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DEPARTMENT OF COMMERCE  
BUREAU OF FISHERIES  
HUGH M. SMITH, Commissioner

WATER-POWER DEVELOPMENT IN RELATION  
TO FISHES AND MUSSELS OF  
THE MISSISSIPPI

By ROBERT E. COKER

*Director United States Biological Station  
Fairport, Iowa*

APPENDIX VIII TO THE REPORT OF THE U. S. COMMISSIONER  
OF FISHERIES FOR 1913



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# WATER-POWER DEVELOPMENT IN RELATION TO FISHES AND MUSSELS OF THE MISSISSIPPI.<sup>a</sup>

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## INTRODUCTION.

Begun in January, 1911, and practically completed in June, 1913, the dam on the Mississippi between Keokuk, Iowa, and Hamilton, Ill., is not only an eminent feat of engineering and of efficient and expeditious construction, but it marks an epoch in man's utilization of the greatest North American river. Two hundred thousand horsepower are made available for commercial uses, 65 miles of water deep enough for unimpeded navigation is provided above the dam, and a single lock of the high lift of 40 feet replaces a navigation canal and chain of three locks formerly necessary for the passage of the Des Moines rapids of the Mississippi, now deeply submerged beneath the waters of Lake Cooper. Substantial public benefits are combined with the execution of such an enterprise.

This unique water-power development will have a great significance for the fisheries of the upper Mississippi, not only in the possible checking of the upstream movement of migratory fishes, but in the large area of lake waters it provides through the submerging of former dry land and the backing up of small tributary creeks. It is important to point out the significant advantage to fish and mussel life of the great additions to the feeding and breeding grounds covered by comparatively still water; it is also necessary to call attention to the probable deleterious effect of the dam as an obstruction to the free movement of fishes from the lower river to the upper, and vice versa. How advantage and disadvantage, as regards fish life, are to balance against each other in the future is not to be foretold. Time and observation alone will show, but it is the purpose of this report to present and to analyze the conditions offered by the dam, and to point out the opportunities and the importance of subsequent observations, as well as to offer certain suggestions for the minimizing of harm and the increase of benefit.

It is hoped, too, that the report may serve the broader purpose of pointing out the complexity of the problems involved in the effect of water-power development upon fisheries and of bringing out, even if inadequately, the opportunities and the fundamental necessity of

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<sup>a</sup> The illustrations in this paper are published by courtesy of the photographer, Mr. Anschutz.

a study, not only of fishways, but also of the migratory habits of fishes. There is no view that power development should be sacrificed to fisheries, but we are shortsighted, indeed, if we do not give thoughtful consideration to minimizing any possible sacrifice to fisheries that such developments may entail and to enhancing such advantages as they may afford. In all the active discussion of water-power problems there is almost a painful absence of reference to the fisheries aspects, notwithstanding that the food produced by the American fresh-water fisheries amounts to upward of 330,000,000 pounds, with a value to the fishermen alone of more than \$12,000,000 and a value to the consumers far exceeding this amount.

#### NEW CONDITIONS AND PROBABLE EFFECT UPON MOVEMENTS OF FISHES.

The writer approaches this inquiry with the conviction that the measure of importance of the fisheries of the Mississippi is not found in the existing state of the fishery.<sup>a</sup> The possibilities of the fisheries of the Mississippi and other great rivers will be realized only in the future, near or remote, when, under the pressure of economic conditions, and with the illumination of a more adequate knowledge of the needs of fish life, fish conservation will be more of an actuality than at present. We will then not only comprehend the essential importance of conditions favorable to the development of fish food and to the natural propagation of fishes, but we will know how to supply the necessary conditions. The further belief may be expressed that the future will show that Lake Cooper, as the large body of repressed water above the Keokuk dam is now known, will prove to be an important factor in supplying such conditions and possibly may rival Lake Pepin of the North by offering so large an acreage, or mileage, of comparatively still water provided with shoals and bays sure to be replete with vegetation, and practically free from the deleterious conditions incident to the excessive rise and fall characteristic of ordinary river conditions.

It is one of the tragedies of fish life, catastrophic in degree at times, that the spawning grounds may be found during spring floods far from the main course of the river, where an untimely recession will leave a generation of young fish isolated in some overflow pond, and marked for destruction unless reclaimed by the agency of Government or State. Such fish destruction is evident, and of common knowledge but that which occurs when the flood stage comes late and after the fish have found nests in the originally shallow waters of the river banks at low stage, can only be guessed at. Accordingly, the significance of the interpolation in the course of a great river,

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<sup>a</sup> The fisheries of the Mississippi River and its tributaries yielded in 1908, as shown by the census report, food products of a value well upward of \$2,000,000.

whether by natural or artificial means, of an immense pool, where practically fixed and dependable conditions can be found, is not to be lightly esteemed.

It becomes of greater importance that the possible disadvantages incident to such an interpolation should be eliminated as far as possible. Lake Pepin of the upper Mississippi, a virtual lake of natural origin, is a great natural fish reserve into and out of which fish may proceed at will at either end. Lake Cooper of the middle region of the Mississippi is an artificial lake into and out of which fish may pass unchecked in only one direction.

Any student of fisheries will at first glance make a further comparison of these two expansions of the Mississippi. The body of Lake Pepin has a comparatively straight shore line and in some places is bounded by steep bluffs; there is a relative absence of slues and shallows favorable for aquatic vegetation. Above and below Lake Pepin, however, there are many slues and bayous which offer favorable conditions for the breeding of fishes, and undoubtedly the fish life of the lake is continually replenished from these sources. Lake Cooper, on the other hand, has few bluff shores, and throughout its course, except very near Keokuk, there are many favorable bayous, creeks, and expansions over former agricultural or swampy flats. As regards the proportion of deeper waters preferred by some species of fish, the two lakes might compare more closely, except that the deep water in Lake Cooper is at one end and is less extensive.

The relation of such developments to mussel life may be briefly explained. The very young fresh-water mussels, with rare exception, when first liberated from the incubation pouches of the parent, must become parasitic upon fishes in order to pass through the next stage of their existence. To this end, if the chance offers after liberation, the young mussels, or glochidia, as they are called in this stage, attach themselves to the gills, fins, or scales of a fish. The mussels of economic importance attach themselves almost exclusively to the gills. In attaching or biting on the fish a very slight wound seems to be caused, which begins at once to heal over; but in the process of mending, the glochidium is overgrown and thus inclosed within the tissues of the fish. The mussel is now actually an internal parasite, in which condition it remains for a period of two weeks, more or less. It is thus conveyed wherever the fish goes, until, when the proper stage of development is reached, it frees itself from the host and falls to the bottom; if through a favorable fortune it finds suitable lodgment, it continues its growth to form an adult mussel. Owing to this fact of active transportation by the fish, a mussel born of parents in one part of the river may conclude its development in another region, even at points far upstream



from the parent bed or perhaps in some tributary stream that the fish host may have entered.

Investigations carried on by the Bureau during recent years have shown that mussels do not necessarily attach to fish indiscriminately, but that a given species of mussel may make use of only certain species of fish, as the pimple-back mussel (*Q. pustulosa*) seems to be generally restricted in parasitism to certain species of catfishes, and, a more striking instance, the niggerhead mussel (*Q. ebena*) restricts itself so far as is known to the river herring, or blue herring, *Pomolobus chrysochloris*.<sup>a</sup> Conditions, therefore, which affect the movements of the river herring or the catfish may vitally affect the welfare of these important mussels.

It is not here simply a question of whether mussels will be transported from below the dam to the waters above, but, if the river herring is a truly migratory fish, going down the river in the fall and ascending again in the spring, and, if its course is so checked by the interposition of a dam that comparatively few find the way into the upper river, two results will follow: The fish will become a rare species in the upper river, and the future generations of niggerhead mussels will so generally fail of finding attachment to the only suitable fish, that successive broods will perish, until, with the ultimate death or capture of the old mussels, the species will become extinct in that portion of the river lying above Keokuk; that is to say, in practically the entire Mississippi, for the mussel resources of the Mississippi proper (tributaries excluded) are exceedingly limited south of Keokuk.

On the other hand, it is not to be lost sight of that the flood region of the repressed water will make available new bottoms for clam beds. The future condition is not to be predicted. None of the existing bottom of the new lake is definitive. Bottoms now covered with former land vegetation will acquire a new character in time as they are covered with silt or stream-washed sand. The old channel itself, no longer washed as before by active stream action, will undergo changes. The Des Moines Rapids was formerly the home of abundant niggerhead shells of particularly good quality, which could readily be taken from among the rocks. Deeply submerged as these beds now are, it will be scarcely possible to obtain the mussels. The gradual accumulation of silt over and among these rocks will probably make conditions unfavorable for this species, although other beds of different species may be expected to be formed

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<sup>a</sup> In some publications the name "skipjack" is applied to this species. Except as derived indirectly from books, that common name does not seem to be applied to this species by local fishermen. The name "skipjack," in fact, seems generally to be appropriately applied to the gizzard shad, while the *Pomolobus* is generally and very appropriately designated as the "river herring," local fishermen having correctly recognized its close relationship to the true herrings. It has been learned, however, that the Ohio shad (*Alosa ohioensis*) is not regularly distinguished by fishermen from the river herring. To avoid further confusion the use of the term "skipjack" as applied to *Pomolobus* should be discouraged.

in other parts. A river-lake<sup>a</sup> fauna of mussels may replace a strictly river fauna. Should Lake Cooper eventually rival Lake Pepin—a condition scarcely to be hoped for—it will be one of the most important mussel regions of the country, supporting a mussel fishery exceeding anything known in this territory before.

In concluding this introduction, certain salient points which have been brought out or implied merit a particular emphasis.

