IV.—A NEW SYSTEM OF FISHWAY-BUILDING.

BY MARSHALL MCDONALD.

1. THE OBJECT OF FISHWAYS.

It is a well established fact that the river fisheries of the Atlantic States have steadily decreased both in value and annual production for many years past. In some instances, species that were at one time common in certain of our rivers are no longer taken. Indeed, the annual run of those fish which still continue their migration to the rivers has undergone alarming decrease; and in many cases become too insignificant to furnish the motive or material for organized fisheries.

Several causes, probably, have concurred in producing this decrease: (1.) The capture of the greater portion of the run each year may not have left sufficient to maintain production under natural conditions. (2.) The erection of dams or other obstructions in the rivers has, in some cases, absolutely excluded certain species from their spawning grounds; the result being eventually to exterminate the species referred to in those rivers. In all cases the existence of such obstructions has determined a decrease in the natural productiveness of the stream *pro tanto*—with the diminution of the breeding and feeding area.

The remedy for the condition of things above indicated is to be found: (1.) In the enactment of such legislation as will control excessive fishing, and prohibit destructive methods. (2.) In compensating for the insufficient natural supply by artificial propagation and planting. (3.) In extending the area for breeding and feeding by overcoming natural obstructions by means of fishways.

If the anadromous fishes only entered our rivers for the purpose of spawning, and their progeny spent no part of their life in our fresh waters, then the increase which we could determine by artificial propagation would be practically without limit. The fish-culturist, in order to maintain the supply, would only have to produce the young fry in numbers sufficient to replace losses by capture or by casualty. As regards all the anadromous species, however, which are the object of commercial fisheries, viz, the salmon family, the shad, the herring or alewife, &c., it is necessary that the young, after hatching, should remain for some time in our fresh waters, feeding and growing, and, of course, finding the necessary food in these waters. The extent of the breeding and feeding area of any river basin is, therefore, necessarily the measure of its possible productiveness. A given area, when pressed to its maximum of production, cannot provide for more than a given number of individuals. The extension of the area of production is, therefore, the rational means by which we may determine permanent increased productiveness. Hence arises the necessity for fishways, which are, in short, various constructions designed for the purpose of enabling different species of fish to surmount obstructions which would be otherwise impassable to them.

2. THE NECESSARY CONDITIONS OF AN EFFICIENT FISHWAY AND THE DEFECTS OF THE OLD FORMS.

A fishway, to be effective, must fulfill certain conditions, which are clearly stated by Mr. C. G. Atkins in an admirable article on the subject of fishways, published in the annual report of the United States Fish Commission for 1872–'73, as follows:

"(1). It must be accessible; that is, the foot of the fishway must be so located that fish will readily find it. (2.) It must discharge a sufficient volume of water to attract fish to it. (3.) The water must be discharged with such moderate velocity that fish may easily enter and swim against the current."

To the conditions above stated we may add: (4.) The route to be traveled by the fish should be as short and as direct as possible, and the floor of the fishway should simulate as nearly as may be the bed of the stream.

The first condition may be always fulfilled in the location by arranging so as to have the discharge of water from the fishway in a line with or in the immediate vicinity of the obstruction.

The second condition is more embarrassing. The larger the volume of water discharged through the fishway the better it will be. In the kinds of fishways which are common throughout New England the volume of the discharge is necessarily limited by conditions inherent in the constructions; is compelled to travel a circuitous channel, and usually is delivered from the fishway in such a sluggish current that it offers no sufficient invitation to fish to enter and ascend it. As before stated, the difficulty of a limited capacity for water is inherent in all of these fishway constructions.

The attention of fish-culturists and fishway-builders has been heretofore chiefly directed to different devices for controlling the velocity of the water in the fishway. All these devices may be referred to one of two general forms:

(1.) The "step" or "pool and fall" fishway, in which the water is brought down from its elevation by a series of short drops or falls with intervening pools, the pools being of such dimensions in comparison with the volume of water entering them as to bring it practically to rest after each drop, so that the whole volume of water is eventually delivered from the lower end of the fishway with no greater acceleration than it obtains in falling from one pool to the next. This form of fishway is very common in England and upon the Continent. Possibly some examples of such constructions may be found in the United States, but I have no information of any.

(2.) The inclined-plane fishway, as it is termed by Mr. Atkins, in which the descent of the water is effected by a regular inclination of the floor of the fishway, instead of by "steps" or "pools and falls." In order to control the tendency to acceleration under the action of gravity the base of the incline is made very long in proportion to the height, and by a series of alternating transverse or oblique partitions the water is constrained to follow a narrow, tortuous path with continual changes of direction, the friction developed in its movement being sufficient to overcome the tendency to acceleration. Of this second general form we have many examples in the United States, especially in New England. The common rectangular fishway, the Brackett, the Foster, Pike's, Atkins', Swazey's, Brewer's, and Rogers' are examples of the various designs that have been employed, each differing in minor details of construction, but all belonging to a common system.

