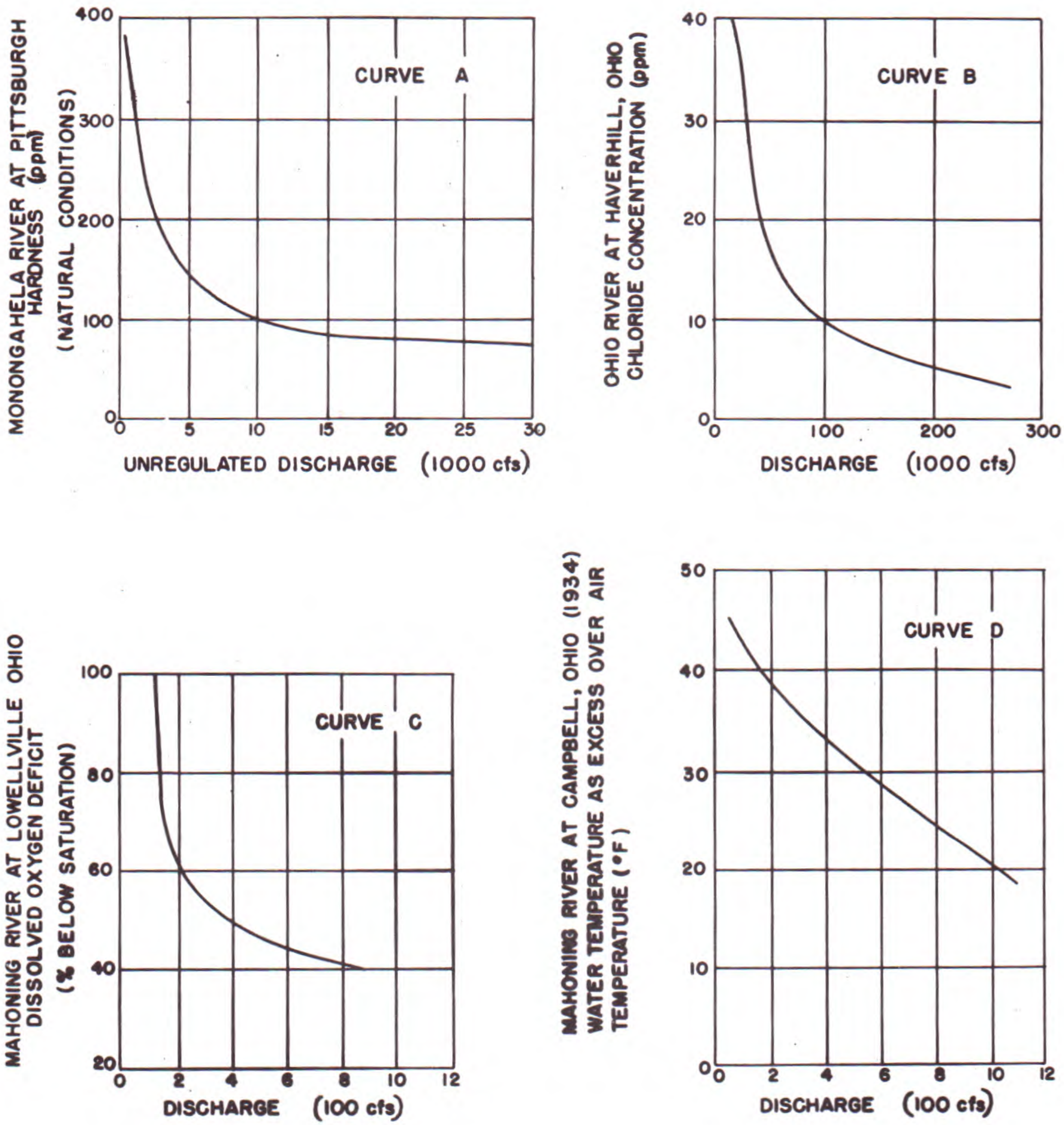


FIGURE I

POLLUTION DISCHARGE RELATIONSHIP

Curve D, adapted from the 1941 studies made by the Public Health Service for the Corps of Engineers in connection with Berlin Reservoir, illustrates the water temperature-stream discharge relationship for the Mahoning River at Campbell, Ohio. Substantial reductions in water temperature already are being provided in that basin by low water regulation.

Concerning the relationship of low flow regulation to stream pollution problems in the Ohio River basin, Mr. Maurice LeBosquet, representing the U. S. Public Health Service, has had the following to say, as noted in a report to the Delegates of the Ohio River Valley Water Sanitation Compact in 1944:

"Locations in the Ohio River basin where low flow (regulation) can be used to advantage include the main Ohio River where benefits will accrue throughout the full length of the stream. On the tributaries, increased low flows can be used to advantage on the Allegheny and Monongahela Rivers in Pennsylvania; the Mahoning, Scioto, and Miami Rivers in Ohio; the Kanawha River in West Virginia; and the West Fork of the White River in Indiana. Increased low flows will have lesser benefits on a great many other tributaries in the Ohio River basin."

ITS PROVISION BY RESERVOIR OPERATION. There are several methods of providing low flow regulation by means of reservoirs in connection with flood control. These involve seasonal use of a portion of the flood control capacity of the reservoir, direct provision of storage capacity in addition to the capacity provided for flood control, or a combination of seasonal operation and direct provision of storage. Low flow regulation also may be an incidental result of reservoir functions other than flood control. Each method has inherent advantages and disadvantages.

Seasonal operation. Under the seasonal plan of reservoir operation water released during the summer-fall dry season must be stored during the preceding late spring. The storage capacity which safely can be released for seasonal low flow regulation use is dependent entirely on the relationship of the flood reduction potential of the reservoir under consideration to the flood problem against which it provides protection. Thus, it is feasible to use 100,000 acre feet of the capacity of Tygart River reservoir for seasonal low flow regulation, whereas such operation will not be feasible at Conemaugh River reservoir in the Allegheny River basin because of the limited flood control capacity provided at the latter site.

In other situations it may not be possible to provide for seasonal low flow regulation because maximum flood control capacity may be required during the summer months. Obviously, each case must be considered on its own merits. Important physical considerations involved in determining the propriety of seasonal reservoir operation for low flow regulation include the following:

a. Storage capacity requirements for reservoir functions other than low flow regulation.

b. Amount of flood control capacity capable of being developed at site under consideration.

c. Drainage area controlled by reservoir.

d. Flood patterns at damsite and at downstream damage areas.

e. Quantity and quality of water available at damsite for storage during late spring season.

f. Effect of storage and discharge operations on quantity and quality of water at critical downstream locations.

The major advantage of the seasonal operation method of providing low flow regulation is the fact that it may involve little or no cost in addition to that incurred for flood control and other purposes. The major disadvantage lies in the limited flexibility of operation under the method. Seasonal operation is feasible at some of the reservoirs in the Ohio River basin program.

Direct provision of storage capacity. From the operational viewpoint, direct provision of storage capacity is the most satisfactory means of obtaining low water regulation. The physical limitations of this method are established by the following considerations:

a. Storage capacity capable of being developed at site under consideration.

b. Storage capacity requirements for reservoir functions other than low flow regulation.

c. Long-term discharge regimen at damsite and critical downstream points.

d. Quantity and quality of water available at damsite for storage.

e. Effect of storage and discharge operations on quantity and quality of water at critical downstream locations.