(1) While the value of the dam will never be measured by its relation to the fishery, the effects, both direct and indirect, will be of exceptional interest and importance. There will be advantage not unmixed with disadvantage.

(2) There is a possibility worthy of serious inquiry that some provisions may be made to lessen the incidental injury to fish life.

(3) The dam will afford a unique opportunity for the study of the movement of fishes in the river, if systematic and continuous observations be undertaken in the early spring and continued through the summer.

(4) The new-formed lake offers an equally unique opportunity for the study of the development of the proper biological conditions for fish life. It would be not only a fascinating study, but one of most vital significance, to trace the development of this lake from a condition of infancy to one of maturity, were there available the means necessary for such an investigation.

(5) The opportunity afforded by this new body of water brings the responsibility of taking definite measures for stocking it with suitable fish and mussels; and scarcely less important is the introduction of suitable aquatic vegetation which otherwise, as our experience at Fairport indicates<sup>b</sup> will be slow to find a desirable development.

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<sup>a</sup> By "river-lake," I mean such a body of relatively still water as would ordinarily be called a lake, which is yet intimately connected with a river, either as interpolated in the course of the river, or as an arm of a river. The conditions in a body of this kind may be characteristic. With the opportunity for the internal circulation, plankton conditions and community life, corresponding in some degree to typical lakes, there are combined in a measure the features of circulation and regular renewal of water corresponding more nearly to usual river conditions. Illustrations are Cross and Pokegama Lakes in Minnesota, Lake Pepin and Lake St. Croix, and in a smaller way, Rice Lake at La Crosse, Wis., which is between the Mississippi and Black Rivers and connected with both. Lake and river faunas are generally quite distinct in character. In fact, it is rare for a lake to yield commercial mussels. In the instances just mentioned we find, however, characteristic river mussels, and, what is more striking, we find that a species such as the so-called fat mucket (*L. luteola*), which is generally abundant and worthless in true lakes, is in these river-lakes abundant and valuable—that is, it has a shell of such thickness and form as to be exceptionally useful for buttons. The adaptations of this species is an interesting chapter in itself. No other species of mussel is so generally worthless and, at the same time, so exceptionally valuable and abundant in particular regions. Are its good qualities attributable to the unusual combination of river and lake conditions, or are they characteristic of a geographic region? Will the same species attain importance in Lake Cooper? When the latter question is answered, as it will be in course of a few years, the answer to the former question will be supplied at the same time.

<sup>b</sup> The Bureau through the Fairport station has already made some plants of fish and mussels, and since this paper has gone to press has undertaken a preliminary study of the plankton of portions of the lake with a view of tracing in this and subsequent years the development of the content of fish food. Further observations are inserted in another portion of the paper.

(6) The lessons which can be learned at Keokuk, if the opportunity can be availed of, will be of far-reaching importance as supplying a basis of information for guidance in future developments upon the Mississippi or upon other rivers.

#### PRELIMINARY OBSERVATIONS.

In June, 1913, it was brought to the writer's attention that the Keokuk dam was being filled with water and, therefore, that a portion of the river bottom below the dam might be exposed for observation. The idea immediately occurred that the practical stoppage of water during the process of filling might cause the congregation of large numbers of migratory fish below the dam, including the river herring which had for some time been sought without success both at New Boston and at Fairport. Mr. Thaddeus Surber, being then engaged upon the investigation of the river herring, was therefore advised to proceed to Keokuk in the hope of finding the desired fish and of securing needed mussels if beds were indeed exposed. The expectation in regard to the fish was fully realized. The fish which had been sought fruitlessly at Fairport and New Boston were found abundantly immediately below the dam.

After an inquiry from the Mississippi River Power Co. regarding the movement of fish, a second visit by Mr. Surber was made July 10 and 11. He reported almost incredible numbers of fish lying just below the dam, large numbers of which were being caught by local residents using hook and line, dipnets, hay forks, etc. During this visit the gates were closed on the Illinois end of the dam, thus leaving the new bed of the river fully exposed where previously there had been water 3 to 6 feet deep. Vast numbers of fish were left stranded and struggling about in the little pools among the large stones, and people from both sides of the river were reaping a harvest, some with gunny sacks filled, others with the larger fish slung on poles, while others still were contented with long strings of fiddlers, sheephead, etc. He estimated that  $1\frac{1}{2}$  tons of fish were removed in the course of a couple of hours.

Below the dam on the 10th and 11th the following fish were observed, given in order of their abundance: Buffalo, carp, paddlefish, sturgeon, sheephead, fiddlers, redhorse, bluefish (*Cycleptus*), toothed herring, and hickory shad. Very few bass and crappie were taken, though they were reported to be unusually abundant; no *Pomolobus* at all were secured, and, according to local informants, none had been taken for several days previously.

I visited the dam September 22 and 23 and again October 11-15, 1913. The administration of the company courteously granted passes for examination of the dam and its works and extended all



information requested. The lock was also operated for purpose of demonstration.<sup>a</sup>

#### DESCRIPTION OF THE KEOKUK DAM.

The figures and essential data regarding the construction plan are largely gleaned from a lucid description of the dam comprised in a booklet entitled "Electric Power from the Mississippi River" and issued by the Mississippi River Power Co., at Keokuk in 1912 and 1913.

The plant consists of the following principal elements (see pl. II): A dam proper, 53 feet high over all and four-fifths of a mile long, extending across the Mississippi from the Illinois shore at Hamilton and connecting at its western end with the power house, which is built in the river several hundred feet from the Iowa shore; the power house has its length almost parallel with the river shore, extending in a downstream direction from the terminus of the dam proper, and is practically one-third of a mile in length, over 132 feet wide, and with the great height of 177 feet 6 inches or from 25 feet below the surface of the limestone river bottom to nearly 110 feet above the surface of the lake at high water; the lower end of the power house (one-third of a mile below the dam) is joined to the Iowa shore by a series of constructions, including a section of dam about 100 feet long, which provides a narrow chute and houses the machinery for operation of the lock and dry dock, the lock 110 feet wide and 400 feet long, inside dimensions (618 feet over all), and the dry dock, 150 by 463 feet.

It thus appears that a bay or harbor of considerable size is formed between the power house and the Iowa shore, limited on the lower side by the lock and dry dock. This is called the fore bay and is protected on its upper side by a curved ice fender composed of concrete arches in a series 2,325 feet long and 300 feet of floating boom which may be opened back during the navigation season. It extends from the upper eastern or offshore corner of the power house (that is, from the western terminus of the dam) to the Iowa shore, the direction being somewhat curved, and the total length about half a mile.

The parts which are of immediate interest to us are the dam, the power house, and the lock.

#### THE DAM STRUCTURE.

The dam proper is merely for the repression of water and the provision of spillways. It is 4,278 feet long, or, with its abutments, practically 1 mile. (Pl. II.)

<sup>a</sup>I desire to acknowledge the courtesy of Maj. M. Meigs, United States engineer, who extended me the privilege of examination of the lock and facilitated my investigation in other ways.

The dam structure is composed of 119 spans, each consisting of two piers supporting an arch, which upholds a causeway. Between the piers is placed in each span a section of spillway, the part over which the water flows. This bridge-like structure, with the water flowing over the spillway sections, extends from the Illinois bluff, to which it is tied by an abutment, across the river to the upper outer corner of the power house on the Iowa side, to which it is tied by another abutment.

The piers are 6 feet thick, and the distance between piers—that is, the width of each of the 119 spillway sections—is 30 feet. The height of spillways is 32 feet. The upstream face of each spillway section is vertical, the downstream face having a curve designed to conform to the under surface of a body of water of this size and depth running over a vertical obstruction to the current; the spillway face is made to fit the under surface of the water to avoid friction as much as possible; the curve of the downstream face delivers the water in a horizontal direction down the river. (Pl. II.)

The stream over the spillway has a depth between 7 and 11 feet. We thus have at each spillway in use an unretarded waterfall of considerable volume with an abrupt drop of 32 to 40 feet, deflected only at the bottom, where it shoots out among the rocks with immense force in the form of a raging, foaming torrent, dashing against the rocks with indescribable commotion. For the protection of the base of the dam from the erosion due to back currents, a broad, low concrete apron is now being laid to flank the dam on its lower side. It would be impossible for a fish to ascend such a fall from below, or even, in all probability, to pass downward through it and escape alive. This is inevitable to the existence of such a dam, so that the opportunity for fish passage must be sought elsewhere.

Between the top of each spillway and the lower side of the overhanging causeway is an arched opening about 19 by 30 feet which will permit the passage of ice and drift with the water. These openings are partially closed by steel gates, 11 by 32 feet, which work in deep slots in the concrete and serve to control the head within certain limits, as well as to regulate the flow to conform with the minimum requirements for navigation as determined by the Government.

The dam proper is not at right angles to the course of the river below but has a slight downstream direction from east to west, so that the upstream end of the dam structure, as of the entire plant, is on the Illinois side. In ordinary times only a few of the spillways are in use simultaneously, so that the main stream of the river so far as it is determined by the flowage over the spillways—the waste water, so to speak—may be changed at any moment from one side of the river's course to the other through a distance of nearly a

mile. (Pl. II.) In practice it is found necessary to be continually changing the gates in order that all may be in perfect order and no risk be run of any gate sticking or failing of operation at a critical time. The gates are raised or lowered by traveling cranes and require about 13 minutes to lower.