Most of these forms may be built either on an incline leading straight down from the dam or with a return section so as to deliver the discharge from the fishway close up to the foot of the dam, or they may be built in spiral form and boxed over so as to be made secure against floods and ice. The fishway of Mr. J. D. Brewer is peculiar in the fact that the channel to be followed by the fish is a zigzag groove excavated or framed in the floor of the incline, which is built either of masonry or strong timbers; the strength of the construction being such, it is presumed, as to prevent its destruction by floods or ice. The Rogers fishway is recessed into the dam and boxed over, the lower end discharging the water on a line with the face of the dam. This construction could, however, be applied to any of the forms above indicated and has been proposed in several of them.

The experience of fishway builders in New England has shown that for dams 10 feet in height or more it is not allowable to build the incline with a rise of more than 1 foot in from 12 to 16, requiring a length of incline of 140 feet for a 10-foot dam. The actual path, however, traveled by the water and traversed by the fish ascending would be some two or three times the length of the incline, so that fish passing up an inclined-plane fishway rising 10 feet vertically, would necessarily travel a distance of from forty to fifty times the height of the dam. For example, in the fishway over the Hadley Falls dam on the Connecticut River, the total length of the incline is about 450 feet. The distance to be travelled by the fish ascending it is not far short of 1,500 feet, to overcome an ascent of about 29 feet. All the different designs of fishways constructed according to the incline-plane system have, when judiciously located, proved more or less successful in passing certain species of fish. In all, however, the labyrinthine route to be traversed, and the insignificant flow of water through them, constitute very serious objections.

3. AN IDEAL FISHWAY.

If it be possible by any practical construction to deliver the whole volume of a stream over a dam or other obstruction with such moderate velocity that the weakest and least adventurous fish could readily swim against it, we would practically destroy the obstruction, and would establish for the migratory species a passage up to their spawning-grounds as free and unrestrained as if no obstruction existed. In practice, of course, this ideal can be realized only in exceptional cases, for industrial necessities, or considerations of cost, will necessarily limit the dimensions of the fishway and the amount of water that may be discharged through it; but just in proportion as we approximate this ideal in our fishway constructions do we approach more nearly the solution of the problem of free circulation of the anadromous fishes in Continental waters.

When the commission of fisheries was inaugurated in the State of Virginia, in 1875, one of the most important questions presented to it was how to make adequate provision to get the anadromous fish over the innumerable dams that obstruct the main water-courses of the State and all their tributaries. The white shad (*Alosa sapidissima*) is one of the most important food-fishes in all the tributaries of the Chesapeake, and in times past has furnished the motive of immense and profitable fisheries. The restoration and maintenance of this valuable fishery was one of the most serious questions presenting itself to the consideration of the Commission. The James and the Rappahannock Rivers were obstructed at the head of tide by insuperable dams, interposing effectual obstructions to the further upward migration of the anadromous species. Years ago, before obstructions existed, the migration of the shad in James River extended into the heart of the Alleghanies, two hundred and fifty miles above tide-water, and in the Rappahannock to the very base of the Blue Ridge Mountains. The curtailment of the breeding area, by the erection of dams on both rivers, had determined a corresponding reduction in the productive capacity of the streams, and, in concurrence with the irrational and unrestrained methods of fishing pursued, had rendered franchises, once valuable, worthless, and industries, once profitable, precarious and unproductive. A fishway that would freely pass shad up over these obstructions, and recover to production the breeding area of water from which they had been excluded, promised the means of restoring these most valuable fisheries.

The gentlemen who were then commissioners of fisheries for the State of Virginia were pleased to select me to visit the Centennial Exposition at Philadelphia, with instructions to make a careful study of the models of all the forms of fishways there exhibited, with the view of finding one that would be adapted to our purpose. A careful study of all was made, and I was reluctantly forced to the conclusion that none of them fulfilled the necessary conditions of successful operation, and I returned discouraged, with the conviction that an efficient shad-way was a thing of the future.

4. THE PRINCIPLES OF THE NEW FISHWAY, AND THE DETAILS OF ITS ARRANGEMENT.

The conditions to be satisfied in a successful fishway construction are as follows: (1) The water should be delivered down a straight unobstructed channel. (2) In sufficient volume to invite the entrance of fish. (3) With such moderate velocity as to permit their ready ascent. (4) With a view to economy in construction, it is important that the inclination or slope of the way should be much more considerable than in the ordinary inclined-plane fishway.

