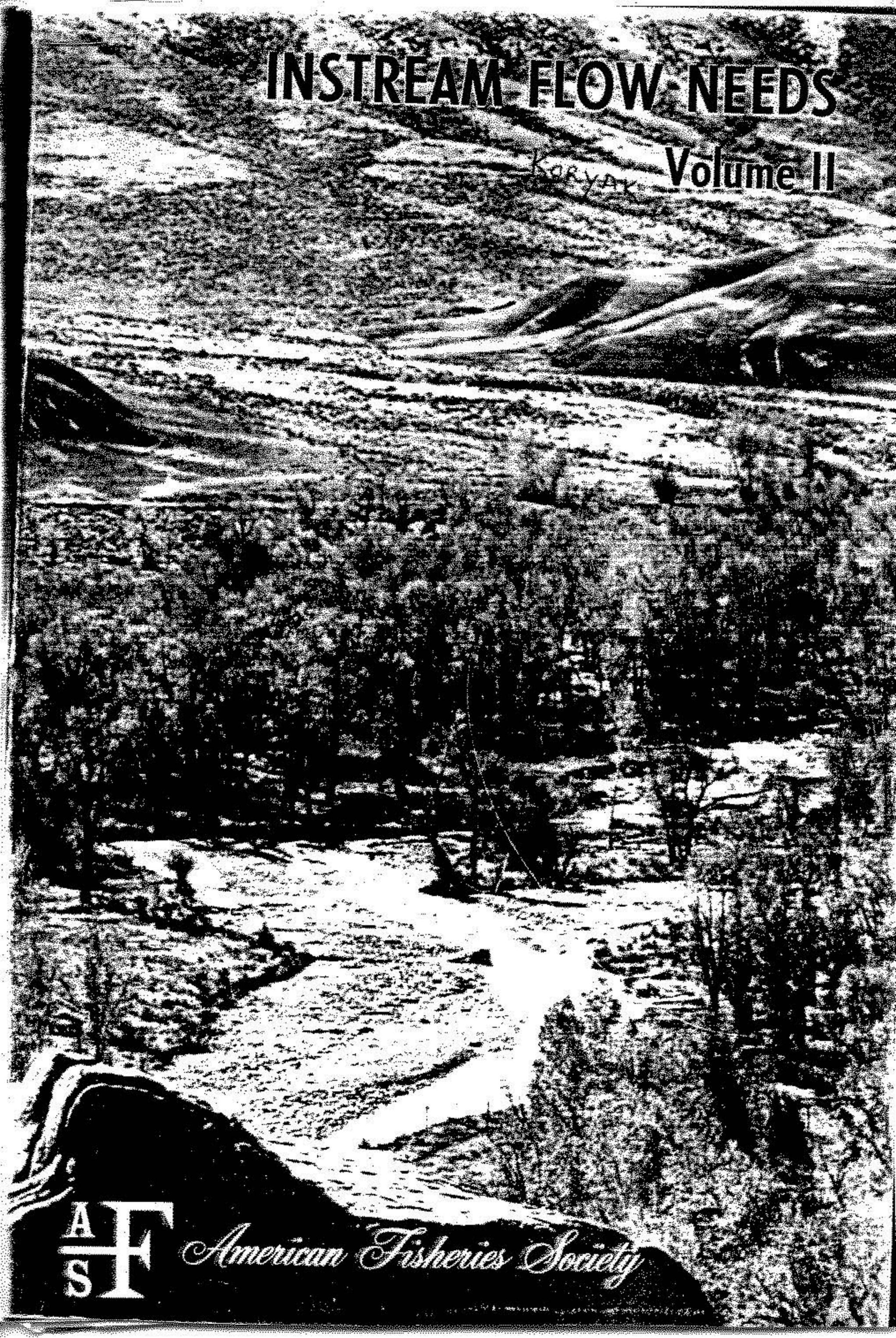


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THE INFLUENCE OF MAINSTEM
NAVIGATION DAMS ON WATER
QUALITY AND FISHERIES
IN THE UPPER OHIO RIVER BASIN

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ABSTRACT

The design and operation of mainstem navigation dams were found to significantly influence a number of physical, chemical and biological parameters. The effect of the mainstem projects on dissolved oxygen was the most dramatic.

Dissolved oxygen stratification can develop in navigation pools during low summer flows. Reaeration was observed downstream of navigation structures during high and intermediate flow periods. However, during low summer flow periods, dissolved oxygen depressions were created downstream of certain projects. Such depressions were noted below gated dams where the outlet sills are submerged in the receiving pool.

The greatest reaeration benefits achieved on the Upper Ohio River, where a dissolved oxygen problem exists, are at a gated structure with elevated sills and where water is discharged over step weirs. The reaeration potential of existing gated navigation structures is dependent on operational schedules during low flow periods.

INTRODUCTION

The first lock and dam projects on the Ohio River were completed in 1830. By 1929 the entire 981 mile length of the Ohio River had been pooled by a series of 46 mostly movable crest, low head navigation dams. In the mid-1950's a program was begun to modernize the lock and dam system. The new system, when completed, will consist of a series of 19 high-lift, gated navigation dams.

The purpose of this study is to evaluate the effect of existing and replacement slackwater navigation structures on water quality and fishery resources.