Accordingly, as regards those fishes which are seeking an upstream destination, so far as their course may be determined by the spillway current, they will be directed toward the foot of the dam or to the outskirts of a small sea of raging waters (at one side or the other, or midway of the river), where in any case they are confronted by an impassable barrier. If the stream is suddenly changed by the closure of gates at one place and opening of others in another part, the fish may be left in enormous quantities in the suddenly isolated pools among the rocks, where they are at the mercy of those who would capture them. Just this condition has occurred on some occasions when fish could be taken with clubs and hay forks or with any convenient tool. This condition is more or less inevitable, but its recognition may serve to suggest the necessity for care that the condition be not caused unnecessarily. In any case stringent measures should prohibit the slaughter of these fish and provide for their rescue and restoration to the river. It is probably within the province of the Government, in conjunction with the power company, to prevent the wanton destruction of the fish left suddenly helpless under an emergency condition.

#### THE POWER HOUSE.

The power house is of great importance, not only as the actual seat of the machinery which converts water head into power in utilizable form, but as the place through which there will always be passing a considerable quantity of water. (Pl. III.) The spillways of the dam, it will be understood, serve only to supplement the flow of water through the power house, taking care of the elements of fluctuation in the volume of the river and of variability in the use of water for power.

The power house is not alongshore, but arises out of the body of the lake, as it were, forming the eastern boundary of the fore bay, for about one-third of a mile (pl. I.) Its exact length as designed is 1,718 feet, but only one section equal to one-half of this length is now completed. The foundation walls of the entire building are, of course, in place as an essential part of the dam as a whole. The outside wall of the building toward the Iowa shore is not built solid to the bottom, but is supported on a series of arches, so that the water from the fore bay has free access to an inner or head bay within the building and extending its entire length. The outer wall of the building, facing the Illinois shore, rises from the downstream



bed of the river and is flanked by the tail-race or tail-bay, an important feature for our consideration. Between the head-bay and the tail-race intervene the turbines or power units, of which there are now 15 installed and 15 more in contemplation. These are arranged in a single linear series from the upper to the lower ends of the house.

The water from the head bay is admitted to each turbine through four gates, each 22 feet high by 7 feet 6 inches wide, the opening being protected by coarse screens or iron gratings, which exclude the passage of large drift, but are not fine enough to prevent the passage of any but the largest fish; the openings between bars of the gratings are 6 by 23 inches. The four intake passageways are of a special design and converge into a single large scroll chamber 39 feet in diameter around the turbine. Other gates or guide vanes at this place control the passage of water into the turbine chamber, whence, after setting the turbines in motion, the water passes down through the enlarging draft chamber out into the tail-bay below. The draft chamber is circular at its upper end just below the turbine, where it is 15 feet in diameter, or about 2 feet greater than the diameter of the water passage through the turbines. At once, however, it begins to enlarge in diameter and take a curved form by which it changes direction from the vertical to the horizontal and changes from a circular to an oblong shape in cross section. The outer openings of the draft tube below are 22 feet 8 inches in vertical diameter and 40 feet 2 inches in horizontal diameter. The bottom of these openings and the bottom of the tail-race is about 25 feet below the bottom of the Mississippi.

Between the head-bay and the tail-race there is normally a head of 32 feet. It is calculated that the velocity of the water at the top of the draft tube, immediately under the turbine, will normally be 14 feet per second, or 9 miles per hour, while at the point of discharge into the tail-race it will be 4 feet per second, or less than 3 miles per hour. The water in the tail-race itself may have a greater velocity.

It has been complained that many fish are destroyed by the turbines. It is possible that descent through the turbines would be fatal, but it is scarcely conceivable that fish in course of ascent would reach the turbines. It is to be remembered that the water passes the turbines in course of a vertical descent of 32 to 40 feet with greatest velocity where the turbines intervene. It is hardly possible that fish would successfully breast a vertical current of such force. It is not generally the swiftest fish that seek the darkest passageways. The blades or buckets of the turbines, of course, though revolving at high speed, are not slashing through the water as the uninitiated might suppose, but are driven before the water. Assuming, therefore, that a fish could make the tortuous passage from tail-race to head-bay against the velocity of the water, the tur-

bine buckets would probably interfere less with its course than the solid walls that confine the water.

There are not infrequent reports of the finding of specimens of the spoonbill-cat or paddle-fish below the dam, with the spoonbill cut or broken clean off. Such injuries are attributed to the blades of the turbines, but the reports have not been as yet of such frequency as to indicate any serious degree of damage.<sup>a</sup>

The bottoms of the lower openings of the draft tubes are 25 feet below the natural bottom of the Mississippi. (See p. 14.) The tail-race is excavated to a corresponding depth from the upper end of the power house down to the region of the lock below. This is, for our purpose, one of the most significant features of the dam. The tail-race constitutes a narrow but deep channel, through which the water used in the power house is conveyed downstream to join the natural main channel of the river on the Iowa side near the bridge. The remainder of the river bed conveys, besides an overflow from this tail-race, only the spilled water from the dam, which may at various times be greater or less than the flow in the tail-race, according to the stage of the river above. It may be imagined that at the ultimate development of the plant the amount of water used regularly in the power house will be approximately equal to the minimum low-water volume of the river, since the storage capacity of the lake is not considerable as compared with the size of the plant.

Not all of the water from the draft tubes will follow the direct course, for the channel is not strictly confined, and a considerable surface current will always overflow from the tail-race toward the body of the river. At the time of this writing (October, 1913) the tail-race is to a considerable extent confined by the old cofferdam; but it is probable that this will be blasted out, permitting more extended lateral overflow. There will always be a strong flow of water in the tail-race corresponding at least to the volume of water required to supply the minimum demands of power. There will probably be little fluctuation of current from day to day at corresponding hours except with seasonal changes of lighting demands, but there will be a regular ebb and flow (considering the tail-race only) in the course of each 24 hours, since the use of electrical power is usually least during the early hours of the morning. This variation is very carefully watched by the company, so that it may be compensated by opening or closing gates over the spillways of the dam to minimize the effect on navigation in the river below.

The tail-race is the one perpetual passageway for water below the dam, and it is of interest to inquire in a later paragraph if the fish which may be attracted against this current may not be deflected by some simple means toward the only avenue of escape into the

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<sup>a</sup> Several cases have come under the writer's observation.

waters above. The tail-race will always be comparatively free from drift or ice, which must be screened out above for protection of the turbines. It will not be strictly free of drift below the power house on account of there being in the lower end of the power house a small spillway, or chute, through which drift that has entered the head-bay may be shunted to the tail-race below. Close to this chute, but just without the west power-house wall, is another small spillway for shunting the drift which may collect in the region of the lock.

#### THE LOCK.

The lock was an essential requirement of the Government in order to provide for the necessities of navigation. It is of particular interest also since it is the only passageway by which it is supposed fish may pass from the lower river to the upper. The lock, built by the proprietors of the dam and deeded to the Government, is located below the power house and inshore from it, the upper eastern corner of the lock being connected with the lower western corner of the power house by a short section of dam provided with narrow spillways, as before mentioned. (Pl. I.) The lock is 110 feet wide and 400 feet long inside and has a maximum lift of 40 feet. The time required for locking a boat through is about 15 minutes. For such a great lift in so large a lock to be accomplished in so short a time requires a most efficient and special arrangement for filling and emptying the lock.

The bottom of the lock (which is 8 feet below the water level at the lowest stage of the river) is a gridiron of culverts, the mains being under the bottom of the walls running lengthwise of the lock, and the crossbars of the gridiron being culverts crossing the lock floor at intervals. The largest of these culverts are 13 feet in diameter and the smallest are 6 feet in diameter. The culverts are cast of concrete around steel lining. The angles in them are so sharp and the water pressure and velocity will be so great that the friction of the water against the concrete would wear the latter if it were not protected with steel. The outlet ends of the culverts discharge on the side of the lock at right angles to the course of the river.

By adjustment of a series of valves the water in the lock is permitted to run out into the river through the culverts. After the boat has entered and the gates are closed, the culvert valves of the filling system will be opened, the water from the higher level of the fore bay will rush through the culverts entering the lock chambers through fifty-seven 3-foot culvert openings until the level within the lock is the same as that of the fore bay, the boat being lifted 40 feet vertically within a few minutes. (Pl. VI.) As soon as the upper gate is submerged the boat may pass out and continue its course through the deep water of the bay and lake. In leaving the lock



the boat passes over the front wall of the lock which is covered by 8 to 14 feet of water, according to the stage of the lake.

It should be remarked that the lower gates, which are of heavy steel truss construction, swing open, while the upper gate is of a new submerging type. This gate is a heavy steel truss containing air chambers below and works up and down in vertical slots of steel. There is also an emergency gate a short distance in front of the regular upper gate which may be used when necessary to repair the latter.

It will be inferred from the above description that the fish would not be likely to enter the lock from below during the process of emptying, since to do so would be to pass through the deeply submerged sharp-angle, culverts or tunnels out of which the water is discharging apparently at enormous velocity. Correspondingly it is not to be expected that they would gain the upper lake from the lock during the process of filling, since to do so entails passing down through the same tunnels against the rush of water under a 40-foot head. It is possible that a few might make their exit in this way after the lock is nearly filled.

It is also clear from the description of the working of the lock that the gate above is not submerged except when the lock is full, nor are the gates below opened except when the lock is empty. In other words, there is no ingress or egress through the gates for fish that are working upstream except when the water in the lock is stationary, which is to say, when ascending fish are least tempted to move in that direction.

Another feature of the lock construction is significant. The upper opening of the lock does not extend down to the bottom, but is largely closed from below by a solid concrete wall over 30 feet high. (Pl. VI). A fish entering the empty lock from below finds 8 feet of water at the lowest stage of the river; leaving the full lock above it finds 8 to 14 feet of water between the top of the submerged gate and the lake surface according to the stage of the lake. To find its way out, therefore, it must make a vertical rise of 25 to 35 feet, without the presence of any definite current to direct its movements, or else, as before mentioned, it may seek its way out through the *dêep* tunnels beneath. How will this head wall affect the movements of bottom-loving fish?