How to construct so as to fulfill these conditions was the problem to be solved. Two methods suggested themselves. It was possible to make the water do work in its descent, and thus control velocity. A fishway could be constructed on this principle by an evident modification of the ordinary turbine wheel. And such a fishway could be made to serve both as a passage-way for fish and as a motive power for machinery. This idea, however, was soon abandoned, for the double reason of its complexity and the limitations to its application that would necessarily exist. The second fruitful idea was that if each molecule of water could be compelled to traverse a constrained path, its final direction in any one circuit being against gravity, it could be brought to rest at a lower level—the friction developed in movement having neutralized in part the force of acceleration. The molecule falling from its second position of rest through a similar circuit, and in succession through any number of circuits, would finally reach any defined lower level with no greater velocity than that attained in the first circuit described. Were it practicable to subject every molecule of water passing through a fishway to the constrained movement above indicated, the result would be a descending current, the average velocity of which would not exceed the average velocity of a molecule in passing to consecutive positions of rest under the conditions above stated.

How this idea has been realized in practical constructions will be understood by reference to the following figures and descriptions.

If we take a hemispherical bowl (Fig. 1), and holding a marble at A, upon the edge of the bowl, we release it, it will fall, under the influence of gravity, through A′ to A″, coming to rest at A″, some distance below the edge of the bowl. The vertical distance between the positions A and A″ measures the force of acceleration that has been counteracted by friction by traveling the constrained path A A′ A″. If now we take a number of similar bowls and cut them off to the line A A″, and arrange them as in Fig. 3, and start a marble at D′, it will pass from D′ to C′, reaching C′ with no greater velocity than that acquired in passing from A to A′. If, however, the marble were allowed to roll unobstructed from A to A″, down the incline plane D C (Fig. 2) it will have acquired a velocity equal to $8\sqrt{DB}$ approximately. We see, then, in this case, how it is possible to deliver a molecule from a given position to a definite lower position without the increase of velocity that would arise if the molecule fell freely under the action of gravity or rolled down a smooth incline. If it be possible to compel every molecule of water descending through a fishway to submit to the conditions above indicated, then the problem how to control the velocity of a descending current would be solved. Now, to apply this to liquids, we arrange a series of bent tubes, shown in Fig. 4. By suitable arrangements we keep the longer branch of the higher tube of the series full of water. The water escaping from each tube will rise against gravity until it comes to rest, then fall into the longer branch of the adjacent tube in the series, and, after passing through the entire series, be finally discharged from the shorter branch of the lowest bent tube with no greater velocity than it acquired in passing through the first member of the series.

Construct a series of these tubes with branches brought close together, cut away obliquely the upper end of the longer branch of each member of the series, so as to permit access of water, pack them side by side in oblique position in an inclined sluice, as shown in Fig. 5, and we have the solution of the problem with which we started. For if we suppose a current of water to be running through the inclined trough or sluiceway, the first effect will be to fill the tubes with water and establish a flow through them; the water entering the longer branch of each tube will escape from the shorter branch with a velocity due to the head or vertical distance between the two ends of the tube. This final direction being obliquely up the slope, each particle of water will describe a path, as is indicated by the curved arrows shown in Fig. 5. The effect will be that we will have an ascending current in the sluice on that side of the sluice where the shorter branches of the tubes are situated. The velocity of this ascending current will become less and less as we pass toward the middle of the sluice, where there will be a line or section of practically eddy water, and beyond a descending current, becoming more rapid as we pass to the further side of the sluice, where we find a current descending with uniform velocity, the maximum limit of which will be the velocity of the water escaping from the shorter branches, provided the supply of water and the capacity of the tubes are properly proportioned.

The illustrations here given present briefly and graphically the principles applied in the McDonald system of fishway building.

5. Adaptability of the system.

The flexibility of the system adapts it to the widest range of conditions occurring in practice. An effective passage may be provided for fish over obstructions, with the supply of water that will flow through a cross section six inches square, or the fishway may be expanded so as to take the entire discharge of a river. Constructed roughly of boards it furnishes at a nominal cost the means of re-establishing in our innumerable trout streams the natural conditions of reproduction. These fishways may be made so light as to be readily portable, so that, in the season when the fish are not running, they may be stored away under shelter and thus protected from decay or destruction by ice or floods. In public parks and trout preserves, where considerations of cost are not controlling, the fishway may be built of iron in ornamental designs, and while serving its essential purpose, made to contribute to the picturesqueness of the landscape. Solidly built of stone and iron, and of dimensions proportioned to the volume of the stream, it may be made strong enough to resist the utmost force of floods and ice, and by furnishing an easy passage for shad, salmon, and other anadromous species of fish, make possible the restoration and maintenance of our valuable river fisheries, in spite of the obstructions which are the inevitable and necessary adjuncts of civilization.