The Ohio River is formed by the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania. The study area is limited to the upper 130 mile long reach of the Ohio River and the entire Monongahela River. The Monongahela River is a major navigable tributary of

the Ohio River and like the Ohio River, the Monongahela River Navigation System is also in the process of being modernized. In 1974, when the study was initiated, there were 9 navigation dams on the Ohio River Mainstem within the study reach. At present there are 6 dams on the same reach of the Ohio River. On the 129 mile length of the Monongahela River there are 9 navigation dams. All of these navigation structures are under the jurisdiction of the U.S. Army Engineer District, Pittsburgh.

The flow in the Ohio River is extensively regulated and the effects of mainstem navigation projects on water quality is strongly related to flow. In the Pittsburgh District there are a total of 15 flood control reservoirs, 9 of which supply low flow augmentation. The system of Corps of Engineers' water resource development projects in the study area is shown in Figure 1.

Chronic water quality problems in the study area include serious domestic and industrial pollution in the lower Monongahela and upper Ohio Rivers. Acid mine drainage from bituminous coal mining operations is nearly a basin wide problem and previously, the Monongahela River was severely degraded by mine drainage. Considerable progress in pollution abatement has been made, but the amount of pollution from non-point sources in the study area is substantial and will remain a problem in the future.

METHODS

The study plan was to conduct intensive three dimensional sampling surveys of the Upper Ohio River and the Monongahela River during a wide range of flows. Sampling stations were established immediately above and below navigation dams, at mid-length in navigation pools and at other strategic locations, such as above and below major tributaries, cities and industrial areas. There are 53 stations on the Upper Ohio River and 45 on the Monongahela River. Nine of these are transect stations. At the transect stations sampling was at mid-channel, 1/4 point right bank and 1/4 point left bank. All other stations were located at midchannel. Vertical measurements of water temperature, dissolved oxygen, and conductivity were taken at the surface, three feet below the surface, five feet below the surface and then at five foot depth intervals to the bottom. Water samples for all other parameters were collected three feet below the surface and approximately three feet from the bottom.

In order to examine changes in the same approximate block of water as it progressed downriver, the sequence of sampling proceeded in a downstream direction.

Dissolved oxygen and water temperature were the principal parameters of the study. These parameters were measured in the field with a pressure compensated Yellow Springs Instrument Company Model 54 Oxygen Meter, connected by 50 feet of calibrated cable to a combined Y.S.I., dissolved oxygen, thermistor and mechanical agitator probe. Also attached to this probe assembly was a conductivity probe.

These probes were designed for limnological work. They are relatively lightweight and their resistance to even a low Ohio River flow makes accurate vertical sampling difficult. Therefore, it was necessary to adapt this equipment for sampling in flowing water.

Vertical measurements were obtained by lowering the probe assembly to the various desired depths along a plumb steel cable. The steel cable was weighted by a brass torpedo weight (Columbus-type) suspended just off the bottom. The probe assembly was attached to a one-foot long pipe section through which the steel plumblines had been threaded. Allowing some downstream drifting of the survey boat, a 30 pound weight was adequate for the highest flows encountered. Had sampling been conducted from stationary objects such as bridges, experience indicates that a 100-pound torpedo weight would have been necessary to get a plumblines to the bottom during the high flows.

Other parameters, besides dissolved oxygen and water temperature that were monitored in the study, include phytoplankton, aquatic vascular plants, phosphate, nitrate-nitrite nitrogen, Kjeldahl nitrogen, iron, manganese, lead, copper, zinc, chromium, sulfate, filtrable and non-filtrable solids, turbidity, color, conductivity, transparency, hardness, pH, alkalinity, acidity and flow. The results of rotenone sampling of lock chambers conducted cooperatively by the U.S. EPA, ORSANCO, the States of Pennsylvania, West Virginia and Ohio, and the U.S. Fish and Wildlife Service provided the fish data.

RESULTS

The results of this study indicate that navigation dams significantly influence the dissolved oxygen concentrations of the rivers they pool. In the following presentation the degree and nature of this influence under a variety of flow conditions, and how it varies with the design of the projects is discussed.

Figure 2 illustrates surface dissolved oxygen variations along the 130 mile long reach of the Ohio River below Pittsburgh, Pennsylvania at three different summer flows. A two dimensional profile of the low flow survey (10,000 to 13,000 cfs¹ variation along the study reach) is presented in Figure 3. The two dimensional profile shows the development of horizontally stratified patterns of dissolved oxygen distribution at low flow. This stratification was slight or nonexistent at the higher Ohio River flows.

As demonstrated in Figures 2 and 3, Montgomery Dam (Ohio River Mile 31.7) was the most efficient reaeration structure of the navigation dams examined on the Upper Ohio River. At a flow of 20,000 cfs the hydraulic structures of Montgomery Dam add at least 200,000 pounds of oxygen a day to the Ohio River. The direct influence of Montgomery Dam is measurable for more than 15 miles downstream (Figure 3). A less obvious effect of Montgomery Dam is that at low flows the supersaturated discharge is drawn largely from a low dissolved oxygen concentration stratum of the pool.