Parenthetically, it may be said that the effect of the unwonted variation in pressure within the lock may have a real (but quite unknown) influence on the movement of fishes. The depth of water in the lock varies from 8 to 48 feet. The possible demoralization of the fish by the turbulence of waters suddenly boiling up from below under a 30 to 40 foot head is perhaps uncertain, though we may infer that its effect would not be the happiest.

As a matter of observation, fish are found in the lock. When the lock is emptied a few fish are often seen stranded on the broad top of the wall at the upper end of the lock. More often, perhaps invariably, some are caught between the rails on the top of the submerged gate when this is raised. The space between these rails is about 8 by 110 feet or 880 square feet. Only a few fish were thus taken under my observation, but I was informed that as many as 50 to 100 had been caught in this way at one time. We do not know whether these fish were going into or coming out of the lock. It is possible that the lock acts as a sort of fish trap into which fish of the immediate vicinity stray, and by means of which some of these fish are transferred infrequently from pool to river, or vice versa, without reference to migratory movement. The lock chamber is a little over an acre in extent (44,000 square feet) and such an area in nature will accommodate a large number of fish without indicating any special assemblage of fish seeking a passage in a definite direction. The actual fact, and the significance of the facts, may be determined only by systematic observations judiciously interpreted.

#### THE QUESTION OF A PRACTICAL AND EFFECTIVE FISHWAY.

At the outset it may be stated that an ideal fishway is afforded only by the free channel of the river itself. We can not have water powers in the course of the stream, without some sacrifice of the free movements of fishes. Artificial fishways may, however, be practically effective, and locks are sometimes accepted as proper fishways, especially where occurring in the course of canals or narrow streams. It does not follow that a lock will be effective in all situations. Some features of the present case will first be recapitulated.

(1) The position of the lock is near the Iowa shore, from which it is separated only by the dry dock and the Government reservation on filled ground built out from the shore. (Pl. I.)

(2) The width of the lock opening is 110 feet, as compared with the approximately three-fourths of a mile breadth of the river. Its opening is perhaps one-thirtieth of the width of the river.

(3) The location of the lock is out of the principal currents, though not far removed from the important tail-race. It is not certain, therefore, that even a proportion of the fish equal to the ratio of the width of the lock to the width of the river would find entrance to the lake through this chamber. That a considerable number of fish should be found in the lock is not inconsistent with this statement.

(4) The filling and emptying of the lock is accomplished by methods which do not encourage the entrance or exit of migratory fishes during these processes. Fish may freely enter from below when the lower gates are open and, by rising toward the surface, may leave for the lake when the gate at the head is opened; but at these times the

water in the lock chamber is practically stationary. It has been suggested that this defect might be remedied by providing in some way that a slow but practically continuous flow of water might prevail through the lock.

(5) There are factors of pressure and of serious disturbance or turbulence of the water which may have significant effect upon the moving tendencies of fish in the locks.

(6) The lock is operated on an average about nine times a day, during the season of navigation, and requires from 15 to 30 minutes for the passage of one or more boats.<sup>a</sup>

(7) The movements of fishes can not be subjected to rules, nor even accurately defined, except after such patient and systematic observations as have not yet been made.

Any fishway to be effective, must receive the fish at some point of convergence and give them practically uninterrupted opportunity for ascent. The fishway should be in operation at least as early as the ice goes out in spring, and preferably sooner, and it should be so attended and cared for as to be always in unobstructed condition. The lock can not be said to meet these conditions.

The engineering difficulties of providing an effective fishway over a dam 40 feet high and a mile wide are not to be underestimated, and must be given careful consideration. Were it an impossibility to have a fishway under these circumstances, we should simply have to fall back upon the law of compensation and accept a great loss in exchange for a greater benefit. The stakes to be lost are, however, perhaps greater than may at first be supposed. The reduction of important fisheries in the entire upper Mississippi and the possible extinction of one of the most valuable mussels of the same portion of the stream are not to be lightly considered.

It is not impossible to suppose that practically all fish that approach the lower end of the tail-race could be made to converge toward the position of the lock or its juncture with the power house. It is possible that an open weir of coarse-meshed wire netting stretched out as a wing from the foot of the lock entirely across the stream below the tail-race would accomplish this purpose. The feasibility of this is suggested by the fact that the tail-race is so largely free from dangerous drift materials. A decided downstream angle to the wing net would not only increase its efficiency but would facilitate the passage around the end of the weir of the drift not screened out above, even if some attention were required to insure such clearance.

The desirability of a fishway at any point depends upon determination by experiment as to whether a large proportion of the fish could be

<sup>a</sup> Records from the lockmaster's book for a period of 46 days show 224 lockings "down" and 191 lockings "up," or a total of 415 operations.



concentrated at this place. Some simple experimentation is worth while, if only for guidance in case of future constructions. Were there installed a floating boom directed from the lower offshore angle of the lock structure downward and outward across the main flow from the power house, it would be practicable for experimental purposes to supplement this by suspending a weir of coarse-meshed wire netting below the boom. The object would be to determine whether fish in large numbers could be deflected in the direction of the lock. The possibility of a fishway near the Illinois end of the dam, which, as has been brought out, is the point farthest upstream, is also worthy of consideration; although the difficulties are here greater, on account of the exposure to floating ice and other drift, and because of the changes of flow from one part of the dam to another. It is possible that, after the period of construction is entirely passed, it will not be necessary to make entire changes of flow during the season of active migration of the fishes. It may be borne in mind that, on account of the tremendous disturbance resulting at the foot of the spillways, most fish will find their direct approach checked at several hundred feet from the base of the dam, although they may, and do, pass around the region of disturbance to reach the very foot of the dam. Accordingly a fishway having its foot at some distance from the dam might be in position to receive the fish at the uppermost point of direct approach.

Reverting again to the tailrace as a region of unceasing current, one may look down from the platform along the outside wall of the power house upon the upper part of the tailrace, where the big draft tubes are discharging columns of water 25 by 40 feet, directed with great force against the opposite face of the tail-bay some 75 feet from the power house. Meeting this obstruction, the waters are thrown into terrific commotion before they can be turned downstream to follow the direction of the excavated raceway. In this raging, whirling, ebullient current, no fish could find a rest or pursue a definite course. But the water is always overflowing now between the piers of the abandoned cofferdam flanking the tail-bay, and will, after the cofferdam is entirely removed, overflow in a continuous sheet toward the center of the river. This is of interest as a tolerably fixed condition, as opposed to the variable conditions characteristic of the spillway portion of the dam.<sup>a</sup> It appears plausible that fish will work up along this line of overflow, finding ultimately a terminus at the foot of the dam. If it be possible to provide a fishway on the dam at a point near the upper end of the tail-race, it is probable that the opportunity for concentration of fish would be more uniform here than at any other point on the dam proper, and likewise that the problem of preventing damage from floating ice and drift would be simplified

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<sup>a</sup> Note the later observations inserted on page 25.

by the proximity of the head of the fishway to the power house and the present ice fender.

The possibility of a dipnet and hoist operated at the angle of power-house and dam, or elsewhere, is suggested by the congregation of fish in such places. None of the suggestions mentioned in this section is offered as a practical solution of the problem; rather as indicating some possible lines of preliminary experiment.

Finally, the question is sometimes asked if fish in migration are working along the bottom or near the surface. The answer is that there are bottom-loving fishes and surface fishes. The essential fact is that a fishway is intended for the use of fish working upstream, or those engaged upon the return journey. Consequently it must be located at a point that fish naturally approach in fighting a current. Needless to say, it should operate continuously, and not intermittently, unless the fish were prevented in some way from seeking another place while waiting for the opening of the way.

It is much easier to proclaim the desirability of a fishway than to say what sort of a fishway and what location for it would be practically effective. The problem which is raised is simply this: To determine by continued observation under varying conditions at what points the fish naturally converge or may, by artificial means, be made to converge; then to inquire what sort of passageway would be practicable and effective to permit and encourage ascending fishes to rise from the river to the lake. When these questions are given a definite answer, intelligent action can follow. If the end is necessary, and practicable of attainment, it is worth expense; if it is not found feasible to converge and give reasonably free passage to migratory fish, it is useless to waste relatively large sums for the name of "fishway." The whole matter at this stage may be expressed as a biological problem, definitive answer to which should not and can not be given except on the basis of further experience.

#### LAKE COOPER.

It is indeed desirable that ascending fish should have access to the great breeding grounds of Lake Cooper. Regarding the lake, it is not pertinent in this connection to add much to the references made in the introduction concerning its relation to fish and mussel life.

As a region of repressed and relatively slack water, Lake Cooper extends above Burlington, Iowa, with a length of 65 miles and a width of 1 to 3 miles. It will not here be discussed except to remark that it has caused the submergence of many islands and low-lying shoreland and formed numerous deep coves and bays. Much of the submerged farming lands of high value are to be reclaimed by systems of levees and drainage. The growth of trees upon many of the flooded islands and shores has been removed by the company that there

might be no danger to navigation. The maximum lake level is not yet attained; there may be a rise of 3 or 4 feet in the course of the next few years, to be made gradually in accordance with arrangements between the company and the property owners affected. The greatest depth in ordinary times will be about 40 feet, but the general depth will be much less.

There will ensue a good deal of decomposition of old land vegetation under water, but the effect of waves and surface wind currents, in connection with the circulation resulting from the regular flow of the river, will do much to reoxygenate the water. In course of time a proper growth of vegetation will be found in the bays, and this will form a most significant feature in the bionomics of the mature lake.