6. Mode of construction.

As an example of construction we have given in Fig. 6*a* the elevation, and in Fig. 6*b* the plan of a double fishway built of timbers. It consists of an inclined sluiceway of boards, the sides and bottom of which are supported by suitable framing. The sluice has in this case an inclination of 1 foot in 3. The upper end is let into the dam so that its upper line is flush with the crest line of the dam. The lower end descends to the water below the dam and is firmly anchored by being secured by bolts either to the rocky bed of the stream or to piles suitably placed, or by other suitable means. Intermediate supports may be provided by trestling, as shown in the figure, by log cribs or by rubble masonry. The inclined flume or sluice thus established furnishes the foundation for the structure of the fishway proper, which is placed within it. Details of construction are given in Figs. 7, 8, and 9, which are on a scale one-quarter inch to the foot.

The substructure having been established, we begin by setting up along the center line of the trough or sluice the bulkheads *i i i*, &c., at intervals of 12 or 15 inches. These are made of planks 1½ inches thick, 2 feet long, and 15 inches wide, which are firmly attached to the flooring of the sluice either by spikes or bolts. Posts *h h*, &c., of 1½ inch stuff, 9 to 12 inches wide, and extending from the floor to the upper edge of the inclined trough, are now set up at similar intervals of 12 to 15 inches and firmly secured to the sides and bottom of the trough. To the posts *h h*, and bulkheads *i i*, the fifteen-inch joists are securely nailed or bolted. The floor *d* (Fig. 8), of 1½-inch plank, is next laid and nailed to the inclined joists, as shown in Figs. 7 and 8. Upon the floor *d* next set up the short return buckets, *m m*, &c. (Figs. 8 and 9), securing the same to the parts *h h* and to the floor by nailing or other suitable means. The cap *e e* (Fig. 8), made of a single 2-inch plank, is fastened securely to the sides, *b b*, the posts, *h h*, and the return buckets, *m m*, thus completing the construction.

We have here realized in timber the same construction and secured the same control of the descending current as shown in the experimental apparatus (Fig. 5). The course of the water is shown by the arrows. When a sufficient supply of water is brought to the head of the fishway we will have an average depth of waterway above the floor *d* of 10 to 12 inches. Any excess of water over the amount needed to fill the fishway will be shed over the sides, and the fishway will continue in efficient operation in any stage of water.

In the drawings (Figs. 7, 8, and 9) the open spaces between the bulkheads *i i*, &c., and also the head of the fishway, where the water passes under the floor *d*, directly from the dam, are represented as guarded by a wrought-iron grating. This is only necessary where the exposed position requires that the weak points be protected from injury by ice or drifting timbers. The grating may be dispensed with where other safeguards are made use of.

7. LOCATION.

The proper setting or location of the fishway is a matter of prime importance to secure satisfactory operation. Where the cost of the construction is considerable the location should be made under the direction of a competent engineer and after a careful study of the locality.

In all cases the following conditions are to be observed in the construction: (1) The water capacity of the fishway must be in proportion to the volume of the stream. The more water we can discharge through the fishway the more satisfactory it will be in operation. (2) The upper end of the fishway must be set at such level as to run full at ordinary spring stages of the stream. (3) The discharge from the fishway should be made close to the face of the dam. (4) The fishway must be so located as to be sheltered from ice and drift, or, when this is impracticable, it must be built strong enough to resist injury. Where these conditions are realized in the construction complete satisfaction in operation may be expected.

In Figs. 10, 11, and 12 are presented three plans of actual constructions, which will furnish useful suggestions as to location.

Fig. 10 shows plan of fishway on the Rappahannock River, near Fredericksburg, Va. The water is brought to the head of the fishway by a culvert piercing the flood-wall. The fishway is built on a slope of 1 foot in 3, and in two sections, so as to bring the discharge close to the abutment. This has been in successful operation two seasons.

Fig. 11 shows plan of fishway at Bosher's Dam, on James River, Virginia, 9 miles above Richmond. This is a later and improved design, though embodying the same principles of construction as shown in the Fredericksburg way. Here advantage was taken of the locality to shelter the way behind the high flood shown in the drawing. Two arched culverts admit the water to a sluice which conducts it to the head of the fishway. This discharge of water is too far from the face of the dam to secure the best results, and it will be necessary to erect a deflecting wall at the lower end, to turn the current around the abutment. This fishway has been in operation since the middle of May, 1883, and since the water has been turned on all the river species except the shad have been observed passing in large numbers. Very few shad have reached the dam this season, the total catch by the nets being less than two hundred.

Fig. 12 shows plan of fishway on canal dam No. 4, on the Potomac River, near Shepherdstown, W. Va. This was built in the winter of 1882, stood without injury the heavy ice drifts and floods of the late winter, and during the season just past has given full satisfaction to those who have watched its operation. The black bass and other river species have been observed to pass it in numbers and with ease. In this case the fishway is sheltered behind the abutment on the Maryland side of the river, the upper section being suspended to the abutment by stout wrought-iron brackets. The water is conducted to the head of the fishway from the crest of dam by a trunk leading around the face of the abutment.