The major advantage of the direct provision of storage capacity method of providing low flow regulation is the complete flexibility of operation under that method. The major disadvantage is that single-purpose use of storage capacity is involved, resulting in costs in addition to those incurred for the other reservoir functions provided. The capacity of many of the reservoirs in the reservoir program for the Ohio basin might be increased, at added cost, to provide storage capacity for year around use in the interest of low flow regulation.

Combination method. The combination method of providing low flow regulation comprises direct provision of a portion of the required reservoir capacity plus seasonal provision of the remainder. The method is subject to the limitations, advantages, and disadvantages of the separate methods of which it is comprised. This method is adaptable to a number of the reservoirs in the Ohio River basin program.

Incidental low flow regulation. In addition to provision of low flow regulation in combination with flood control it is possible to obtain incidental low flow regulation benefits in connection with certain other reservoir functions, notably the production of hydroelectric power. Basically, reservoir operations for power production are much the same as those for low flow regulation, in that water is stored during periods of high flow for release when natural stream discharge is of inadequate volume. Such operations may be conducted on a seasonal basis, by direct provision of storage capacity, or by a combination of these means. Run-of-river hydroelectric plants have no appreciable low flow regulation effect.

Frequently hydroelectric plants are used for peaking purposes, resulting in large variations in discharge which, under certain conditions, may be objectionable from the pollution abatement viewpoint. When such objectionable conditions are experienced they often can be overcome by provision of re-regulation works below the hydroelectric projects or by other means, with a net beneficial result on downstream water quality during low flow periods.

EXAMPLES. A further understanding of the applicability of low flow regulation as a pollution abatement measure perhaps best can be obtained by consideration of examples of reservoirs already in operation for low flow regulation in the Ohio River basin.

Tygart River Reservoir. Tygart River reservoir is provided by means of a concrete gravity dam located 23 river miles above the mouth of Tygart River, a Monongahela River tributary, and 152 river miles above the head of the Ohio River at Pittsburgh. It controls a drainage area of 1,184 square miles and was placed in operation early in 1938. The total storage capacity of the reservoir at spillway crest elevation is 289,600 acre feet. A minimum pool of 11,200 acre feet capacity is maintained. The reservoir is operated in the primary interest of flood control during the winter-early spring season and for flood control and low flow regulation on a seasonal basis during the late spring-summer-fall season. Storage allocations to these purposes are as follows:

Function	Storage allocation (acre-feet)
Minimum pool	11,200
Flood Control	
Winter	278,400
Summer	178,400
Low water regulation	
Winter	-
Summer	100,000
Total storage capacity	289,600

Careful analysis of the flood producing potential of the Tygart River basin above the reservoir, in relation to the downstream flood problem, has demonstrated the propriety of seasonal allocation of reservoir capacity to the low flow regulation function. Figure 2 shows the guide or rule curves which establish the pattern of low flow regulation operations. They are designed to insure a minimum flow of 340 cubic feet per second in the Monongahela River at Dam No. 8, under the most severe drought conditions of record. Examination of the curves discloses that impoundment is begun in April and that discharge from storage in the interest of low flow regulation normally extends from July to mid-December. Monthly average additions to the flow of the Tygart-Monongahela-Ohio system are of the following order:

Month	Average additions (acre-feet)
April	(-) 60,000
May	(-) 35,000
June	(-) 5,000
July	10,000
August	20,000
September	20,000
October	20,000
November	18,000
December	12,000

(-) Denotes impoundment

PERTINENT DATA	ELEVATION (FT. M. S. L.)	CAPACITY (ACRE FEET)
SPILLWAY CREST	1167.0	289,600
TOP LOW WATER REGULATION POOL	1094.0	111,200
MINIMUM POOL	1010.0	11,200

OPERATING RANGE FOR LOW WATER REGULATION LIES BETWEEN UPPER AND LOWER GUIDE LINES.

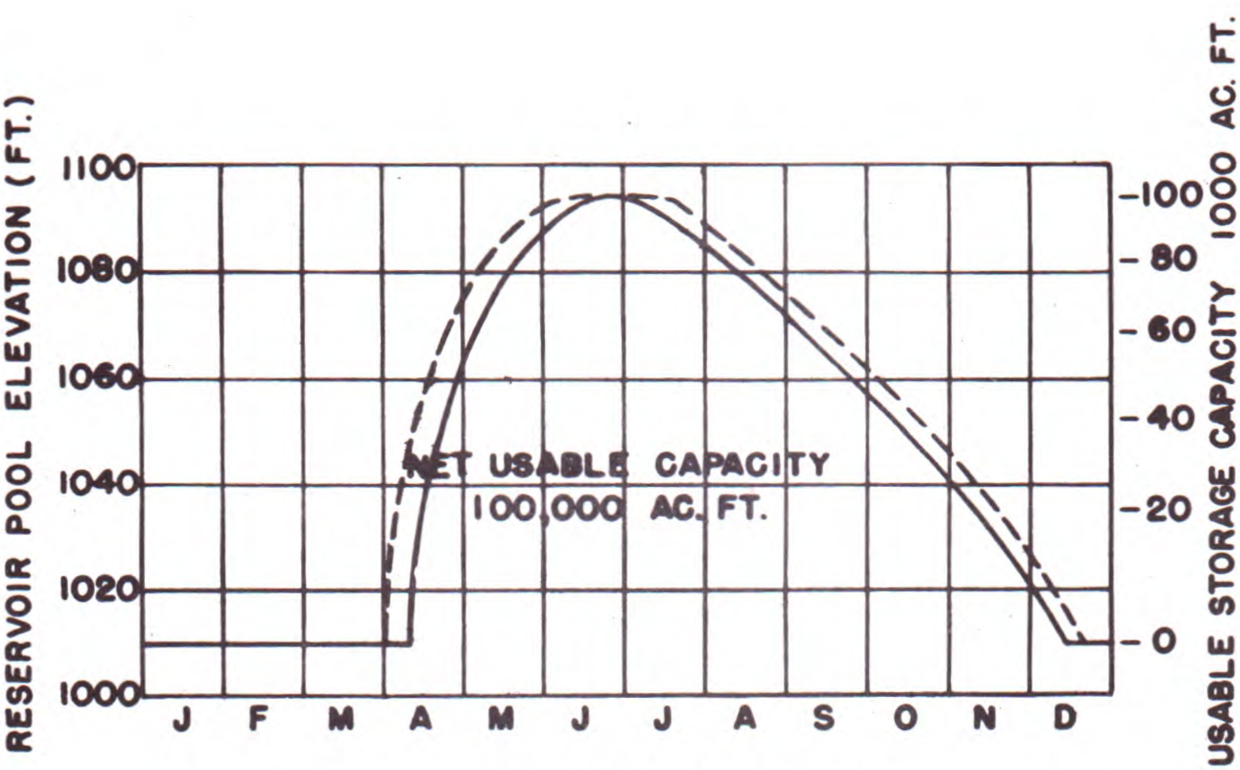


FIGURE 2

TYGART RIVER RESERVOIR
GUIDE CURVES
FOR
LOW WATER REGULATION

While releases from Tygart River reservoir ordinarily are not based on consideration of water quality, because of the basic requirement that an adequate volume of flow be maintained for navigation purposes, reduction in stream hardness results from its operation because of the prevailing inverse relationship between hardness and discharge in the streams of the Ohio River basin subject to pollution by mine drainage.

