XXIII.—ON FISH-WAYS.

By Charles G. Atkins.

A—INTRODUCTORY REMARKS.

In the present paper, it is proposed to discuss devices for facilitating the progress of fish over dams in their *ascent* only. The question of their descent is by no means devoid of importance; but the difficulties and dangers attending this stage of their migrations are of a totally different kind from those that assail them on their ascent, and are to be met by a different set of expedients. Indeed, in most cases, neither the adult fish nor the young requires any sort of assistance in descending. If there is a sufficient body of water falling over the dam, they go with it safely and readily, tumbling down from great heights and rarely sustaining any injury. It is only where the peculiar configuration of the river and the dam or the scarcity of water leads them into dangerous rocks or mill-wheels that they require attention. The investigation of this branch of the subject is therefore of less pressing importance than that of the means of securing their ascent.

B—HABITS OF MIGRATORY FISHES.

Before discussing the mode of constructing fish-ways, it is necessary to consider briefly the habits and peculiar traits of the several species for whose use they are designed, so far as these habits and traits concern the present subject.

The only American species for which it has been thought expedient to build fish-ways are the salmon, shad, and alewife. All three of them ascend the rivers in spring and early summer in order to reach suitable places to deposit their eggs. The salmon comes both earlier and later than the other species, and proceeds immediately to the vicinity of its spawning-grounds on the upper waters, where it lies in quiet pools until the following autumn, its spawning-season. The shad comes while the river is still in full volume, later than the earliest, and earlier than the latest, run of salmon, and spawns within a short time of its arrival in some gently-flowing part of the river. It neither ascends so far nor pushes into so small streams as the salmon. The alewife, coming a little in advance of the shad, but largely in company with that species, spawns often in the still waters of gentle rivers, but more generally in lakes and ponds from the largest to the smallest size, to reach which it will, when necessary, push up extremely small brooks.

It is a notable characteristic of all these migratory species to return, for the purpose of procreation, to the very waters where they themselves were born. Thus, each river, and, in general, each branch, each lake, and each pond, has its own army of migrating fishes, feeding and growing in the sea, and sending off each season a detachment to the parent-waters to continue the work of reproduction. The instinct that leads them into their native waters, though not strictly infallible, is so remarkably strong that those fishes that stray from the true way constitute a very small percentage of the whole army. Illustrations of this truth are to be found in many marked instances. The salmon of the Kennebec, where a small area of spawning-ground is still accessible, yearly pursue the course toward the upper waters of that river, so rarely turning off into the tributary, Androscoggin, that hundreds are caught in the former to one in the latter, though in natural fitness for salmon-breeding, aside from the facilities for ascending it, the Androscoggin is certainly not inferior. In a comparison of the Penobscot and Union, the case is stronger still. This established trait has an important bearing on the question of the ascent of migratory fishes past an obstruction that has been for generations impassable. Though known facts hardly warrant the conclusion that fishes will not often try to ascend to a higher point on the river than was reached by their parents, there is nothing to forbid the conclusion that they have less inclination to seek the higher waters than they would have had if they had been born there.

The behavior of these three kinds of fishes while in the vicinity of obstructions is found to correspond in some degree to the range of their migrations. Salmon and alewives, whose migrations extend to higher and smaller streams than those frequented by shad, are found to take more readily to narrow passage-ways than the latter.

Alewives are hardy, venturesome, little fish, following the main stream where it is practicable and easy, but ready enough to turn aside and seek a narrow way around a difficult point. They have been known to rush up a fish-way between the legs of the carpenter who was giving it the finishing strokes, and a trough only eight inches wide, divided into compartments, which were connected by passage-ways only four inches wide, has afforded ready passage to large numbers of them.* They exhibit a strong, gregarious instinct, moving in dense bodies as if by a common impulse. They always move over falls by day, and their favorite time is a bright sunny afternoon. On the approach of night, they drop back and rest in still pools until the next day is well advanced. So great is their inclination at night-fall to yield a little to the current that sometimes a large body of fish that has passed out of a fish-way just at dusk will settle back into it and rest in its bays, if they are easy enough, till

*Report of the Massachusetts Commissioners on Inland Fisheries, January, 1869, p. 6.

morning. In a fish-way without bays, I suppose they would pass down quite through it. Their movements, except in very difficult places, are always leisurely. At East Machias, when ascending the rapids below the fish-ways, they are generally several hours in accomplishing a distance which they are capable of doing in a few minutes. When occasion requires, they exhibit great agility and hardiness. They will turn on their sides and push themselves up a steep inclined plane against a sheet of water not half as thick as their bodies. Nevertheless they are ordinarily easily frightened, and one dip of a net or even the sight of a moving form will often drive them back from a fall or deter them from entering a fish-way.