Montgomery Dam is a gated structure. Because the invert elevation of the outlets (fixed sill elevation 667 msl²) is 15 feet below the surface of Montgomery Pool, the stratum of water which is relatively low in dissolved oxygen during low flow stratification is evacuated from the pool. This water is then violently aerated when discharged into New Cumberland Pool (normal pool elevation 664.5 msl) over step weirs. Also, at Montgomery there are reaeration benefits from each overflow weir on either end of the dam plus turbulence from revised gate operations.

The revision of gate operations resulted from field observations at Montgomery Dam to determine the amounts of oxygen which could be added by

¹cubic feet per second

²feet above mean sea level

increasing discharges per gate at low flows by using fewer gates with larger openings. It was found that 1 gate open 2 feet provided 50 percent more oxygen than 2 gates open 1 foot. The additional oxygen was the result of induced turbulence from the gate operation.

The stepped weir configuration below the gates at Montgomery is always submerged except for the top step and probably would have been even more effective had it been constructed higher above the tailwater. A section of Montgomery Dam, along with typical sections of the other principal types of navigation dams in the Upper Ohio and Monongahela Rivers is shown in Figure 4.

As can be noted in Figure 3, another project with an extremely beneficial impact on the dissolved oxygen concentration of the Ohio River is Emsworth Dam at Ohio River Mile 6.2. Emsworth Dam is located in a section of the Ohio River where a sometimes severe oxygen sag is created by the contributions of oxygen demanding waste materials from the Pittsburgh Metropolitan area. Water from a lower stratum of Emsworth Pool is discharged over a sill that is elevated six feet above the receiving pool (Dashields Pool). The discharged water must pass over an apron at the toe of Emsworth Dam with an energy dissipating end sill. Considerable reaeration is achieved at Emsworth Dam, though it is probably not as effective a reaeration design as Montgomery Dam.

Likewise, the fixed crest Dashields Dam oxygenates the Ohio River. Reaeration at Dashields is apparently somewhat increased by a toe apron. Emsworth, Dashields and Montgomery Dams are strategically located. During the 10,000 to 13,000 cfs low flow survey graphically presented in Figure 3 they contributed 65,000, 30,000 and 97,000 pounds of oxygen a day respectively to the Ohio River. Individually and as a system, these three projects have an extremely beneficial effect on the dissolved oxygen concentration of the Ohio River at low flow.

It should be emphasized that while 10,000 to 13,000 cfs was the lowest Ohio River flow surveyed in this study, flows less than 10,000 cfs are not uncommon in the Upper Ohio River. The minimum mean monthly flow of record during the critical warm summer months at Emsworth (August 1930) was 1,284 cfs. Had low flow augmentation from existing storage reservoirs been available at that time, the mean monthly flow at Emsworth during August 1930 would have been 4,205 cfs. At 5,000 cfs dissolved oxygen

concentrations can be expected to be considerably lower than those measured in this study.

Dams number 12, 13 and 14 were movable crest or wicket dams that have been removed since the study was initiated in 1974. At higher flows the wickets were down and the river was free flowing. At lower flows when the wickets were up, aeration was only by impact turbulence. While the reaeration potential of impact turbulence alone is not great, dams 12 and 13 were strategically located around the Wheeling, West Virginia area where their limited reaeration was significant.

Reaeration was observed at New Cumberland, Pike Island and Hannibal Dams at high and intermediate flows, but at low flows these projects create downstream oxygen depressions. All three of these dams are gated structures. The discharge from both Pike Island and Hannibal is completely submerged and the sills of New Cumberland Dam are elevated one foot above the normal elevation of Pike Island Pool.

At higher flows, aeration at these projects is achieved by submerged discharge turbulence which creates a hydraulic jump. However this degree of turbulence does not occur at low summer flows, and low dissolved oxygen water from stratified upstream pools is discharged with very little reaeration.

The nine navigation dams on the 129 mile long Monongahela River were also evaluated individually and as one interrelated flow dependent system. Opekiska Dam is the only gated navigation dam with submerged outlets on the Monongahela River Navigation System. As was observed with similarly designed dams on the Ohio River, dissolved oxygen depressions occur downstream of Opekiska Dam during low flow periods.

A low flow (650 to 1,800 cfs) length-depth dissolved oxygen profile of the system of pools and dams on the Monongahela River is presented in Figure 5. As shown in this figure low flow dissolved oxygen stratification is extreme in Opekiska Pool. At higher flows, stratified distribution of dissolved oxygen was not evident in Opekiska Pool, but during the low summer flow survey shown in Figure 5, dissolved oxygen in Opekiska Pool decreased vertically from a maximum of 10.2 mg/l at the surface to a minimum of 0.1 mg/l at the bottom.

This extreme dissolved oxygen stratification was accompanied by well-defined thermal stratification as can be noted in Figure 6. Figure 6 shows

a two dimensional water temperature profile for the Monongahela River during the 650 to 1,800 cfs survey. Included in this figure are the locations of major tributaries and of all industries with an average withdrawal over 200 million gallons per day.

The invert elevations of the outlets of Opekiska Dam are 26 feet below the surface of Opekiska Pool. At this depth, during low flow conditions, water with a low dissolved oxygen content is discharged without sufficient reaeration to prevent a dissolved oxygen depression in Hildebrand Pool.