Figure 3 illustrates the highly beneficial effect of the described method of Tygart River reservoir operation on the hardness of the Monongahela River at Pittsburgh for an extremely dry year such as 1930, during which reductions as great as 150 parts per million would have been effected in monthly average hardness. Average results for a longer period such as that of 1930 through 1934, while less spectacular than the 1930 results, would be about as follows, on a monthly basis:

Month (Average 1930 through 1934)	Hardness * (parts per million)			Discharge * (cubic feet per second)		
	Natural	Regulated	Change	Natural	Regulated	Change
Jan	97	97	0	15,800	15,800	0
Feb	81	81	0	15,800	15,800	0
Mar	75	75	0	27,200	27,200	0
Apr	89	93	(4)	20,500	19,600	(900)
May	105	114	(9)	16,300	15,700	(600)
June	146	152	(6)	5,100	4,900	(200)
July	160	146	14	4,600	4,900	300
Aug	188	158	30	5,400	5,700	300
Sep	158	127	31	4,600	5,000	400
Oct	200	169	31	2,800	3,100	300
Nov	197	158	39	5,600	5,900	300
Dec	129	127	2	13,500	13,600	100
Average	136	125	11	11,400	11,400	0

*Effect of flood control operation disregarded because of its relatively small influence on monthly average discharges and consequently on monthly average hardness.
( ) Denotes increase in hardness and decrease in discharge during storage period.

The foregoing tabulation indicates that seasonal use of storage capacity equivalent to slightly more than 1 percent of the average annual volume of flow in the Monongahela River at Pittsburgh for the 1930-1934 period would have provided almost a 10 percent reduction in the average hardness prevailing during that period incidental to the provision of a dependable navigation water supply.

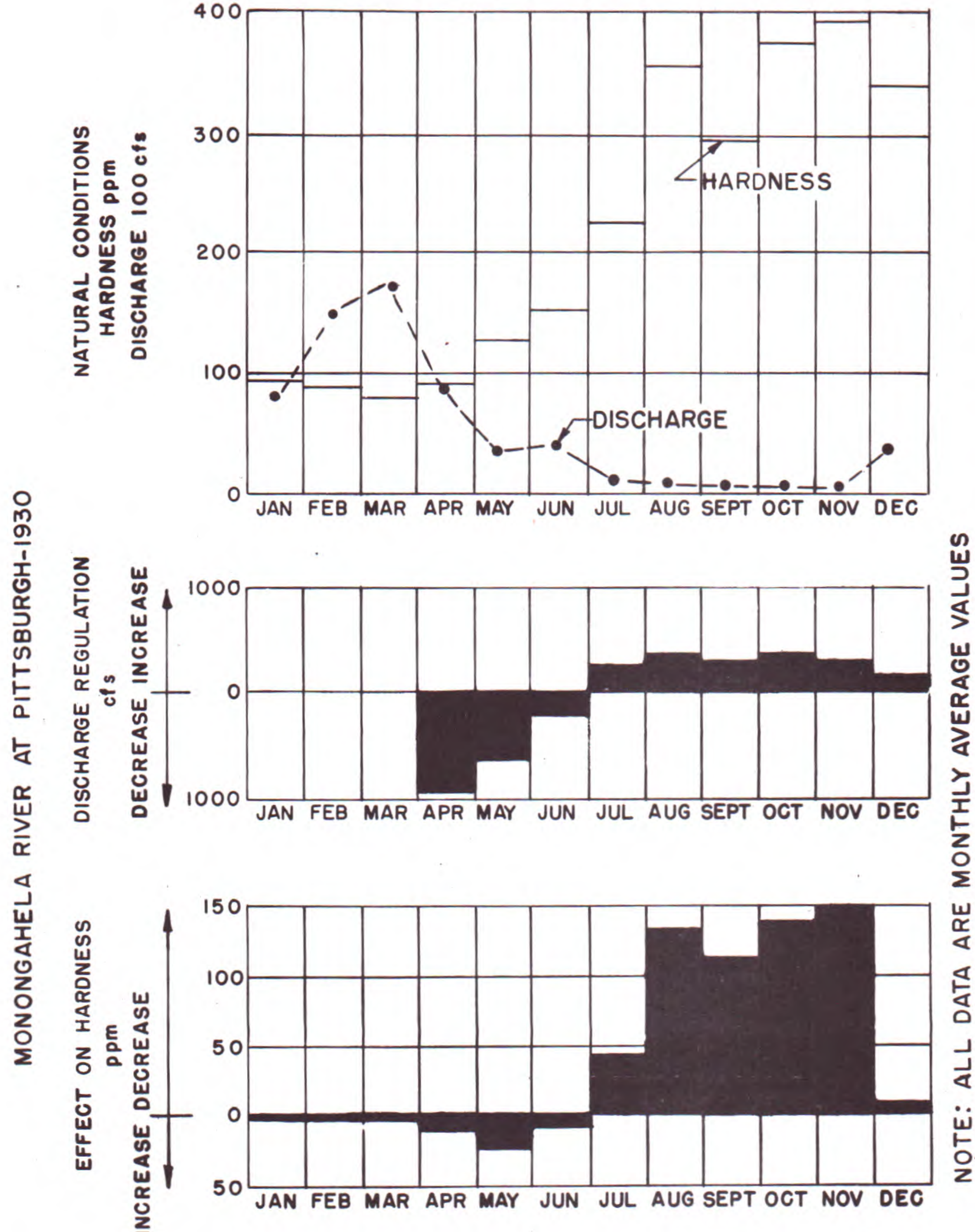


FIGURE 3
TYGART RIVER RESERVOIR
EFFECT OF OPERATION FOR
LOW WATER REGULATION
1930 CONDITIONS

Youghiogheny River Reservoir. Youghiogheny River reservoir, an example of a project providing low flow regulation by combined seasonal operation and direct storage provision, is located in the upper Youghiogheny River basin, a Monongahela River tributary. Reservoir storage allocations are as follows:

Function	Storage allocation (acre-feet)
Minimum pool	5,200
Flood control	
Winter	151,000
Summer	99,500
Low water regulation	
Winter	97,800
Summer	149,300
Total storage capacity	254,000

In accordance with the above schedule a minimum capacity of 97,800 acre feet is available for unrestricted use for low flow regulation purposes and an additional capacity of 51,500 acre-feet is available for seasonal use. Youghiogheny River reservoir operation is more closely keyed to pollution abatement needs than is possible in the case of the Tygart project, and is more flexible, as indicated on Figure 4. It is based on providing discharge from storage in an inverse relation to the discharge prevailing at downstream points. Examples of operations in accordance with Figure 4 follow:

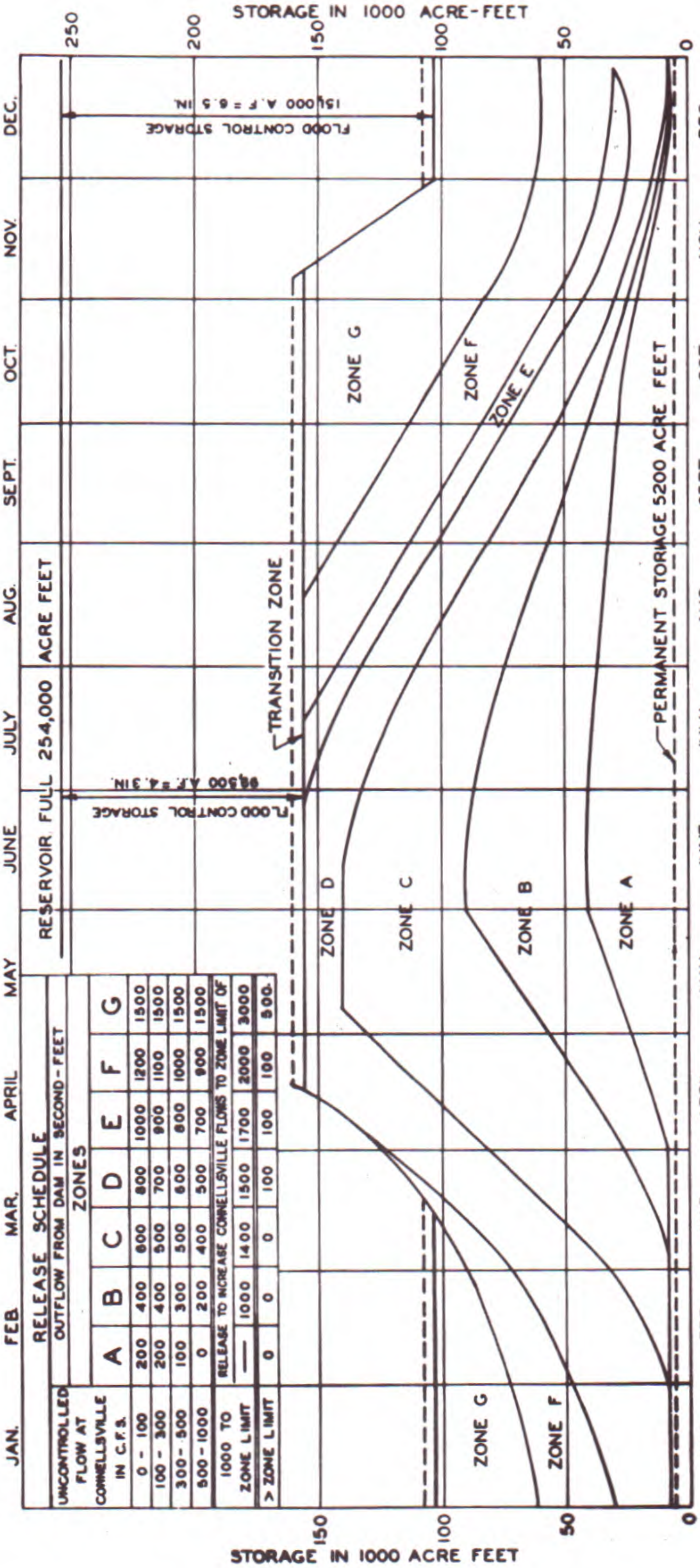
Assumed zone of operations: Zone D (As for example when 100,000 acre feet of water are in storage on 20 August; 40,000 acre feet of water are in storage on 25 October, etc.)

Condition: Flow from uncontrolled area between the dam and Connellsville is 200 cfs

Action: A release of 700 cfs is indicated

Condition: Flow from uncontrolled area between the dam and Connellsville is 1,200 cfs

Action: A release of 300 cfs is indicated (to reach the Zone D limit of 1,500 cfs)



RELEASE SCHEDULE

UNCONTROLLED FLOW AT CONNELLSVILLE IN C.F.S.	OUTFLOW FROM DAM IN SECOND-FEET — ZONES A	B	C	D	E	F	G
0 - 100	200	400	600	800	1000	1200	1500
100 - 300	200	400	500	700	900	1100	1500
300 - 500	100	300	500	600	800	1000	1500
500 - 1000	0	200	400	500	700	900	1500
	RELEASE TO INCREASE CONNELLSVILLE FLOWS TO ZONE LIMIT OF						
1000 TO ZONE LIMIT	—	1000	1400	1500	1700	2000	3000
> ZONE LIMIT	0	0	0	100	100	100	500.

FIGURE 4
YOUGHIOGHENY RIVER RESERVOIR
GUIDE CURVES
FOR
LOW WATER REGULATION

ECONOMIC CONSIDERATIONS. In the planning of reservoir projects the Corps of Engineers has received valuable aid from the Public Health Service in regard to the need for and value of low flow regulation. The economic value of low flow regulation in the Ohio River basin is substantial. As is the case with other pollution abatement measures, however, assignment of a precise monetary value presents practical difficulties. For example, reduced hazards to health are difficult to evaluate in dollars and cents unless such arbitrary yardsticks as the cost of health insurance, workmen's compensation costs, and so on are used. In general, however, a conservative estimate of low flow regulation benefits can be obtained by estimating the cost of providing equivalent results by alternative means. Thus, if a reduction in sewage treatment requirements can be made if low flow regulation is provided the difference between the cost of partial and complete treatment facilities may be credited as a low flow regulation benefit. If there is real need for the sewage treatment the crediting of benefits in this manner is sound. The timing of project provision is another factor of major significance in evaluation of low flow regulation benefits.

On the basis of evaluation studies made by the Service, and additional evaluation studies made by the Corps, the latter has estimated that Tygart, Youghiogheny, Berlin, and Mosquito Creek reservoirs already have provided low flow regulation benefits amounting to about $20,000,000. This estimate is based on evaluation of improvements effected in domestic, industrial, and navigation water supplies and upon reduction in the cost of waste treatment facilities.

In connection with the portion of the estimate related to waste treatment facilities it has been assumed that if such facilities have not been provided to date but that an ultimate reduction in treatment requirements has been made possible by virtue of low flow regulation, the temporary value of the low flow regulation prior to satisfaction of the reduced waste treatment requirements is equivalent, on an annual basis, to the reduction in the annual cost of required waste treatment facilities which ultimately can be realized.

Reduced to the basis of an annual value per acre foot of reservoir capacity utilized the foregoing benefit estimate exceeds by several times the average annual cost of that capacity, indicating the economic feasibility of low flow regulation.