Salmon are less inclined than alewives to leave the main current of a river, and their superior size and strength enable them to pass with comparative ease over falls that alewives would attempt in vain. It is commonly supposed that the scaling of a perpendicular fall of six or seven feet marks the limit of a salmon's power; but it is a well-attested fact that under favorable circumstances they have surmounted perpendicular falls of more than twice that height. A case in point is Carratunk Falls on the Kennebec, where the whole river rolls over a precipice into a gorge only about 60 feet wide. The height of the fall is 16½ feet, and it is as near perpendicular as the great volume of water and the narrowness of the gorge will admit. The depth of water at the foot of the fall is unknown; a pine log more than 50 feet long, going down endwise, disappears with great velocity, but is never heard to strike bottom, and when it re-appears, after a prolonged absence, it leaps nearly its whole length into the air. I have it from several trustworthy sources that many salmon have been seen to surmount these falls. They were observed in all the reported cases to leap through the air obliquely and strike the column of falling water at the height of 10 to 13 feet from its base, and swim from that point to the summit of the fall. Only those succeeded that struck the face of the fall with head straight against the current, and the majority of the leaps were unsuccessful. This feat would probably be impossible, were it not for the great depth of the water at the base of the fall, which affords sufficient space for the salmon to acquire a great momentum. In the pond at Bucksport, salmon have been seen to leap from still water 10 feet deep and clear a hedge 5½ feet high. In passing over low falls they rarely leap, but swim up in the sheet of falling water, which must have a considerable body to make the ascent possible, a thin sheet of water often causing the salmon to expose parts of his organs of locomotion to the air; an occurrence which sends him back to the foot of the fall. From what has been said to illustrate the strength and agility of the salmon, it is not to be inferred that they will pass all falls where it would be possible for them to do so. Leaping is something rarely observed, and it is quite likely that salmon hesitate long before attempting it, and that a large part of them will never attempt it. At the Augusta dam, below which, in favorable seasons, some hundreds of salmon are caught one is so rarely seen to leap, that I have never heard of an instance, and for a salmon to surmount it by swimming up the sheet that falls over it can hardly be thought possible.

Salmon move both by night and by day. It is generally assumed by European authorities that they will pass dams more readily by night than by day. It is the opinion of the Penobscot fishermen, however, that they rarely, if ever, attempt the passage of difficult places by night. In support of their opinion, they state that at Ayer's Falls, when it was customary to fish on the dam and in the passage-way now set apart for a fish-way with dip-nets, no salmon could be caught during the night; the drift-nets plied on the shallow rapids a short distance below being meanwhile quite successful. At daylight, however, fortune deserted the drift-nets, and from that time till the day was well advanced it rested with the dip-nets on the falls.

The shad, superior to the alewife in size and strength, is far inferior in courage. Timidity is one of its prominent characteristics. It is said to be frightened by the shadow of a bridge across its path. In a broad current it sometimes surmounts impetuous rapids, but I have never heard of its ascending a perpendicular fall, and it rarely ventures to follow up a small side-current, such as would suffice for the passage of salmon and alewives. So little success has attended the efforts to induce shad to ascend fish-ways, that in discussing most of the devices noticed in this paper they will be almost entirely left out of the account.

C—THE CONSTRUCTION AND LOCATION OF FISH-WAYS.

In the planning of a fish-way, there are several important things to be considered. The fish demand that it be accessible, attractive, and easy of ascent. The parties at whose expense it is built demand that it be durable and reasonably cheap. The owners of the water-power demand that it be not wasteful of water. To meet these various desiderata requires a careful consideration of the questions of location, capacity— form, material, and mode of construction. For our present purpose, however, it will be sufficient to discuss briefly the questions of accessibility, attractiveness, and ease of ascent, and then notice the principal devices by which it has been sought to attain them.