A stratified pattern of dissolved oxygen distribution was also apparent in Hildebrand Pool at low flow. The vertical dissolved oxygen profile varied from a maximum of 6.4 mg/l at the surface of Hildebrand Pool to a minimum of 3.9 mg/l at a depth of 29 feet. The "hypolimnetic" strata in Hildebrand Pool was largely contained below the invert elevation of the sills.

The outlets of Hildebrand Dam are elevated above the next receiving pool, Morgantown Pool, and reaeration from Hildebrand Dam was sufficient to mitigate the dissolved oxygen deficit that was originally created by the Opekiska Dam discharge. Reaeration at Hildebrand Dam may also be increased by dentated sills which flip the discharged water.

In general, with the exception of Opekiska Dam, either limited reaeration or no significant change was observed below all navigation structures on the Monongahela River at low flow. There are no exceptionally effective reaeration structures in this system. None of the Monongahela River projects demonstrated dramatic reaeration potential comparable to that observed at Montgomery Dam and Emsworth Dam on the Ohio River. Exclusive of design features, the low flow reaeration potential of navigation dams on the Monongahela River does not equal that of the Ohio River projects mentioned because of the difference in the hydrology of the two streams. The Monongahela River at base flow is a low yielding stream and the amount of augmenting storage on the Monongahela is very low compared to the overall augmentation available for the Upper Ohio River. During the relatively frequent periods that summer flows along most of the Monongahela River are less than 1,000 cfs, the turbulence of discharge from mainstem navigation structures is not adequate to produce reaeration benefits comparable to those achieved on the Upper Ohio River.

Several other parameters besides dissolved oxygen were found in this study to be measurably affected by navigation dams. Suspended solids, including suspended iron oxides, were found to partially settle in the long navigation pools with some mixing and resuspension below navigation dams. Decreases in total phytoplankton concentrations were observed below some of the gated projects at low flow. On the Monongahela River the basic design features of navigation dams were observed to effect the occurrence and distribution of vascular aquatic plants. In pools impounded by gated structures, which maintain a relatively stable pool elevation, submersed and floating-leaved macrophytes were prevalent. In those pools behind fixed crest dams where water-level fluctuations can be substantial, emergent aquatic plants were more abundant.

The effect of navigation dams on the mainstem fisheries of the Upper Ohio River Basin is complex. The pooling of the mainstems has apparently affected the composition of fish by creating an environment which is favorable to species such as the gizzard shad and the deep-bodied suckers. Except in relation to longterm trends, beneficial effects of storage impoundments are not easily identified because of gross pollution in the Pittsburgh area.

In 1962 the Ohio River Valley Water Sanitation Commission³ summarized lock chamber fish sampling results for the 100 mile section of the Ohio River below Pittsburgh as follows:

"The black bullhead⁴ contributed nearly a third of the total weight (32.2 percent), the emerald shiner 16.7 percent, the carp 11.6 percent, the skipjack herring 10.6 percent, and the gizzard shad 8.9 percent, for a total of 80 percent."

More recent studies indicate a qualitative and quantitative improvement in both the Upper Ohio River and in the Monongahela River. This

³Ohio River Valley Water Sanitation Commission. 1962. Aquatic-life Resources of the Ohio River. Cincinnati, Ohio.

⁴The species which was identified as the black bullhead (Ictalurus melas) in 1962 is now widely considered to be a local variation of the brown bullhead (Ictalurus nebulosus).

improvement has been dramatic in some reaches, however, considerably less significant improvement has been observed near the Pittsburgh Metropolitan area where substantial industrial and domestic pollution problems still exist.

DISCUSSION

It is a desirable goal to maintain the dissolved oxygen of navigable rivers at or above saturation levels. This would increase the capacity of these streams to assimilate waste discharges and therefore promote desirable forms of fish life and recreation and provide more acceptable sources of domestic and industrial water supplies. The utilization of navigation dams to assist in achieving this goal would be especially appropriate, as there is evidence that the pooling of a river decreases its waste assimilation capacity. For example, field studies on the pool above Markland Dam on the Ohio River have revealed that replacement of five original low-head wicket dams with the single large Markland Dam structure has decreased the waste assimilative capacity of the Ohio River about 30 percent in the Cincinnati reach of the pool⁵.

Increased low flow augmentation is one alternative for increasing the reaeration potential of navigation structures. This could involve both the regulation of systems of storage reservoirs to maintain flow and the coordination of navigation structures to gain the maximum advantage from available energy in terms of reaeration.

The operation of existing gated navigation projects can be revised to increase the discharge per foot of gate width by using fewer gates with larger openings. However, at many projects, restrictions imposed by stilling basin action, downstream riprap stability, currents, channel scour, available tailwater and other reasons may limit the operation to create turbulence for the sake of reaeration alone.

⁵Federal Water Pollution Control Administration. 1968. Investigations of Waste Assimilative Capacity of Markland Pool, Ohio River. Ohio River Division, Corps of Engineers, U.S. Army. Cincinnati, Ohio.

The problem can be most effectively approached in the design of new projects and the modification of old structures. When these projects are to be constructed on streams with recognized or anticipated oxygen deficiencies, significant water quality benefits could be realized at low additional costs by designing and incorporating aerating hydraulic structures. If this consideration is ignored, existing dissolved oxygen problems can be further aggravated, especially by the new gated structures.