PRESENT AND POTENTIAL LOW FLOW REGULATION PROJECT DEVELOPMENTS

CURRENT STATUS. The general applicability as a pollution abatement measure of low flow regulation available in connection with the Ohio River basin reservoir program has been outlined briefly in the foregoing discussion. Several specific examples have been given and the current construction status of the reservoir program has been indicated. Low flow regulation already is being provided by five reservoirs and will be provided by another in the immediate future. Still another reservoir, now under construction, will provide low flow regulation upon its completion. The table on page 19 indicates the current status of the reservoir program in this respect. The seven reservoirs involved provide for a storage capacity reservation of 466,600 acre feet for low flow regulation purposes. In addition, a total storage capacity of 3,130,000 acre feet used for power draw-down purposes in the Cumberland River basin provides incidental low flow regulation. The entire 981 miles of the Ohio River and 1,340 miles of tributary streams are subject to benefit.

Exclusive of the regulation incidental to power production, the aggregate increase in summer flow will approximate 1,300 cubic feet per second based on 85 percent utilization of storage and uniform increase in flow during July through November. Operation of the projects on a schedule based on observed discharges at key points - as, for example, as is done in the case of Youghiogheny River Reservoir - may permit increased flows during critical periods averaging substantially more than the above amount.

FUTURE STATUS

The approved reservoir program. While the approved Ohio River basin reservoir program offers considerable promise in regard to provision of additional low flow regulation, both on the tributaries and the main stem, competition for reservoir capacity exists between many worthwhile reservoir functions such as flood control, hydroelectric power production, direct water supply, low flow regulation and recreation. Proper resolution of the problems of reservoir use will aid in meeting the objective of maximum public benefit from investment in water control facilities. Allegheny River reservoir, a unit in the approved reservoir program, provides an example of the resolution of such problems.

The concept of a reservoir for flood control and other purposes on the upper Allegheny River main stem is of long standing, pre-dating by a substantial number of years the authorization of Allegheny River Reservoir for flood control by the Flood Control Act of 22 June 1936. Further authorized investigation of the project, reported in House Document No. 300, 76th Congress, 1st Session, disclosed the advantages of multiple-purpose reservoir development at an upper Allegheny River main stem site. As a result a modified project, to serve the combined

LOW FLOW REGULATION ASPECTS OF RESERVOIR PROGRAM
CURRENT STATUS

Reservoir	Damsite			Miles Below Pittsburgh at Which Flow Enters Ohio River	Low Water Regulation					
	State	Stream	Miles Above Ohio River		Type Operation	Storage Allocation (Acre Feet) Seasonal	Direct	Total	Miles of Stream Benefited in Ohio River Basin	Average Increase in Flow July Through November **
Completed Reservoirs										
Tygart	W. Va.	Tygart River	152	0	Seasonal	100,000	0	100,000	1,133	280
Youghiogheny	Pa.	Youghiogheny River	90	0	Combined	51,500	97,800	149,300	1,071	415
Berlin	Ohio	Mahoning River	93	25	Combined	23,000	33,600	56,600	1,049	160
Mosquito Creek	Ohio	Mosquito Creek	61	25	Combined	11,300	63,100	74,400	1,017	205
Delaware	Ohio	Olentangy River	162	357	Seasonal	5,600	0	5,600	786	15
Wolf Creek	Ky.	Cumberland River	461	920	Incidental	-	-	2,142,000 *	522	3,500
Dale Hollow	Tenn.	Obey River	388	920	Incidental	-	-	496,000 *	449	810
Center Hill	Tenn.	Caney Fork River	336	920	Incidental	-	-	492,000 *	397	805
Reservoirs Under Construction										
East Branch Clarion	Pa.	E. Br. Clarion River	193	0	Combined	19,700	44,600	64,300	1,174	180
Sutton	W. Va.	Elk River	159	266	Seasonal	16,400	0	16,400	874	45

* Maximum draw-down for power purposes.

** Estimated on basis of 85% utilization of low water regulation storage; 50% utilization of power draw-down storage; and uniform increase in flow from July to November, inclusive.

interests of flood control and low flow regulation, was authorized by the Flood Control Act of 18 August 1941 as a unit of the comprehensive plan which had been adopted in 1938 for flood control and other purposes in the Ohio River basin.

As contemplated in House Document No. 300/76/1, the project now eligible for selection for construction would comprise a concrete gravity dam with controlled spillway. The damsite would be in the vicinity of Kinzua, Pa. At full pool elevation 1,365 the reservoir limits would extend upstream to the vicinity of Salamanca, N.Y. A total storage capacity of 1,125,000 acre feet is contemplated. Of this amount a capacity of from 910,000 to 585,000 acre feet would be reserved for flood control on a seasonal basis, and a capacity of from 195,000 to 520,000 acre feet would be reserved for low flow regulation. A minimum pool of about 20,000 acre feet would be provided. The reservoir would be operated in the primary interests of flood control and low flow regulation for the benefit of the Allegheny and upper Ohio River valleys. Ultimate provision of the project, as in the case of the other remaining units in the approved program, is dependent upon appropriation by Congress of the funds required for its detailed planning and construction.

Reconsideration of the operation of reservoirs already completed also may be involved in determining the future status of low flow regulation from the approved reservoir system, the Muskingum River reservoir system being a case in point. Low flow regulation could be obtained from that system by use of the conservation pools now maintained at relatively constant levels for recreational purposes, and, possibly, by limited seasonal operation of several of the reservoirs. While public demand now appears to favor operation of the Muskingum system in the present manner, the system does provide a water reserve which could, upon demonstration of public need and demand, be used for low water regulation during critically dry periods. This situation is another example of the type of problem which must be resolved in connection with reservoir planning and operation.

Figure 5 has been prepared in order to indicate in a general way and on a conservative basis the low flow regulation potential of the approved Ohio River basin reservoir program, on the basis of one of the many possible combinations of reservoir operations for that purpose. Final decisions in regard to the amount of low flow regulation to become available in the several tributary basins and, thus, on the main stream, must await detailed study of the reservoir projects remaining to be constructed and, in certain instances, an expression of local interest in the provision of that reservoir function. Examination of Figure 5 discloses that the approved reservoir program has a potential for increas-