1.—SITUATION.

Accessibility may be set down as the first essential quality. To secure t, the foot of a fish-way must be so located that the fish will readily find it. Now, as has been before remarked, salmon, shad, and alewives all follow the main current of the river until they meet some obstruction sufficiently formidable to check their progress; at the base of this they swim many times back and forth, extending the search at each turn but a short distance down the shore on either hand. If there be no convenient pool at the base of the fall, they drop back occasionally to pools farther down, but on starting afresh the chances are that they will again follow the main current, to be again baffled by the insurmountable fall. In this way they will repeatedly pass the mouth of a fish-way that opens into the main stream at some distance below the obstruction without noticing it, being attracted by the superior volume of the main river, while one whose entrance is in close proximity to the fall will soon be discovered.

The mode of securing an accessible location is sufficiently simple. It has been the general practice heretofore, in building ways for salmon and alewives, to place the upper end at the crest of the dam, or very near it. If the height to be overcome is very small, only a short fish-way is required, and it can generally be built for its whole length straight down the river, without carrying its lower end too far from the dam. But if a great length is required, the simplest way of avoiding difficulty is to turn the lower part of the fish-way at whatever angle may be required—even directly reversing it in many cases—and bring the lower end back to the vicinity of the dam. Thus, if the fish-way must be 350 feet long, it may be carried from its upper end 200 feet down stream and then brought back 150 feet, so that it will discharge its waters 50 feet from the dam. These reversed fish-ways have been built in many places, and this may be considered the most eligible form of Smith's, Foster's, and similar devices. In Pike's and Cail's spiral fish-ways, the same end is sought and attained by keeping the whole structure within a few feet of the dam, so that, on whichever side the water is discharged, it will always be sufficiently near the dam. In some cases it is practicable to place the upper end of the fish-way in a canal at such a distance below the dam that it may slope directly toward the latter and end near it. Such a location has been adopted in plans recently devised for a fish-way at Augusta, on the Kennebec. In devising a way for shad through the dam at Columbia, on the Susquehanna, the Pennsylvania commissioners deemed it essential that the foot of the fish-way should be no farther down the stream than the face of the dam, so that in searching for its entrance the shad should not be compelled to fall back at all, but should find it as a gap in the dam itself, in and above which the whole body of the fish-way was placed. So far as accessibility is concerned, such a location is perfect.

A fish-way may with propriety be located at either end of a dam which is built straight across the river and at right angles with its course, other things being equal; but it is always desirable to have it nearer to the strongest current and the main channel of approach. This desideratum cannot, however, always be secured; considerations of convenience and safety oftener dictating the location.

If the dam crosses the river obliquely, the best location is generally at the upper end, toward which the fish naturally tend as soon as they encounter the obstruction. This is illustrated by the success of the fish-way at Warren, on the Saint George, where both the obliquity of the dam and the tendency of the current lead the fish directly to the fish-way.

It is sometimes the case that the approach to the dam from below is obstructed by a natural fall of sufficient difficulty to seriously impede the ascent of fish. Under these circumstances it is often admissible to place the mouth of the fish-way at a distance from the dam, which, under ordinary circumstances, would prove fatal to its success. Departure from the general rule is, however, to be taken only with extreme caution; since an error in this respect is often irremediable.

When from any cause it is impracticable to place the mouth of the fish-way in close proximity to the dam, it is sometimes practicable to turn the fish into it by a hurdle or other artificial obstruction placed across the stream. It would be better to place the hurdle obliquely; the mouth of the fish-way being at its upper end. Extensive contrivances of this sort cannot be maintained in our larger rivers, nor in those smaller ones where timber-refuse and other rubbish abound. A hurdle extending a short distance into the stream is frequently serviceable. One has been* devised to turn shad into the fish-way at Holyoke, on the Connecticut.

2.—ATTRACTIVENESS.