ACKNOWLEDGEMENTS

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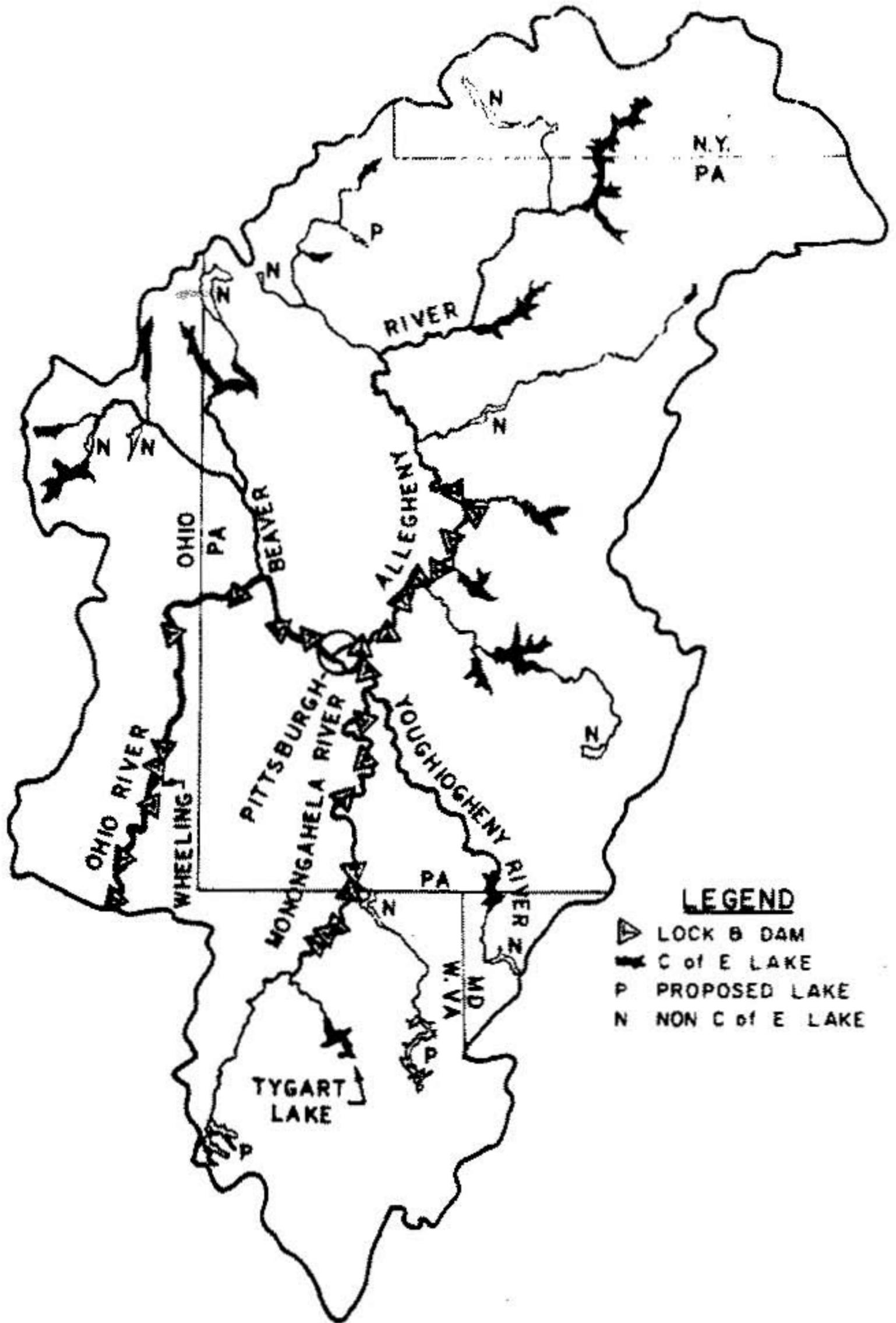


Fig. 1. Pittsburgh District Corps of Engineers System of Water Resource Development Projects