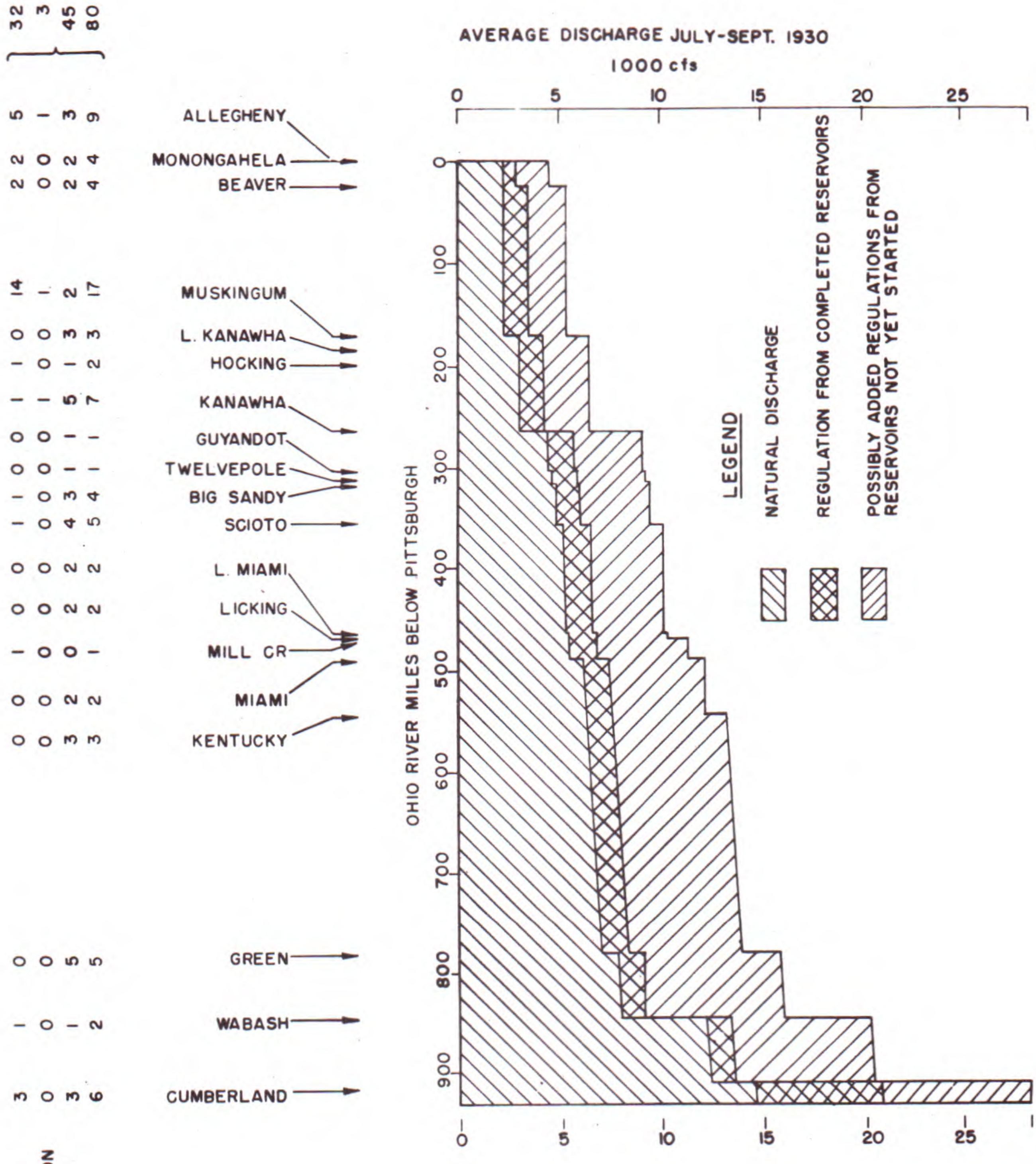


FIGURE 5
FLOW REGULATION POTENTIAL
OF
APPROVED OHIO RIVER BASIN
RESERVOIR PROGRAM

ing drought period flows in the Ohio River by a very substantial amount and that reservoirs already provided or under construction are effecting from about one-third to one-sixth of the total potential regulation, depending upon the Ohio River location selected.

Other reservoirs. The approved reservoir program is subject to continuing review in connection with detailed pre-construction planning of the various units selected for construction and, frequently, responsive to direct Congressional action calling for engineering investigations. In connection with the latter, existing plans usually are reviewed with a view to determining their current adequacy, and findings are reported to Congress. This was done in the case of Allegheny River reservoir as described above. Congress then determines if additions to or major changes in the approved reservoir plan are in order and, as in the Allegheny reservoir case, may implement its decisions in flood control legislation.

In all of the investigations and reviews called for by Congress, in which reservoirs are involved, consideration is given to water supply and low flow regulation needs. The investigations are conducted in such a manner as to keep the affected State or States advised of progress and to permit opportunity for consultation regarding plans and proposals and for cooperation in the work of investigations. Recent examples of such investigations involving consideration of low flow regulation are those concerning the Mahoning-Grand River basin in Ohio and the West Fork River basin in West Virginia.

In the Mahoning-Grand case, consideration has been given to a storage reservoir on the Grand River, supplemented by diversion-channel excavation, pumping facilities, and other appurtenances, which would permit virtually complete control of the runoff from the upper Mahoning and Grand basins. Important flood control and low flow regulation benefits would result from operation of such a project. In the West Fork basin case consideration has been given to modification of the approved reservoir plan for the basin to provide for low flow regulation as well as flood control. It has been found that a reservoir to serve both functions might be built on the West Fork River above Weston, W.Va. Recommendations have not been submitted to Congress in either case, pending completion of the investigations.

While differences of opinion have arisen in connection with both of the above possibilities because of the need for taking land for reservoir purposes and for other reasons, investigations of this sort provide a means for keeping the approved reservoir program alive and responsive to changing needs in the Ohio River basin.

As has been noted the favorable aspects of low flow regulation were called to the attention of the Commission during its organizational period, and the Commission has taken advantage of the low flow regulation now available plus that assured at an early date in connection with establishment of sewage treatment standards for two reaches of the Ohio River. For example, treatment requirements established for the Cincinnati pool call for a reduction in bio-chemical oxygen demand of up to 65 percent. Commission studies indicate that without the increased flow available in this stretch of the Ohio River resulting from reservoir operation, the maximum requirement for bio-chemical oxygen demand reduction would have been in the neighborhood of 75 percent rather than 65 percent, and that without the benefit of reservoir operation the number of days during a year when a degree of treatment higher than primary would be required would be greatly increased. Low flow regulation, therefore, means a very definite saving in the cost of treatment to all those discharging wastes into the Cincinnati pool.

The Commission has recognized the low water regulation feature of the reservoir program in other ways, as in the case of its Wabash River Survey, where studies indicated that in the event low flow regulation became part of a flood control program the cost of waste treatment in the area surveyed would be materially reduced. However, at the time of the survey, development of a flow regulation program was so indefinite that potential benefits were not considered in evaluating waste treatment requirements.

On one occasion in the past, a statement of policy was enunciated by the Commission regarding low flow regulation benefits from a specific reservoir project. The project involved was the Mahoning-Grand River Floodway mentioned above as being under investigation. The policy adopted was stated in a formal resolution passed by the Commission at its meeting on 11 January 1950. This resolution read in part as follows:

> "Be it resolved, that it is the view of the Ohio River Valley Water Sanitation Commission that the costs which may be allocated to procurement of the widespread sanitation benefits from the Mahoning-Grand River Floodway for flood control and related purposes should be borne by the United States; and
>
> "Be it further resolved, that it is the view of the Ohio River Valley Water Sanitation Commission that the adoption of such a policy in the instant case will: (1) provide for the citizens of the Ohio River basin substantial and widespread sanitation benefits not fully obtainable by other practical means; and (2) will permit an earlier and more complete realization of clean and

sanitary waters in the Ohio River basin, in accordance with the terms of the compact, than may be anticipated without the adoption of such a policy in the instant case; and

"Be it further resolved, that the Ohio River Valley Water Sanitation Commission recognizes the desirability for provision of low flow regulation on the basis of sound technical and economic principles and, to this end, it is the view of the Commission that low flow regulation in the Mahoning-Grand River Floodway properly may be applied as a supplement to, rather than as a substitute for, sewage and industrial waste treatment."