Experience at Fairport with new ponds supplied with Mississippi River water shows that the development of a proper degree of aquatic vegetation is greatly hastened by artificial introduction of suitable plants, and we have found it difficult to obtain these in any variety from the local overflow ponds and slues of the Mississippi. It would be most desirable, therefore, if the Government or State authorities should make such introductions in the various coves and bayous, so that the maturity of the pond as a fish environment might be expedited. Plants of fish and mussels can readily be made. It is understood that several hundred young bass were introduced by the Iowa State fishery department, and the United States Bureau of Fisheries, through the Fairport Biological Station, made a plant in October, 1913, of 2,343 large-mouth black bass and 425 crappie infected with Lake Pepin muckets and local Mississippi River muckets, in about equal proportions (1,380,000 glochidia in all).

#### OPPORTUNITY AND RESPONSIBILITY FOR INVESTIGATIONS.

The problem presented by the Keokuk Dam may well serve to point out the inadequacy of our preparation to deal with situations of the kind—situations which may vitally affect the future food supply of our people. It is not alone an insufficiency of knowledge and experience which confronts us, but a real negligence. In connection with water-power developments everywhere, streams are obstructed with the bare and indefinite requirement for installation of fishways, which, in a large number of cases, become inoperative soon after they are put in. It is not the proprietors of the power developments who are at fault, so much as the public at large who expect the owners to provide and maintain fishways though robbed of incentive and guidance.<sup>a</sup>

The subject of fishways is one of live importance, and one requiring thorough experimentation. It is not the method of laboratory experiment that is needed, so much as that of field experiment and

<sup>a</sup> There are very few sorts of fishways that accomplish the purpose for which they are designed.



continued observation of the movements of fishes and their utilization of fishways. It is unfortunate that more practical experience has not been gained by a strict enforcement of the provisions requiring fishways and subsequent precise observation of their efficient working. In this way would the best of experience be gained.

Passing this subject, there are rare opportunities presented by the situation at Keokuk, to take advantage of which would be of the highest value. •

We are deficient in our knowledge of the movements of fishes. What fishes migrate, at exactly what season does the migration occur with the several species of fish, and what is the extent of the movement with the several species? These are questions that we can not now answer with a satisfactory degree of definiteness. The existence of a practical obstruction in the Mississippi at Keokuk offers an unprecedented chance for exact observations, supplemented as they may be by the series of observations made by the biological station at Fairport, in the upper Mississippi at Lake Pepin, and elsewhere. The full realization of this opportunity can not be accomplished by a cursory examination, but demands a systematic and long-continued investigation undertaken before the movement of ice in the spring.<sup>a</sup>

Observations made by the staff of the Fairport station during the summer and fall of 1913 have revealed the fact that the river herring (*Pomolobus chrysochloris*) has been present just below the dam during practically the entire period and in large numbers. Nevertheless, it would be impossible to say at the present time if this is because the fish are blocked in the effort to proceed up the river, or if we have to do only with the assemblage of an exceptional number of individuals of this species due to peculiarly favorable conditions found in the swift waters below the dam.

The peculiar habits of eels are of particular interest in connection with any effective obstruction of the course of a stream. It is known of some species of eels, and believed to be true of all, that they do not breed in the rivers at all, but only in the depths of the ocean. The young eels, after hatching from the egg and passing through an interesting stage called the leptocephalus, during which they are strictly marine, ascend the rivers to grow to maturity, when they in turn will pass down the rivers to start a new generation upon the first stage of life in the sea. Supposing that few of the new generation of eels should succeed in passing above the dam, we would expect a gradual

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<sup>a</sup> Anadromous fishes are those which ascend rivers to spawn; the only fish of the Mississippi assumed to be anadromous is the Ohio shad, *Alosa ohioensis*. Catadromous fishes are those that go down to the sea to spawn; such are the eels of the Mississippi River. Other fishes are merely migratory having seasonal runs, from upper to lower portions of the river and return. In this class are generally included practically every important food fish, as the basses, wall-eyed pike, suckers, buffaloes, spoon-bill cat, lake sturgeon, shovel nose sturgeon, river herring, and all the larger catfishes. Very few fishes, among which would be the bull-heads, would be left in the nonmigratory or permanent resident class. However, it must be said that the beliefs regarding the movements of fishes require to be submitted to the test of more exact observation.

extinction of the eel in the upper river and its tributaries, while we would look for a relative abundance of young eels below the dam, particularly during the next few years. This is a problem that may lend itself to concrete observation.

A question that raises itself in regard to purely migratory fishes, that is, those that move down the river in the fall and up in the spring, is, to what extent will the presence of the large body of deep water above the dam remove the necessity, or inhibit the tendency, of the fishes to proceed farther in their downstream course?

The destiny of the fish that are interrupted in their upward journey upon reaching Keokuk introduces a new problem. What becomes of these fish? Will they remain there all the summer? Will they turn back and work down the river or find tributary streams? To answer such questions would require close and continuous attention during the spring, and, since the fish can not be watched by the eye, a good deal of systematic trapping and seining at various points. In this connection it may be mentioned that reports were current to the effect that the Keokuk dam had turned innumerable fishes up the Des Moines River, which discharges into the Mississippi only 3 miles below the dam. It was said that more fish were being taken at Ottumwa than could be disposed of. Both Ottumwa and Eldon were visited by the writer in September, and the most careful inquiries made. It was found that the reports had no foundation, other than the hope and belief that the dam would deflect the fish into the Des Moines River as the first opening below Keokuk. Some local persons who did not fish offered some supposed confirmation of the reports, but every one of a considerable number of persons interviewed who fished either as a profession or for sport, agreed in stating that the fishing had been unusually poor during this season, and this condition was attributed to the fact that the river had been too low all the season for fish to ascend. There was some testimony that there had been an unusual run of very small channel cats and carp of 6 or 7 inch length—almost too small to use—but it did not appear that this had been unprecedented; also there was complaint of an increasing number of gars.

The sudden creation of a large lake intervening in the course of a great river with the submergence of islands and shore land, thousands of acres in extent, offers an unrivaled opportunity for investigations of material value. Upon this subject we are at liberty to some extent to draw conclusions a priori, as has been done, but there is none the less the privilege and the responsibility for more detailed inquiry and exact survey which, if completed, would furnish invaluable data for interpretation of the conditions of fish life and the determination of the ultimate requirements for the maximum development of fishery resources.

The problems here outlined are too extensive in scope to be solved in their entirety within the available resources of the Bureau, but the hope may be expressed that the lesson of this occasion may make so wide an impression that, should the fortune of time offer another situation of like significance, the possibilities of the Bureau's service may have been so anticipated that a condition of preparedness shall have been created. The effective conservation and development of the fishery resources is a not unimportant phase of the provision for the future welfare of the country.

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#### APPENDIX.—THE PROBLEM OF THE MIGRATION OF RIVER HERRING.

The following brief account of observations made chiefly during the year 1914 are of interest in this connection. While it was not found feasible to detail anyone for continuous study of the succession and movements of fishes, as would have been desirable, some occasional visits could be made, which were not without value.

The writer visited Keokuk April 15, 1914, when the water was still cool, and practically no movement of fishes had occurred. It was learned that the river immediately below the dam had remained open all the winter, although as a whole below the bridge at Keokuk and above the dam it had been frozen over with thick ice. In the exposed water the wall-eye or "jack salmon" had been present all the winter and fished abundantly with hook and line. Practically the only fish then in evidence were perch and crappie in the slues. A few perch were noted in the lock, and the lock master stated that a large number had been taken at the first locking, about April 10.

A local informant, Mr. Joe MacAdams, was requested to write me of the first appearance of the herring. After a card from him, I visited Keokuk again April 29. He stated that the herring first appeared April 20, and that they became enormously abundant within a few days; on the 27th, according to several informants, during a warm day, one could at any moment see hundreds of them breaking the water in every part of the river below the plant.

The day of my arrival, April 29, was cold, windy, and cloudy, and at first view very few herring were observable. After closer observation, however, they were seen to be present in immense numbers, and congregated in certain locations exactly as had been predicted. (See p. 20 above.) A large number were seen just below the short section of dam between the upper end of the lock and the lower end of the power house; many were observed along the outer wall of the tail-race, but in the angle between the power house and the dam and from this point to the nearest open spillway, a short distance away, the herring were fairly massed. Such a close aggregation of fish can rarely be seen in fresh water. They had evidently followed up along the outer edge of the tail-race until they could go no farther. Again, on



the outer side of the last spillway in use, which was about 700 feet from the power house, there were considerable numbers of herring. From this point to the Illinois shore, a distance of about two-thirds of a mile, not a single herring was in evidence. It was evident, therefore, that the herring had been guided by the moving water, so that they had in consequence assembled in such remarkable numbers on each flank of the stream below the open spillways, many more being guided to the eastward side by the strong current from the turbines.

Opportunity to observe whether they could breast the strong current was favored by the fact that there were three closed spillways between three open on the east and nine open on the west; thus there was a triangle of relatively slack water between two strong currents which met a short distance below. To the west of the westward current fish were abundant; to the east of the eastward current they were still more abundant; but in the triangle between not one fish could be seen. It was evident, therefore, that the power of the currents below the spillways proved an effective barrier to the lateral movements of the fish for some distance below the dam; otherwise not all of the fish would have been on the right side of one current and on the left side of the other.

The powerful currents caused slight eddies on each side, so that the dead water at the foot of the dam on either side was continually being drawn into the spillway streams. The fish were also drawn in, and it was easily observed that the velocity of the streams made them perfectly helpless. As soon as they passed into this stream they were thrown up in the foam and spray and often hurled 20 feet or more, back, sides, or under parts up, to be carried off as soon as they fell. Presumably no injuries were received, as no dead or injured fish were observed in the river below. No fish, as previously indicated, were drawn in from the slack water between the easterly spillways and the westerly, although similar eddies prevailed here.