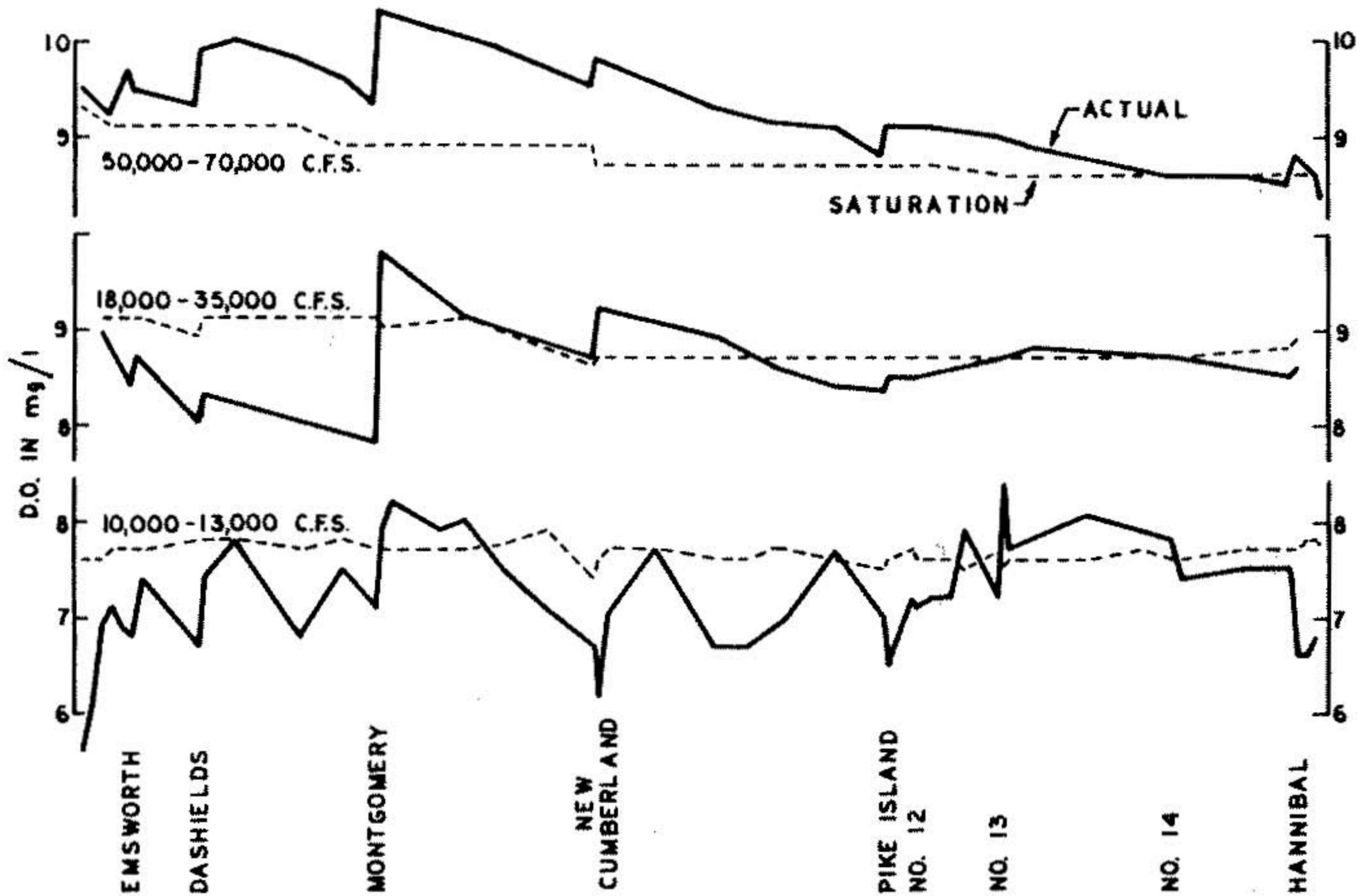


Fig. 2. Dissolved Oxygen Variation in the Ohio River from Mile 0 to Mile 130 at Three Different Summer Flows

EACH ISOPLETH REPRESENTS A 0.5 mg/l DO. INCREMENT

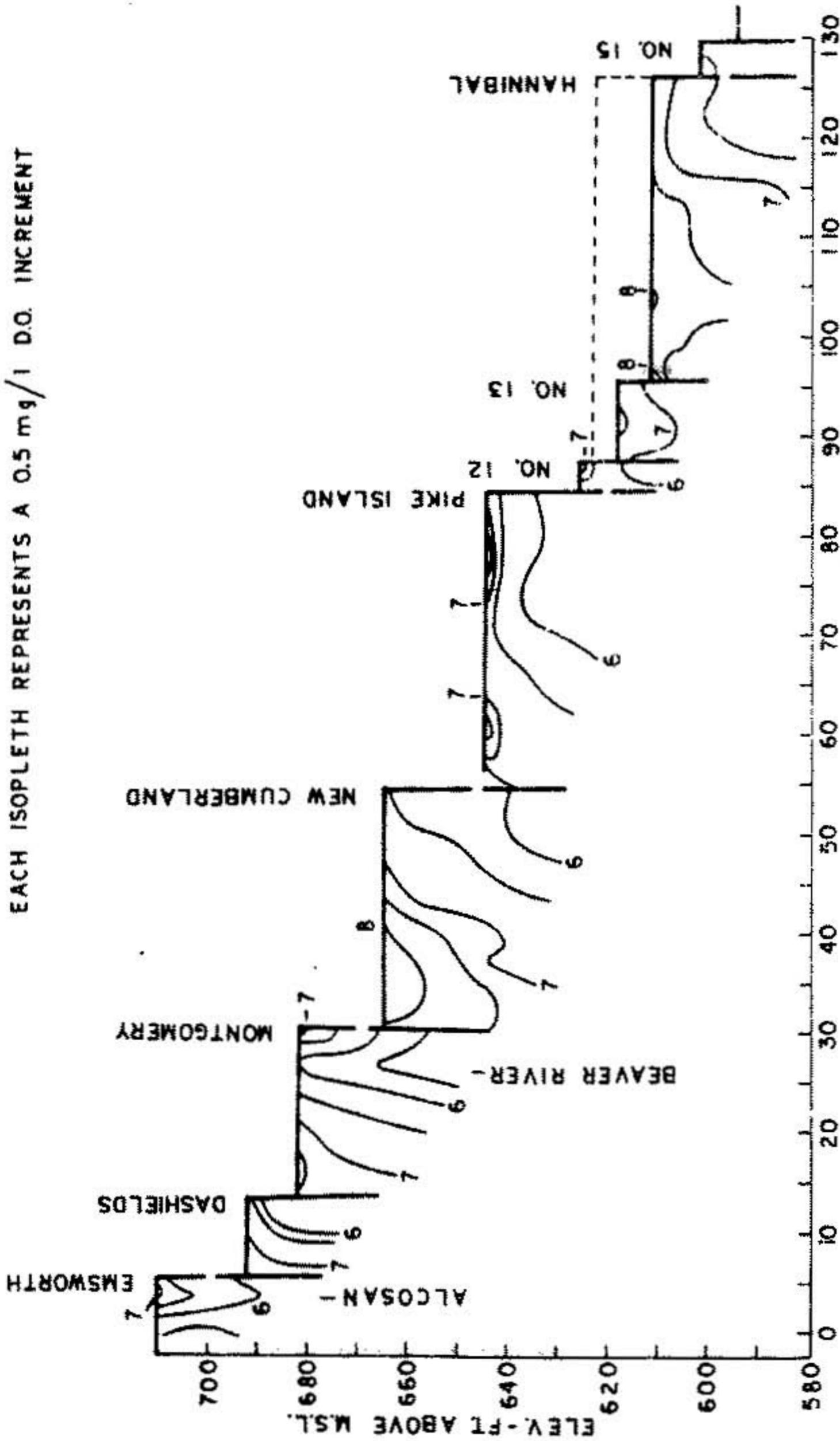
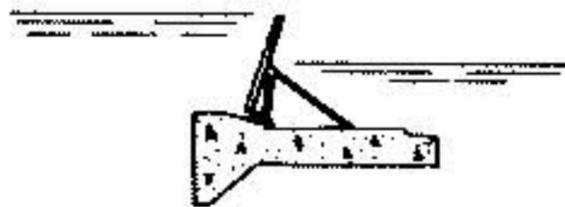