The record shows that adoption of this resolution did not comprise blanket endorsement by the Commission of the principle that the Federal government assume the cost of the low flow regulation features of each flood control project in the Ohio Valley. In fact it was made clear at the time that the Commission desired and intended to consider each such case individually and on its own merits.

Some of the courses of action toward which the Commission may wish to direct its attention with a view to coordination of the pollution abatement and reservoir programs include the following:

a. Expression of the need for and value of low flow regulation from reservoirs now being planned.

b. Consultation with the Corps of Engineers with regard to establishment of schedules for low water regulation operations.

c. Conduct of studies after project completion that would lead to a precise determination of benefits on the basis of operating experience and that would serve as a basis for recommendations to the Corps of Engineers regarding improvement of reservoir operations for low flow regulation.

d. Critical consideration of reservoir projects to insure that they will have no adverse effect on the Commission's program.

e. Consideration of minimum flows required in the future to permit continuing industrial development in the Ohio basin without detriment to the stream betterment program.

SUMMARY

It has been the intent of this report to indicate the applicability of low flow regulation available from the Ohio River basin reservoir program to the problem of obtaining stream betterment. Examples of reservoir operation have been given, economic considerations have been discussed briefly, and the present and possible future status of low flow regulation have been discussed. Much has been done in connection with the Ohio River basin reservoir program and much remains to be done. In the accomplishment of the remaining work, close cooperation between the Corps of Engineers, charged with responsibility for reservoir planning, and the Ohio River Valley Water Sanitation Commission, whose objective is stream betterment for all legitimate uses, will return dividends in the form of substantial low water regulation benefits.

APPENDIX - Pertinent Reservoir Data

Note: The data contained herein are based on varying degrees of knowledge of the reservoir projects involved, ranging from exact knowledge of completed projects to relatively preliminary knowledge of projects on which detailed planning remains to be accomplished. Accordingly, it must be recognized that a portion of the data are tentative in nature. For convenience, reservoirs completed to the point of usefulness are listed as completed. Several additional reservoirs rapidly are nearing completion.

Name of Reservoir	Location of Damsite			Net Drainage Area	Construction Status	Total Storage Capacity
	State	Stream	Miles Above Ohio River	sq. mi.		ac. ft.
ALLEGHENY RIVER BASIN, N. Y. AND PA. (Drainage area 11,730 square miles. Joins Monongahela River at Pittsburgh, Pa., to form Ohio River (Emsworth Pool))						
Allegheny River	Pa.	Allegheny River	201	2,190	Not started	1,125,000
Tionesta Creek	Pa.	Tionesta Creek	156	478	Completed	133,400
French Creek	Pa.	French Creek	165	591	Not started	122,000
East Branch Clarion	Pa.	East Branch Clarion River	193	71	Under construction	84,300
Redbank Creek	Pa.	Redbank Creek	90	460	Not started	142,000
Mahoning Creek	Pa.	Mahoning Creek	78	339	Completed	74,200
Crooked Creek	Pa.	Crooked Creek	48	277	Completed	93,900
Conemaugh River	Pa.	Conemaugh River	65	1,351	Completed	274,000
Loyalhanna Creek	Pa.	Loyalhanna Creek	62	290	Completed	95,300
Sub-total				6,047		2,144,100
MONONGAHELA RIVER BASIN, MD., W. VA., AND PA. (Drainage area 7,380 square miles. Joins Allegheny River at Pittsburgh, Pa., to form Ohio River (Emsworth Pool))						
Tygart River	W. Va.	Tygart River	152	1,184	Completed	289,600
West Fork	W. Va.	West Fork River	168	366	Not started	62,500
Youghiogheny	Pa.	Youghiogheny River	90	434	Completed	254,000
Turtle Creek	Pa.	Turtle Creek	20	54	Not started	20,700
Sub-total				2,038		626,800

APPENDIX - Pertinent Reservoir Data

Name of Reservoir	Location of Damsite			Net Drainage Area sq. mi.	Construction Status	Total Storage Capacity ac. ft.
	State	Stream	Miles Above Ohio River			
BEAVER RIVER BASIN, OHIO AND PA. (Drainage area 3,145 square miles. Joins Ohio River 25.4 miles below Pittsburgh, Pa. (Montgomery Pool))						
Shenango	Pa.	Shenango River	56	592	Not started	127,000
Berlin	Ohio	Mahoning River	93	249	Completed	91,200
Eagle Creek	Ohio	Eagle Creek	74	95	Not started	99,000
Mosquito Creek	Ohio	Mosquito Creek	61	97	Completed	104,100
Sub-total				1,033		421,300
MUSKINGUM RIVER BASIN, OHIO (Drainage area 8,040 square miles. Joins Ohio River 172.2 miles below Pittsburgh, Pa. (Pool No. 18))						
Charles Mill	Ohio	Black Fork	182	216	Completed	88,000
Pleasant Hill	Ohio	Clear Fork	169	199	Completed	87,700
Mohicanville	Ohio	Lake Fork	171	269	Completed	102,000
Mohawk	Ohio	Walhonding River	130	817	Completed	285,000
Millersburg	Ohio	Killbuck Creek	150	381	Not started	77,000
Leesville	Ohio	McGuire Creek	196	48	Completed	37,400
Atwood	Ohio	Indian Fork	188	70	Completed	49,700
Bolivar	Ohio	Sandy Creek	183	502	Completed	149,600
Dover	Ohio	Tuscarawas River	174	777	Completed	203,000
Beach City	Ohio	Sugar Creek	180	300	Completed	71,700
Piedmont	Ohio	Stillwater Creek	198	84	Completed	65,000
Clendening	Ohio	Brushy Fork	184	70	Completed	54,000
Tappan	Ohio	Little Stillwater Creek	174	71	Completed	61,600
Senecaville	Ohio	Seneca Fork	188	121	Completed	88,500
Wills Creek	Ohio	Wills Creek	108	723	Completed	196,000
Frazeysburg	Ohio	Wakatomika Creek	108	139	Not started	62,000
Dillon	Ohio	Licking River	83	748	Under construction	294,000
Sub-total				5,535		1,972,200