It was observed that the roe of the herring was large, and it was thought that they would ripen within a few weeks. A visit was made by Superintendent Canfield May 29, and a number of herring were examined, but they were found to be not quite ready for spawning. A later visit was made by Mr. W. B. Gorham, June 11 and 12, when it was found that the herring had disappeared. This disappearance had not been noticed by the local fishermen for the reason that there were present in large numbers the Ohio shad, *Alosa ohioensis*, which is not generally, if ever, distinguished by fishermen from the herring. There was no clue, therefore, as to what had become of the herring.<sup>a</sup> Later observations at Lake Pepin are mentioned below.

The gathering of herring in such enormous numbers at Keokuk is of particular interest from the fact that this fish has never been gen-

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<sup>a</sup> Later observations (in August) indicate that the disappearance was only temporary.

erally regarded as abundant in the river. Fishermen generally speak of it as uncommon, and yet informants sometimes refer to occasions when they were taken plentifully about the ends of wing dams. It has been supposed, therefore, that the fish is more abundant than common observations indicate, but that it migrates rapidly, keeping in the current where fishermen work least, and tarrying where the water runs swiftly around such obstructions as the wing dams. This supposition seemed to receive confirmation from the observations at Keokuk in 1913.

The question still occurred: Would the herring be found in the upper river after the dam was constructed? On the occasion of a visit by the writer to Lake Pepin in Minnesota on July 19, 1913, a single specimen was taken in a seine haul of our propagation crew. Several fishermen were positive that this was the first specimen seen in Lake Pepin in that season. The foreman of the crew, Mr. William Teachout, was requested to report each subsequent catch, and following is a record of his reports. To check the field identifications, specimens were sent to the Fairport laboratory from time to time, and in each case the identification was confirmed. The seining operations were discontinued in Lake Pepin after September 11, though pursued in the river below the lake. Later hauls in Lake Pepin were made October 17, 18, and 23, without further catch of herring.

BLUE HERRING TAKEN IN LAKE PEPIN DURING 1913.

July 29.....	8	Aug. 27.....	8
Aug. 3.....	53	Sept. 3.....	3
9.....	1	5.....	25
12.....	5	6.....	5
23.....	8	11.....	26
26.....	12		

The observations at Lake Pepin were continued after the seining operations began in Lake Pepin in 1914. A single specimen was taken May 12, a few about the middle of June, after which they were taken more plentifully, especially in July, as shown by the records which follow, covering observations to the date of August 8:

BLUE HERRING TAKEN IN LAKE PEPIN DURING 1914.

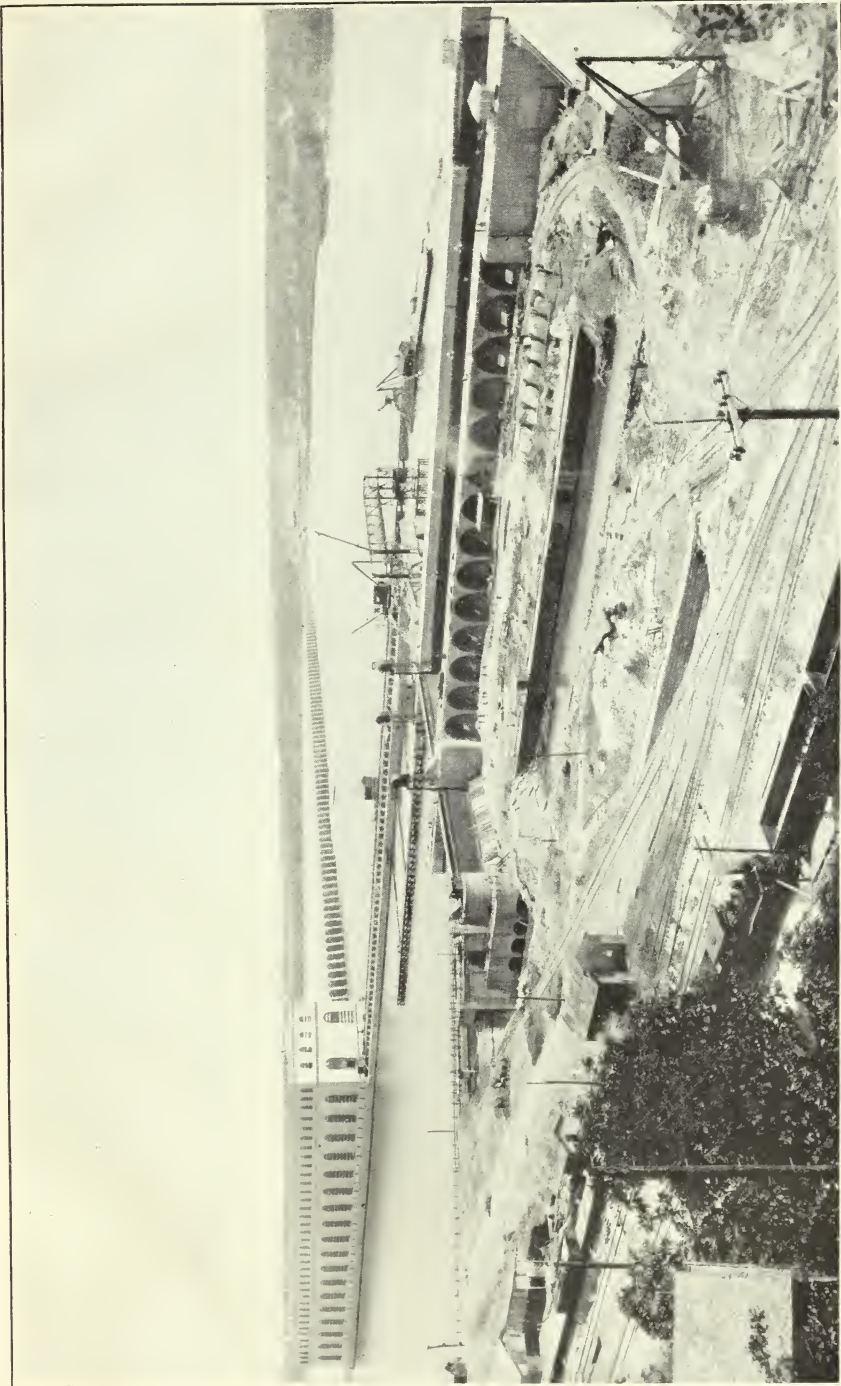
May 12.....	1	July 9.....	1
June 15.....	1	10.....	40
17.....	1	11.....	168
19.....	3	20.....	135
22.....	28	21.....	3
23.....	8	22.....	120
24.....	14	23.....	29
25.....	3	24.....	92
26.....	1	Aug. 3.....	57
27.....	12	7.....	75
July 1.....	5	8.....	1

The fact that the herring became abundant at Lake Pepin shortly after they ceased to be observable at Keokuk suggested that they might have passed through the lock. However, the examples received from Lake Pepin were noticeably smaller than the examples taken at Keokuk. This fact suggested the inference that the Lake Pepin herring might not have come from the river below Keokuk, but might represent younger fish that had wintered at intermediate points or possibly in Lake Cooper. Here the matter must rest pending further and more adequate studies. It is noteworthy that the herring seem to have appeared in Lake Pepin earlier in 1914 than in 1913, and that they appeared to be more numerous in the later year, notwithstanding that the river was obstructed at Keokuk throughout 1914 but not in the earlier part of 1913.

In August, 1914, a number of very young herring were collected by Mr. Teachout. In one shipment, August 26, 1914, 21 specimens were received of fingerlings or yearling herring, the lengths ranging from 122 to 165 millimeters (5 to 6½ inches). On September 5, six somewhat smaller specimens were sent us, having lengths of 107 to 128 millimeters, the smallest being scarcely over 4 inches. Such specimens are of particular interest as the first young herring observed at our laboratory and as indicating that Lake Pepin is a place where the herring breed. Mr. H. W. Clark, who has examined these specimens, reports that even many of these small herring are infected with glochidia of mussels.