The second essential requisite in a fish-way is *attractiveness*. Fish must be invited to enter, and the only known means of extending such

* The following extract from a letter of Mr. J. W. Milner throws additional light on this subject. Speaking (from personal observation) of the Holyoke fish-way, he says: "The reverted portion of the fish-way faces the dam at the point where the sheet of water coming over the crest is the deepest, and where, of course, the most ample volume of water flows. At a high stage of water in the river, the cribs at the mouth of the fish-way are entirely submerged, and the outflow is directly into the face of the strong counter-current coming from the dam. The channel-way on this side next the fish-way is quite clear of rocks, and a free, ample volume of water flows unobstructed by the end of the fish-way, and, deflected by the wing-dam, turns outward until it has passed it. Outside of the channel-way are numerous large rocks and broken, foaming water. The shad seek the open channel-way in their passage up stream, and are led, in following it, close by the mouth of the fish-way; but, feeling the strong, fresh force of the current from the dam, they strike boldly into it, not in the least tempted by the weak current from the fish-way. Standing on the cribs above, I saw this happen day after day. Frequently as many as twenty shad in a school would pass up toward the dam, and they always quickened their movement as they felt the fresh flow of the water coming.

"There were two methods which I thought of for inducing the shad to enter: one was to continue the fish-way along the wing-dam, instead of turning it up stream, and then, by means of a low wing-dam placed a short distance above the mouth, turn a portion of the strong current into the cribs of the fish-way. For a short distance it would be well to take out the bulkheads, so as to make a guide-way to the beginning of the winding current of the ladder. The other method was, to open the side of the crib next to the wing-dam, and make the outlet in the upper compartment of the reverted portion. Heavy iron rods should then be set in the rock-bed of the river in the proper order, and a heavy netting stretched upon them, in the form of one side of the 'heart' of a pound-net, in this way utilizing a principle which the fishermen make so effective in exterminating the fish in aiding them to perpetuate their race and species."

an invitation, after securing a proper location, is to pour out a fair flood of water from the lower end of the fish-way. As has already been remarked, the migratory fishes prefer a large stream rather than a small one. Though any stream, issuing from the obstruction or near it, possesses the capacity to attract them to a certain extent, the attraction of the smaller is wholly or partially overcome by that of the larger stream. A fish-way may discharge a volume so small as to escape for many days the notice of the fish for whose use it was designed. So far as can be judged from its observed conduct, a fish is guided in its ascent of a river almost solely by the current, knowing little more than that its way is upward. When it meets the obstruction of a dam, there are several distinct currents beckoning it on; there are the currents from the waste-way, the mill-wheels, and the leaks, all competing with the current of the fish-way. It commonly chooses first the largest stream, and not learning rapidly from experience, nor early losing courage under repeated and constant failure, it may pass days in repeated ineffectual struggles against the impassable flood of the main stream, alternating with unsuccessful searches for an easier way. It is quite evident that the larger the volume flowing from the fish-way the sooner will the fish find and enter it. It is a reasonable proposition that this volume should bear some definite proportion to the total volume of the river, or to that part of it which passes down by the same channel into which the fish-way empties. The only attempt to fix such a ratio of which I am informed was made by Mr. Samuel U. Roberts in 1869. In discussing the construction of salmon-ladders in Ireland, Mr. Roberts laid down the following rules:

"The least quantity which will supply a salmon-ladder efficiently is that which will pass through an opening 8 inches wide, with a depth of 18 inches of water flowing through it, and the maximum quantity need not exceed that which will flow through an opening 3 feet wide with the same depth.

"I am of opinion that between these two limits a scale may be formed which will secure an adequate supply for salmon-ladders. It occurs to me that the fair basis on which to regulate the quantity is *the extent of the rain-basin of the river*, and I am of opinion that on all new weirs constructed on rivers, whether for navigation or mill-power purposes, the minimum opening to be provided should not be less than 8 inches in width, the sill being 18 inches below the apex or top of the weir; that the depth should be fixed in all cases at 18 inches, but that the width should increase in the following proportions: "When the rain-basin exceeds 50 square miles, the width to be increased at the rate of 1 inch for every additional 50 square miles until it amounts to 12 inches; when it exceeds 250 square miles, the width to be increased at the rate of 1 inch for every additional 100 square miles until it amounts to 18 inches. When it exceeds 850 square miles, the width to be increased at the rate of 1 inch for every additional 200 square miles until it amounts to 3 feet, which may be fixed as the maximum breadth required."