UNITED STATES FISH COMMISSION,
Washington, D. C., August 25, 1883.

EXPLANATION OF THE PLATES.

PLATE I.

Figure 1. Illustration of the combined influence of gravity and friction upon a solid molecule while traversing a constrained path, the final direction being against gravity.

Figure 2. Illustration of the continual acceleration of a solid molecule rolling down a smooth incline under the action of gravity.

Figure 3. Illustration of the manner in which we may deliver a solid molecule from a higher to a definite lower level without acceleration by application of the principle developed in figure 1.

Figure 4. Illustration of the same fact in regard to liquid molecules.

PLATE II.

Fgure 5. Genesis of the fishway, showing how the principles developed in figures 1, 3, and 4 may be applied to deliver a current of water down a straight sluiceway, with a velocity constant after the initial acceleration at the head of the sluiceway.

PLATE III.

Figures 6*a* and 6*b*. General plan and elevation of the McDonald fishway.

PLATE IV.

Figures 7, 8, and 9. Plan and sections of a double fishway to show details of construction. Scale ¼-inch to 1 foot. This way is built of oak or other durable lumber.

The head of the way and open center is protected by wrought-iron gratings, as shown in plan and elevations. Either half of the way may be constructed and operated independently of the other half.

PLATE V.

Figure 10. Outline plan of fishway on the Rappahannock River, near Fredericksburg, Va. Height of dam, 19 feet 6 inches. The inclination of this fishway is one foot in three; width of waterway, 7 feet. The discharge of water from the fishway is close to the abutment of the dam, and the structure is completely protected from ice and floods by its location behind the guard walls.

PLATE VI.

Figure 11. Plan in outline to show location of fishway at Boshler's Dam, James River.

PLATE VII.

Figure 12. Outline plan showing location of fishway at Canal Dam No. 4, Potomac River.

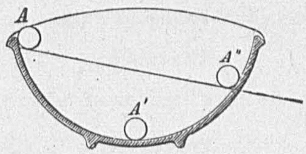


Fig. 1.

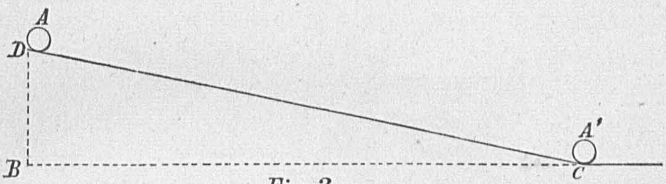


Fig. 2.

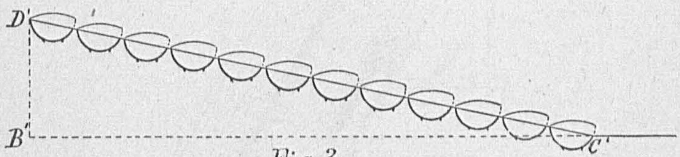


Fig. 3.

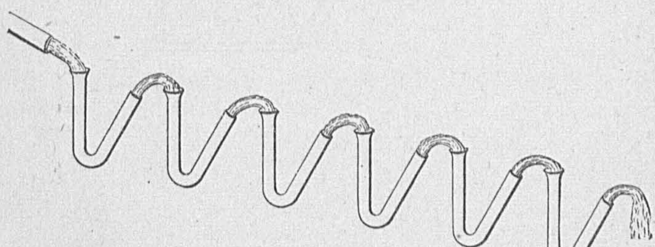


Fig. 4.

Illustrations of the physical laws applied in the McDonald fishway.