APPENDIX - Pertinent Reservoir Data

Name of Reservoir	Location of Damsite			Net Drainage Area sq. mi.	Construction Status	Total Storage Capacity ac. ft.
	State	Stream	Miles Above Ohio River			
LITTLE KANAWHA RIVER BASIN, W. VA. (Drainage area 2,320 square miles. Joins Ohio River 184.6 miles below Pittsburgh, Pa. (Pool No. 19))						
Burnsville	W. Va.	Little Kanawha River	123	166	Not started	58,800
Steer Creek	W. Va.	Steer Creek	85	168	Not started	94,000
West Fork	W. Va.	West Fork	50	241	Not started	85,100
Sub-total				575		237,900
HOCKING RIVER BASIN, OHIO (Drainage area 1,185 square miles. Joins Ohio River 199.3 miles below Pittsburgh, Pa. (Pool No. 20))						
Burr Oak	Ohio	East Branch Sunday Creek	57	33	Completed	26,900
Logan	Ohio	Clear Creek	78	84	Not started	36,600
Sub-total				117		63,500
KANAWHA RIVER BASIN, N. C., VA., AND W. VA. (Drainage area 12,300 square miles. Joins Ohio River 265.7 miles below Pittsburgh, Pa. (Gallipolis Pool))						
Moores Ferry	Va.	New River	311	1,130	Not started	1,010,000
Big Bend	W. Va.	Greenbrier River	168	1,631	Not started	108,500
Bluestone	W. Va.	New River	162	3,435	Completed	631,000
Summersville	W. Va.	Gauley River	137	791	Not started	331,700
Sutton	W. Va.	Elk River	159	537	Under construction	265,300
Birch	W. Va.	Birch River	140	142	Not started	43,600
Poca	W. Va.	Pocatalico River	42	345	Not started	202,000
Sub-total				8,011		2,592,100
GUYANDOT RIVER BASIN, W. VA. (Drainage area 1,670 square miles. Joins Ohio River 305.2 miles below Pittsburgh, Pa. (Pool No. 28))						
Mud River	W. Va.	Mud River	31	270	Not started	140,000
Sub-total				270		140,000

APPENDIX - Pertinent Reservoir Data

Name of Reservoir	Location of Damsite			Net Drainage Area sq. mi.	Construction Status	Total Storage Capacity ac. ft.
	State	Stream	Miles Above Ohio River			
TWELVEPOLE CREEK BASIN, W. VA. (Drainage area 445 square miles. Joins Ohio River 313.3 miles below Pittsburgh, Pa. (Pool No. 29))						
East Lynn	W. Va.	East Fork Twelvepole Creek	38	138	Not started	86,000
Sub-total				138		86,000
BIG SANDY RIVER BASIN, KY., VA. AND W. VA. (Drainage area 4,280 square miles. Joins Ohio River 317.1 miles below Pittsburgh, Pa. (Pool No. 29))						
Haysi	Va.	Russell Fork	153	155	Not started	50,000
Clintwood	Va.	Pound River	166	99	Not started	40,000
Fishtrap	Ky.	Levisa Fork	130	395	Not started	126,000
Dewey	Ky.	Johns Creek	80	207	Completed	88,000
Sub-total				856		304,000
SCIOTO RIVER BASIN, OHIO (Drainage area 6,510 square miles. Joins Ohio River 356.5 miles below Pittsburgh, Pa. (Pool No. 31))						
Delaware	Ohio	Olentangy River	162	381	Completed	132,000
Big Darby	Ohio	Big Darby Creek	129	448	Not started	120,000
Deer Creek	Ohio	Deer Creek	107	278	Not started	97,000
Paint Creek	Ohio	Paint Creek	100	573	Not started	176,000
Rocky Fork	Ohio	Rocky Fork	107	115	Not started (a)	93,200
Sub-total				1,795		618,200
LITTLE MIAMI RIVER BASIN, OHIO (Drainage area 1,755 square miles. Joins Ohio River 464.1 miles below Pittsburgh, Pa. (Pool No. 37))						
Caesar Creek	Ohio	Caesar Creek	53	236	Not started	82,500
East Fork	Ohio	East Fork	31	340	Not started	151,900
Sub-total				576		234,400

APPENDIX - Pertinent Reservoir Data

Name of Reservoir	Location of Damsite			Net Drainage Area sq. mi.	Construction Status	Total Storage Capacity ac. ft.
	State	Stream	Miles Above Ohio River			
LICKING RIVER BASIN, KY. (Drainage area 3,672 square miles. Joins Ohio River 470.2 miles below Pittsburgh, Pa. (Pool No. 37))						
Cave Run	Ky.	Licking River	173	825	Not started	955,000
Falmouth	Ky.	Licking River	62	1,460	Not started	1,005,000
Sub-total				2,285		1,960,000
MILL CREEK BASIN, OHIO (Drainage area 165 square miles. Joins Ohio River 472.4 miles below Pittsburgh, Pa. (Pool No. 37))						
West Fork	Ohio	West Fork Mill Creek	18	29	Completed	11,400
Sub-total				29		11,400
MIAMI RIVER BASIN, OHIO AND IND. (Drainage area 5,385 square miles. Joins Ohio River 491.1 miles below Pittsburgh, Pa. (Pool No. 38))						
Brookville	Ind.	East Fork Whitewater River	32	335	Not started	150,000
Metamora	Ind.	West Fork Whitewater River	38	745	Not started	300,000
Sub-total				1,080		450,000
KENTUCKY RIVER BASIN, KY. (Drainage area 6,940 square miles. Joins Ohio River 545.8 miles below Pittsburgh, Pa. (Pool No. 41))						
Buckhorn	Ky.	Middle Fork	295	397	Not started	153,000
Booneville	Ky.	South Fork	262	697	Not started	485,000
Jessamine	Ky.	Kentucky River	136	3,526	Not started	1,135,000
Sub-total				4,620		1,773,000

APPENDIX - Pertinent Reservoir Data

Name of Reservoir	Location of Damsite: State	Location of Damsite: Stream	Location of Damsite: Miles Above Ohio River	Net Drainage Area sq. mi.	Construction Status	Total Storage Capacity ac. ft.
GREEN RIVER BASIN, KY. AND TENN. (Drainage area 9,220 square miles. Joins Ohio River 784.2 miles below Pittsburgh, Pa. (Pool No. 48))						
No. 2 Barren	Ky.	Barren River	229	941	Not started	1,266,000
No. 2 Green	Ky.	Green River	259	707	Not started	183,000
Nolin	Ky.	Nolin River	194	688	Not started	474,000
Mining City	Ky.	Green River	104	3,844	Not started	3,795,000
Rough River	Ky.	Rough River	160	449	Not started	312,700
Sub-total				6,629		6,030,700
WABASH RIVER BASIN, ILL., IND. AND OHIO (Drainage area 33,100 square miles. Joins Ohio River 848.0 miles below Pittsburgh, Pa. (Pool No. 50))						
Cagles Mill	Ind.	Mill Creek	289	295	Completed	228,100
Mansfield	Ind.	Raccoon Creek	268	252	Not started	47,800
Sub-total				547		275,900
CUMBERLAND RIVER BASIN, KY. AND TENN. (Drainage area 17,720 square miles. Joins Ohio River 920.4 miles below Pittsburgh, Pa. (Pool No. 52))						
Wolf Creek	Ky.	Cumberland River	461	5,810	Completed	6,089,000
Dale Hollow	Tenn.	Obey River	388	935	Completed	1,706,000
Center Hill	Tenn.	Caney Fork River	336	2,195	Completed	2,092,000
Stewarts Ferry	Tenn.	Stones River	213	865	Not started	723,000
Three Islands	Tenn.	Harpeth River	159	885	Not started	715,000
Rossview	Tenn.	Red River	143	925	Not started	372,000
Sub-total				11,615		11,697,000
Total - Ohio River Basin				53,796		31,638,500

(a) Construction initiated by State of Ohio.

OHIO RIVER VALLEY WATER SANITATION COMMISSION
AN INTERSTATE AGENCY
ESTABLISHED JUNE 30, 1948

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