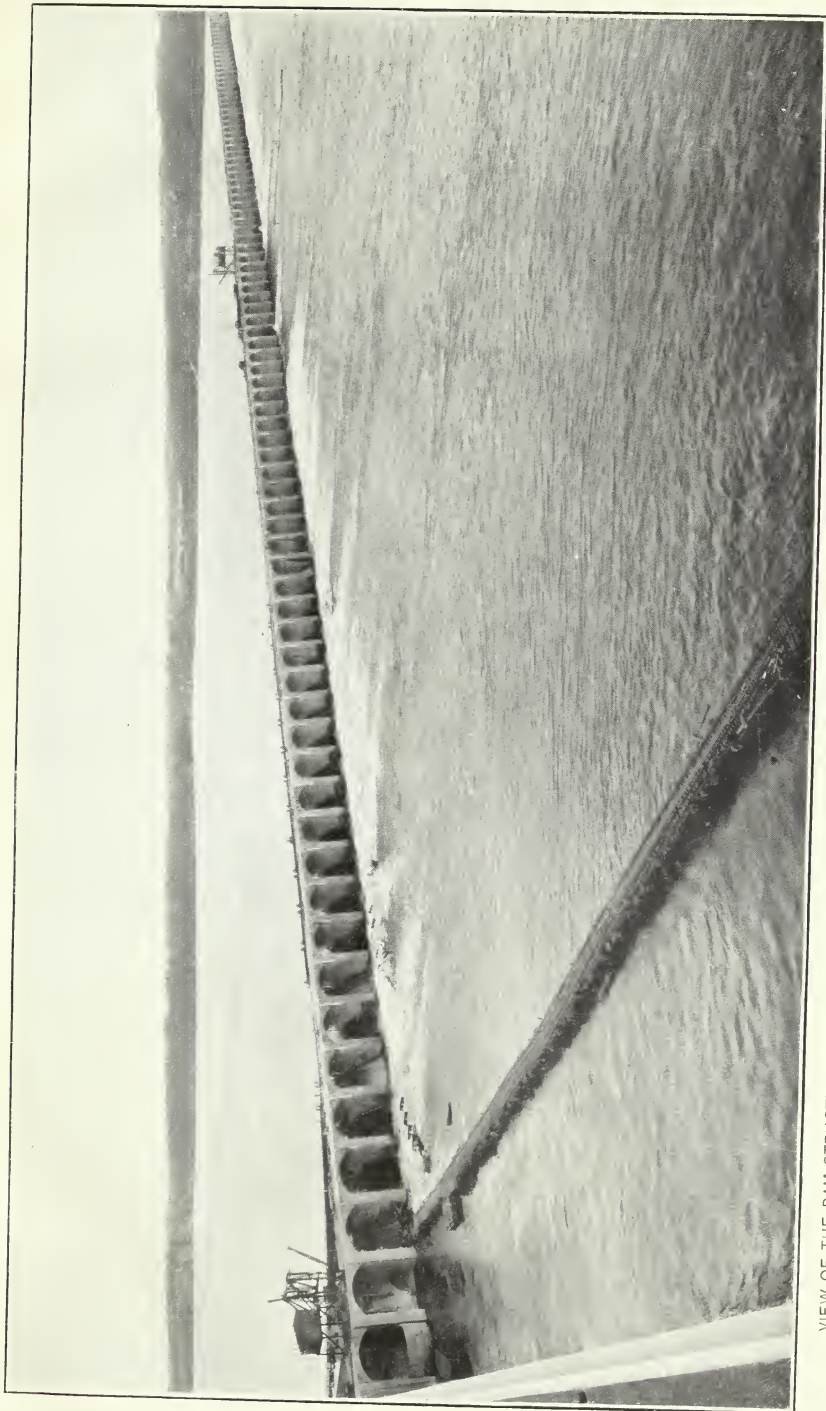




GENERAL VIEW OF THE WORKS OF THE KEOKUK-HAMILTON DAM FROM THE IOWA SHORE.

Hamilton, Ill. in the distant background, showing the dam structure, completed half of power house, foundation of half of power house not completed, the lock, and the region of dry-dock and Government shops where excavation and fill is in progress. On the left in background is the lower portion of Lake Cooper above the dam, and the forebay between power house and foreground. A portion of the ice fender near the power house is barely seen on the extreme left.

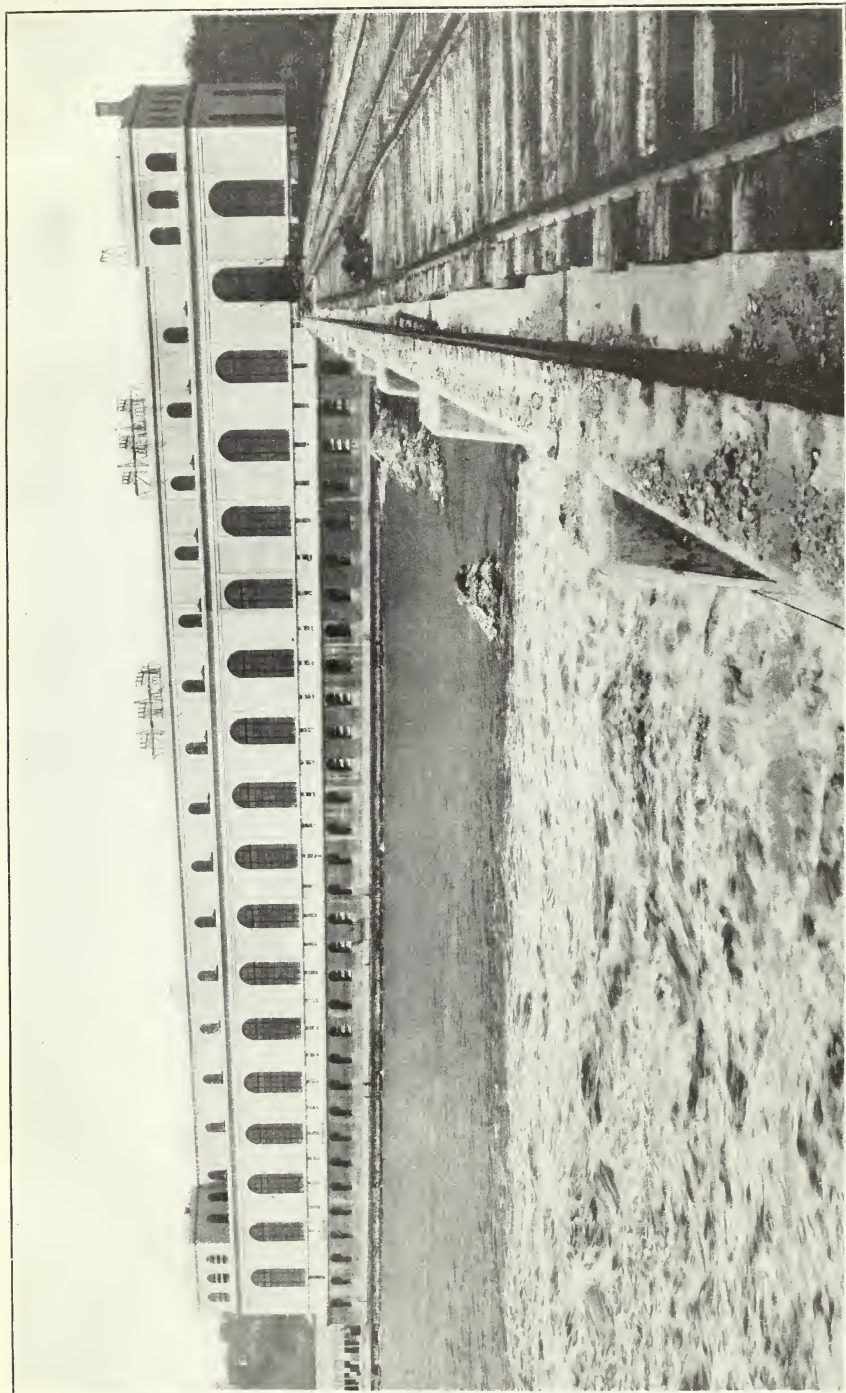




VIEW OF THE DAM STRUCTURE SHOWING THE ARRANGEMENT OF SPILLWAYS; ALSO THE TAIL-RACE FROM THE POWER HOUSE ON THE LEFT.  
A temporary cofferdam separating this tail-race from the river proper is seen in this photograph, but it was subsequently largely removed.

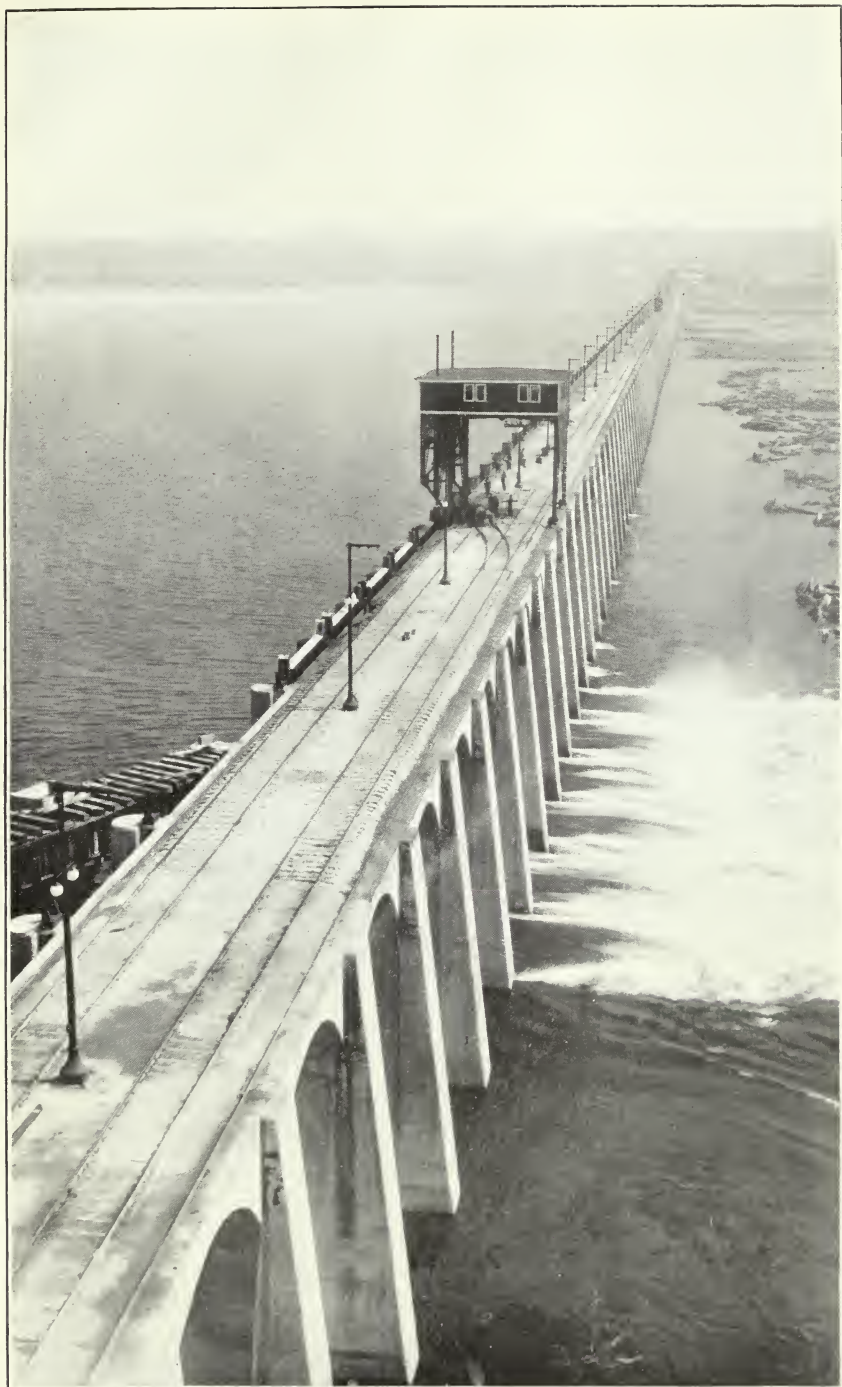






SWIFT, TURBULENT WATER DASHING AGAINST OLD ROCKS BELOW THE SPILLWAYS.