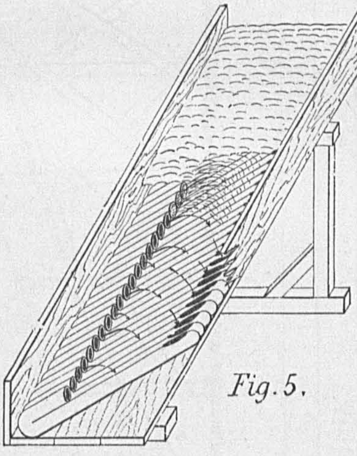
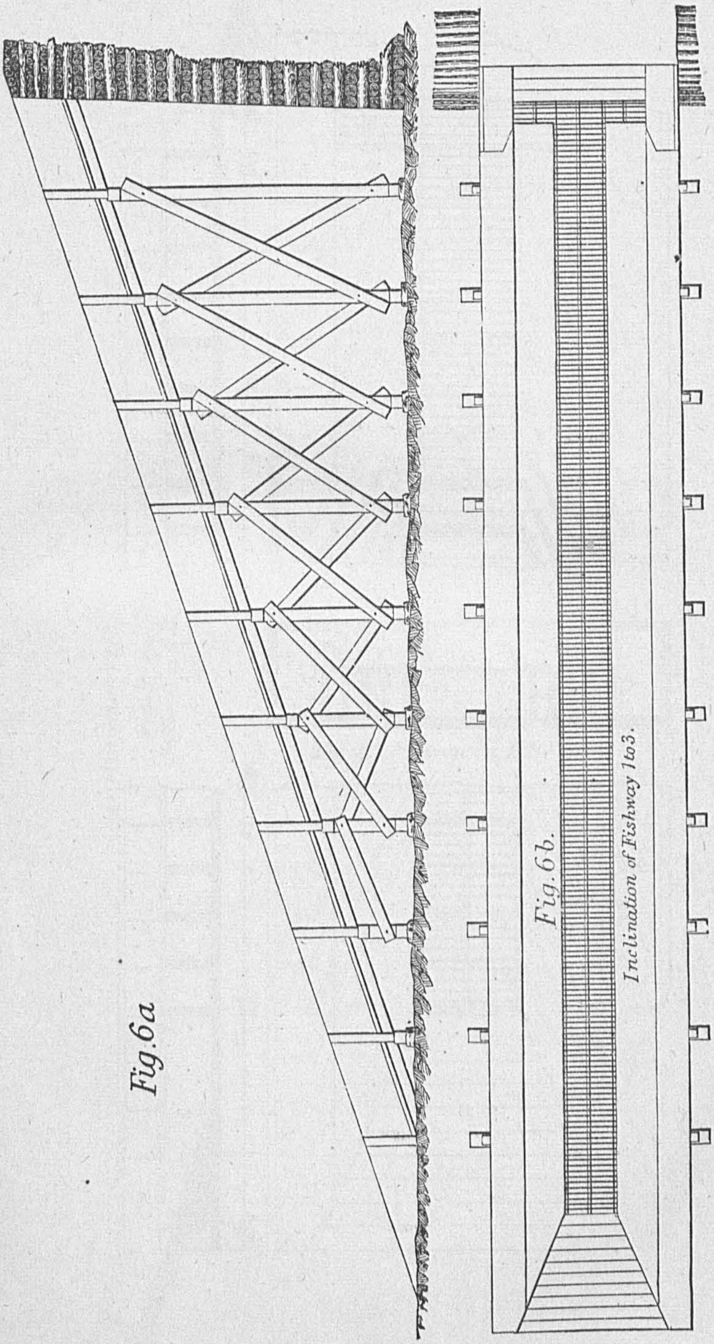
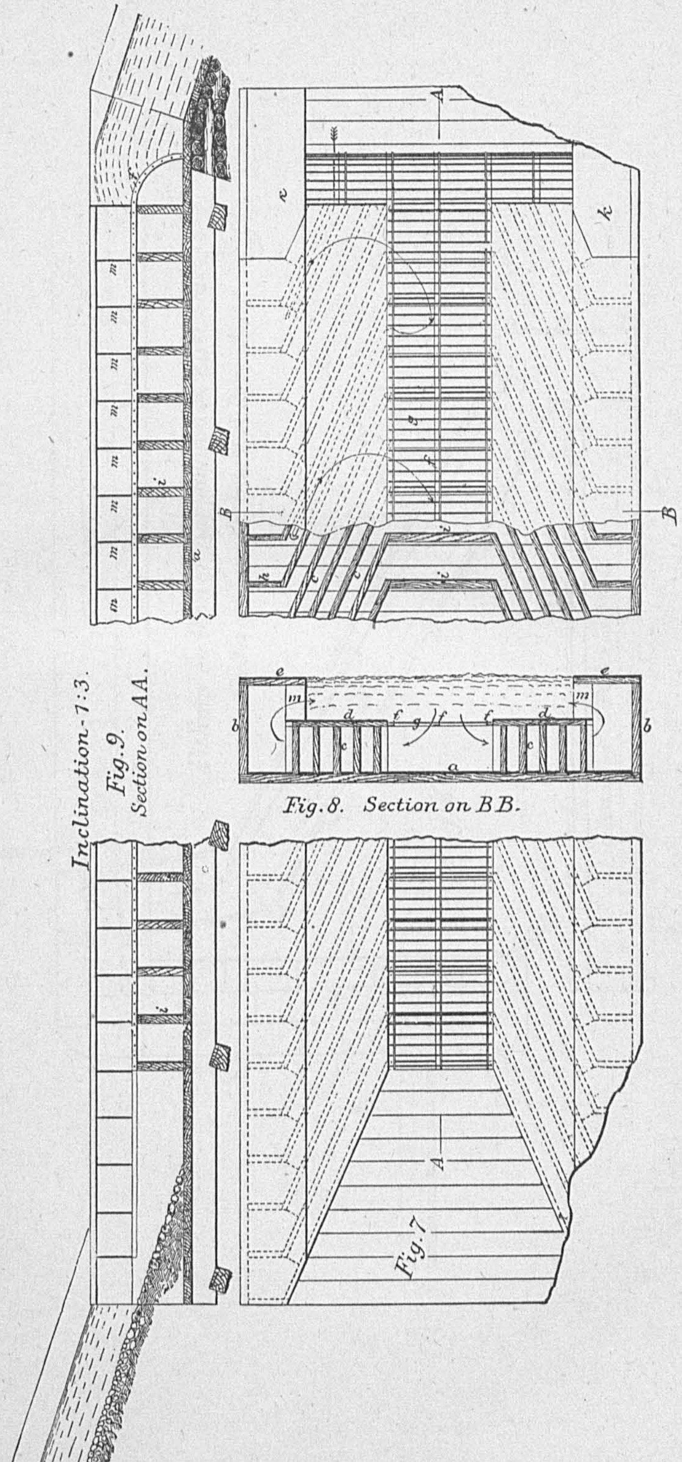