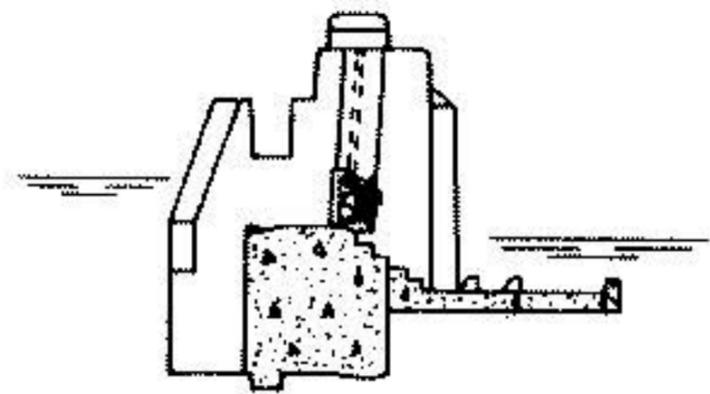
Fig. 3. Length-Depth Dissolved Oxygen Profile of the Upper Ohio River at a Low Summer Flow, 10,000 to 13,000 cfs.



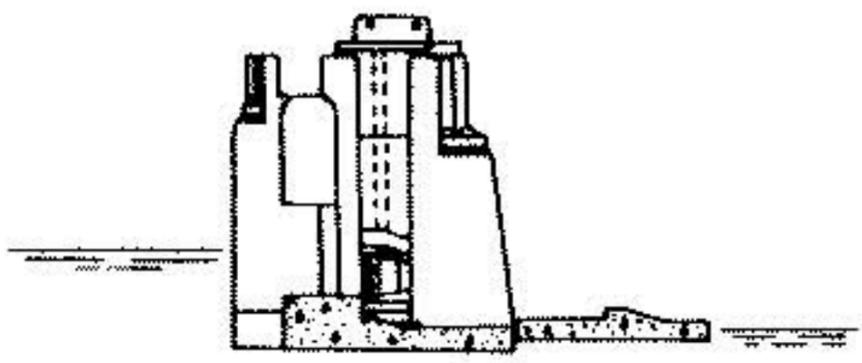
LOCK & DAM 12
WICKET



DASHIELDS
FIXED CREST

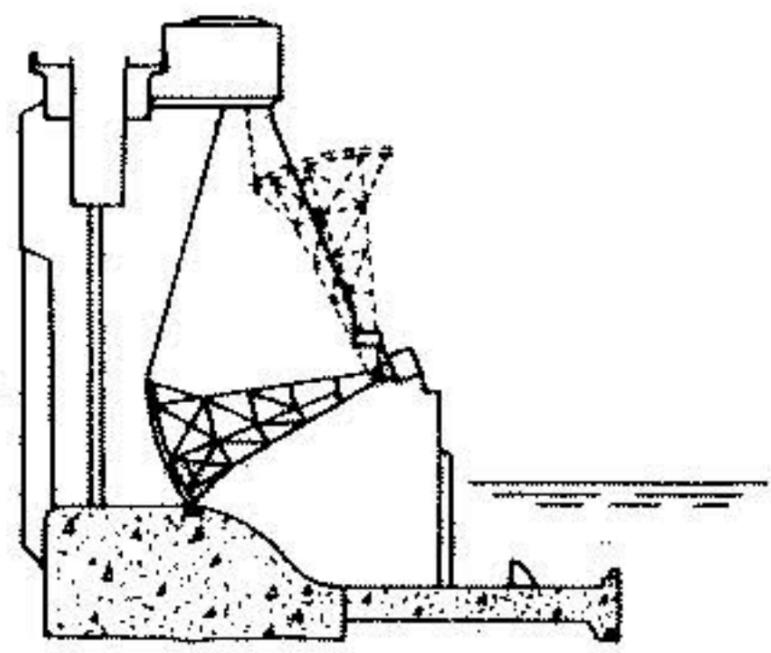


MONTGOMERY



EMSWORTH

THREE TYPES OF GATED STRUCTURES

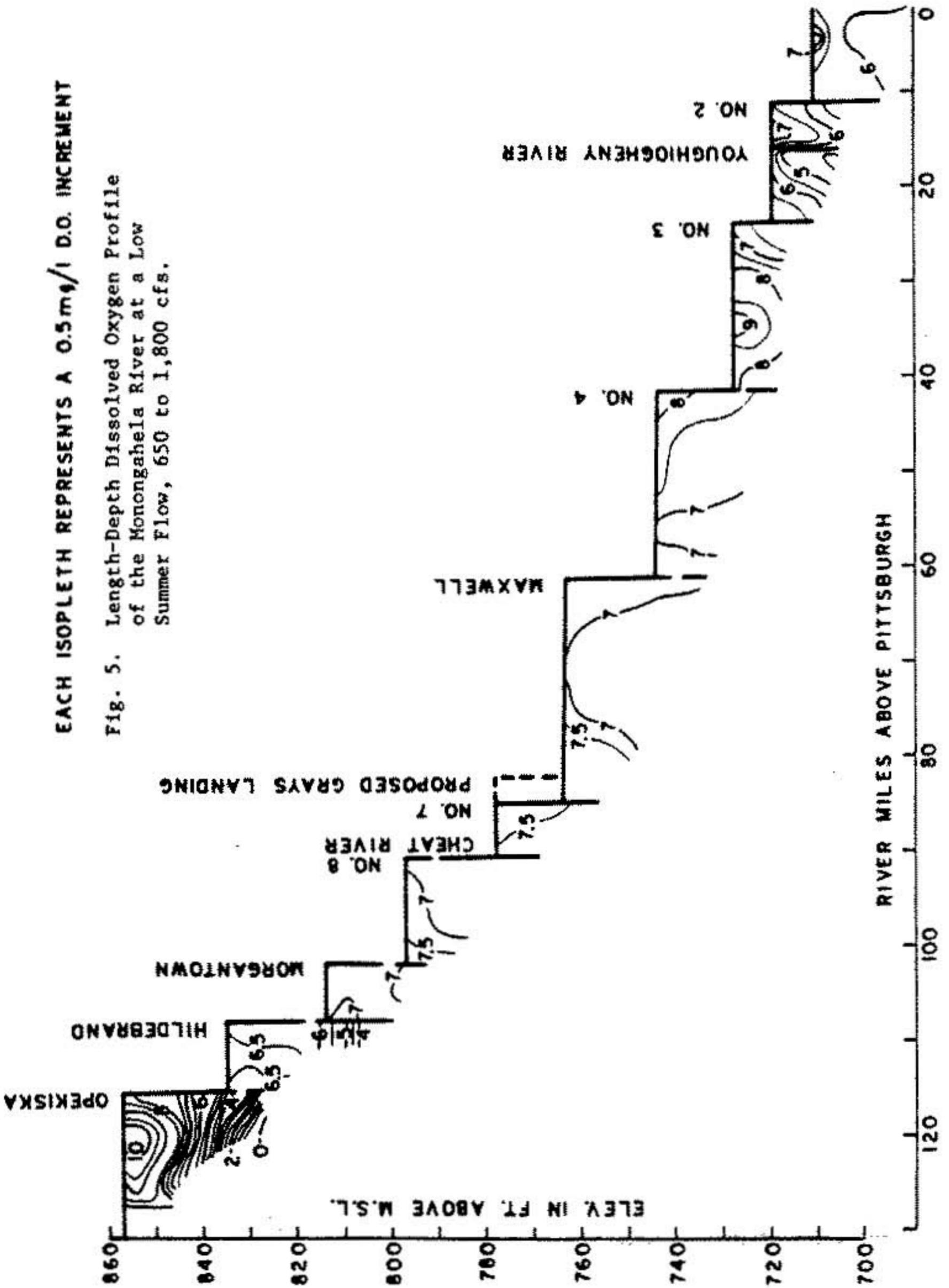


HANNIBAL

Fig. 4. Typical Sections of the Principal Types of Navigation Dams in the Upper Ohio River Navigation System.

EACH ISOPLETH REPRESENTS A 0.5 mg/l D.O. INCREMENT

Fig. 5. Length-Depth Dissolved Oxygen Profile of the Monongahela River at a Low Summer Flow, 650 to 1,800 cfs.



EACH ISOPLETH REPRESENTS A 1.0°C W.T. INCREMENT
 *THE LOCATIONS OF INDUSTRIES WITH AN AVERAGE WITHDRAWAL OVER 200 MGD ARE INDICATED.

Fig. 6. Length-Depth Water Temperature Profile of the Monongahela River at a Low Summer Flow, 650 to 1,800 cfs.