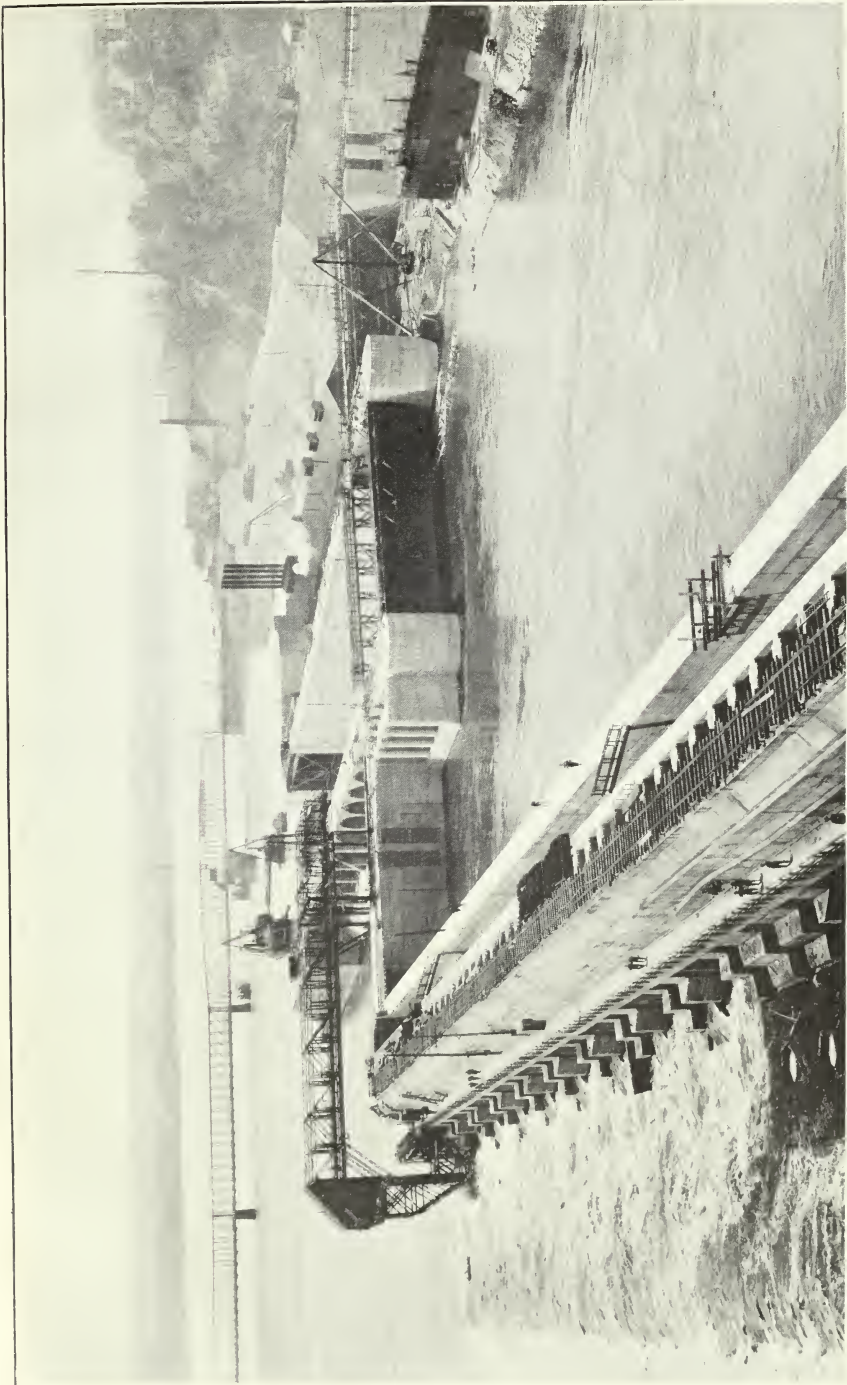


CONDITION BELOW THE DAM WITH SIX SPILLWAYS OPEN. NORMALLY A MUCH GREATER NUMBER OF SPILLWAYS ARE IN USE.

On the outer side of the first and last spillways of such a group an eddy draws into the spillway streams a portion of the slack water at base of dam. (See observations described in Appendix, p. 26.)



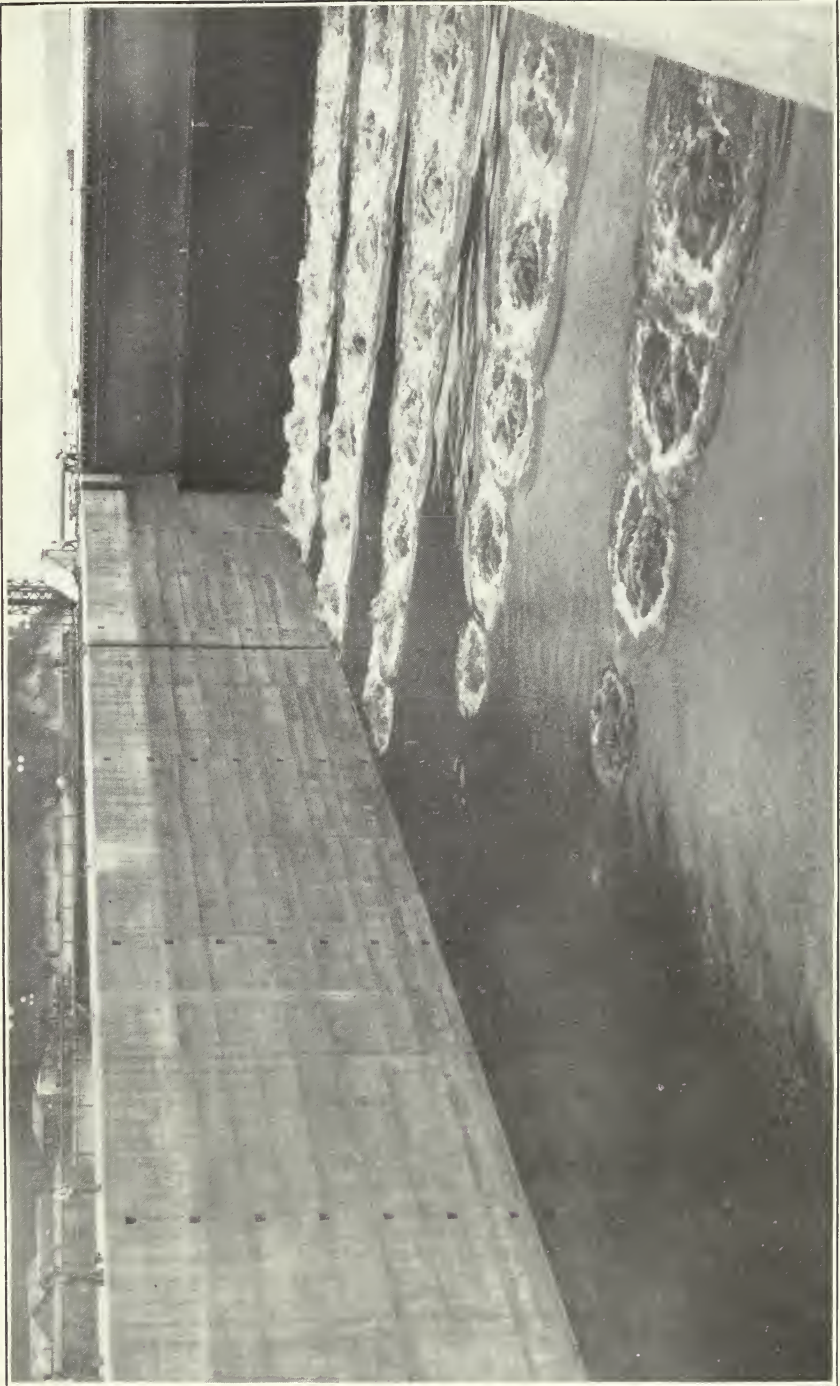




POSITION OF THE LOCK WITH REFERENCE TO THE LOWER END OF THE POWER HOUSE.

From left to right: (1) lower end of power house; (2) short section of dam between power-house foundation and lock; (3) the lock with forward emergency gate raised; (4) the dry-dock in construction with gate raised; (5) filling for Government shops in progress; (6) Keokuk bluffs at extreme left. Waters being passed through the gates of the lower unfinished portion of the power house.





HOW THE LOCK IS FILLED THROUGH A SERIES OF CULVERTS WITH OPENINGS INTO THE BOTTOM OF THE LOCK. THE VALVES HAVE FIRST BEEN OPENED, SO THAT THE LOCATIONS OF ONLY ABOUT 30 OF THESE 3-FOOT OPENINGS APPEAR IN THE ILLUSTRATION.