Fig. 5.

Genesis of the McDonald fishway.



General plan and elevation of McDonald fishway.



Plan and sections of a double way, to show details of construction.

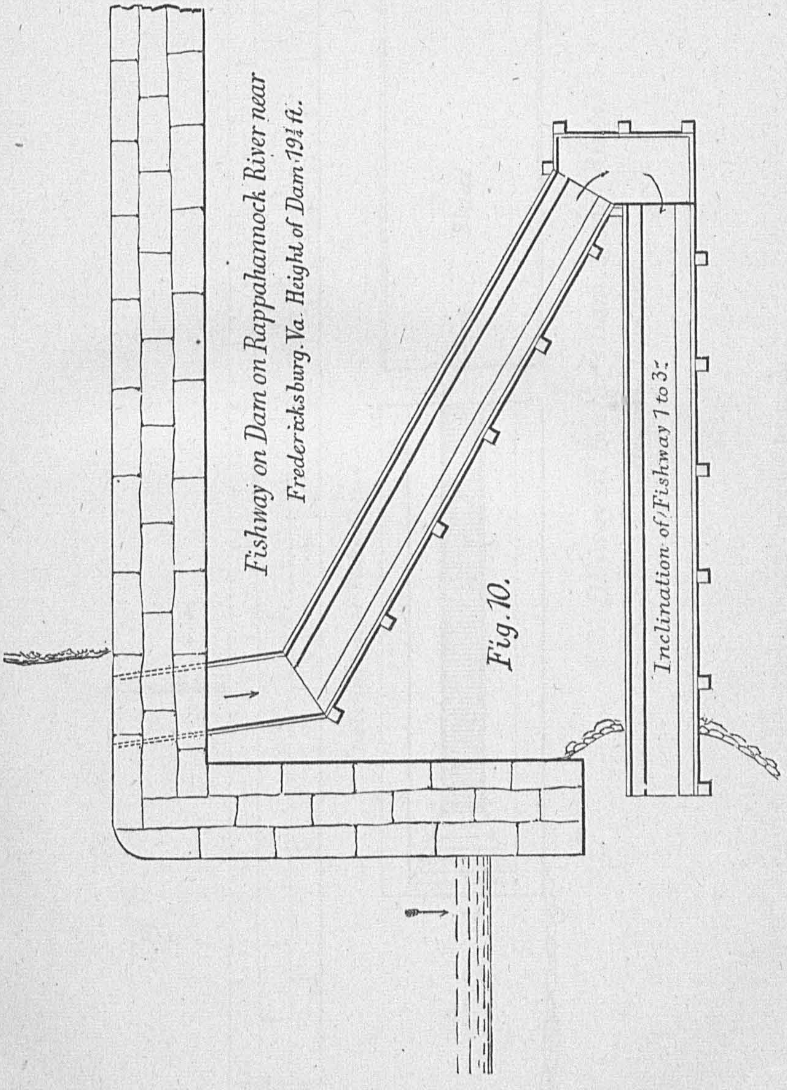
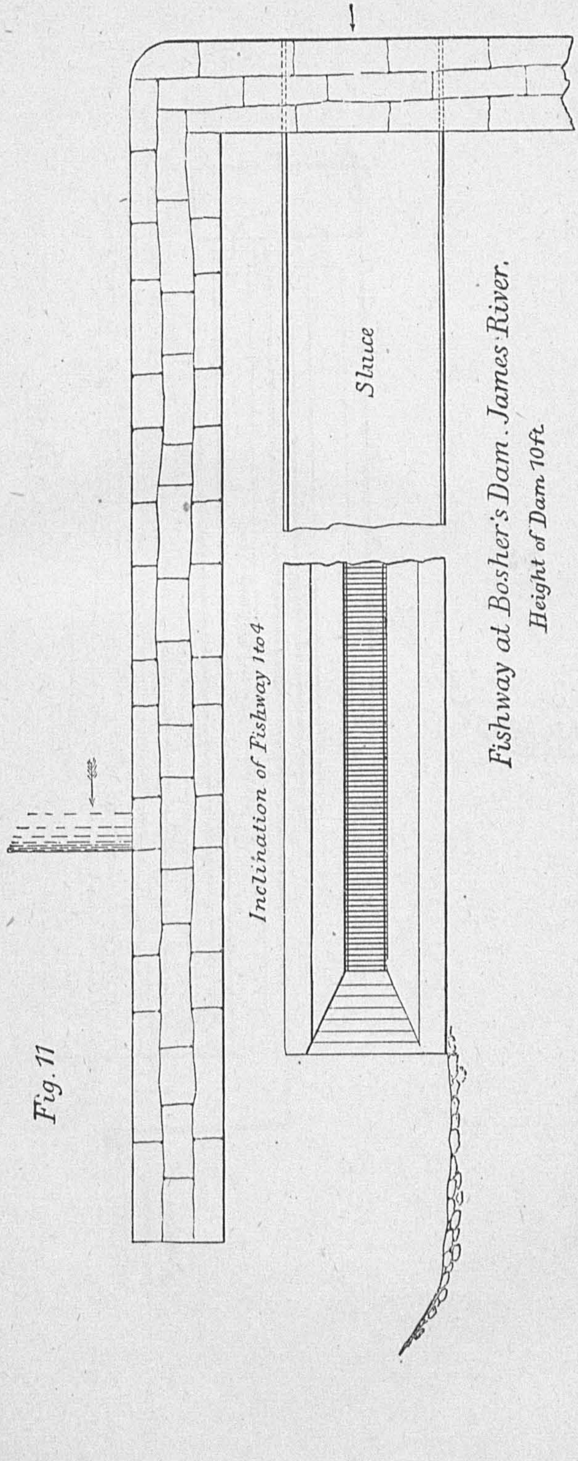


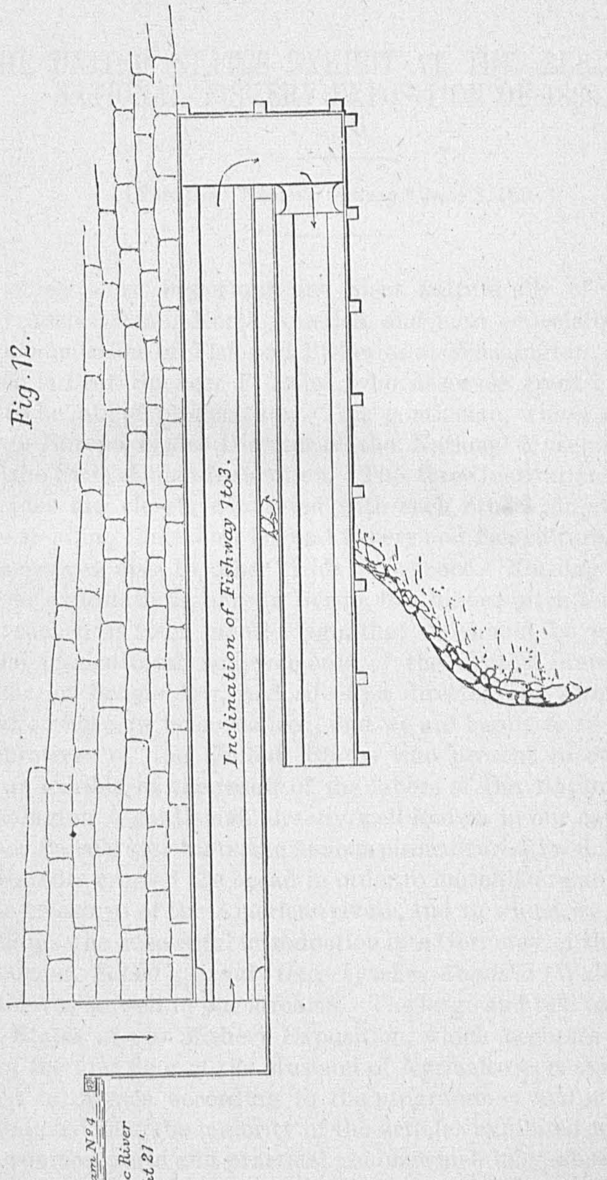
Fig. 10.

Plan in outline, to show location.



Fishway at Bosher's Dam. James River.
Height of Dam 10 ft.

Plan in outline, to show location.



Outline plan showing location of fishway at Canal Dam No. 4, Potomac River.