In the paper from which this extract is made, Mr. Roberts instances three examples of successful fish-ways of the most approved pattern, and we may infer that his conclusions were drawn mainly from observations on their performance, which was certainly very satisfactory. Yet, if the size of the drainage-basin, or the volume of the river, be taken as a basis on which to fix the volume of water admitted to the fish-way, it is hard to see why the ratio between them should not be constant, or why the size of the fish-way should be limited while the size of the river continues to increase. It is quite probable that Mr. Roberts's maximum of 3 feet in width and 1½ feet in depth will be found insufficient for the passage-ways of fish-ways on our larger American rivers. The three examples given by Mr. Roberts are fish-ways on two Irish rivers, the largest of which, the Corrib, drains a basin of about 1,200 square miles, about the size of the basin of the Saint Croix. Between the Saint John and the Hudson are six or seven rivers with larger drainage-basins than that. The Kennebec drains 5,800 square miles; the Penobscot, 8,200; and the Connecticut, over 10,000. In point of volume, however, there does not appear to be so great a disparity. The Corrib discharges, during the summer-season, 120,000 cubic feet of water per minute, while the discharge of the Kennebec at Augusta is estimated at only 380,000 cubic feet per minute through the year;* being probably quite up to the average during May and June, when fish are ascending. The Connecticut, at Turner's Falls, in the winter of 1866, discharged at various times from 300,000 to 600,000 cubic feet per minute.† The comparison of these rivers with the Corrib is not complete without a statement of the peculiar way in which the water of the latter is used. Out of the 120,000 cubic feet flowing in summer past Galway, 100,000 are drawn away above the dam for the use of mills and navigation; only the remaining 20,000 flowing over the dam and down the main channel. Of this small residue, 720 cubic feet (being $\frac{1}{28}$) flow through the fish-way, the passage-ways of which are 2 feet square. Evidently, the salmon, having followed the main channel up to this dam, will much more readily find the fish-ways than they would if the entire volume of the river were pouring over the dam. Such will be the case in every river, and I think it quite plain, in view of these facts, that the size of the drainage-basin is not a safe basis on which to fix the size of the fish-way, but that the volume of water flowing over and through the dam, and the amount discharged from the mills in its immediate vicinity, must be considered in each individual case. The consideration of so many diverse circumstances will, of course, prevent the strict application of any rule; but it may, nevertheless, be instructive to observe the dimen-

* 200,000,000,000 cubic feet per annum.—The Water-Power of Maine, by Walter Wells, Superintendent Hydrographic Survey of Maine. Augusta: 1869, p. 91.

† Ibid, p. 106.

sions demanded in our large rivers by an application of the ratio that has been adopted in all successful fish-ways. All the successful fish-ways that have come to my knowledge have been built on small rivers, mainly, it should be stated, because their construction has rarely been attempted on large rivers, and because various unfavorable circumstances, such as a dearth of fish, have interfered with the testing of those that have been built. I do not think there is an instance of a tested fish-way for salmon and alewives on a river of larger size than the Saint Croix, which is, in drainage-basin, equal to the Corrib, in volume not much inferior, and has on its lower dam, at the head of the tide, a fish-way discharging about the same quantity of water as that at Galway, namely, 720 cubic feet per minute, which is about $\frac{1}{107}$ part of the average total volume of the Saint Croix. This fish-way has been fairly successful with alewives, great crowds of which have been seen passing through it, and it is presumed that salmon, when they could not surmount the dam itself, passed through the fish-way, considerable numbers of them being seen in the river above. The capacity of this fish-way may therefore be considered sufficient for its place.

To carry out the same ratio in the construction of a fish-way on the lower Penobscot, regarding for the moment only the total volume of the river, would require a capacity equal to the discharge of 5,133 cubic feet of water per minute, a volume which could hardly pass through an opening in a Smith or Foster fish-way less than two feet deep and twelve feet wide. Reverting now, for a moment, to the case of the Galway salmon-ladder, and recalling the peculiar features of its location, to which, perhaps, its success was largely owing, we note that the volume of water passing through it was $\frac{1}{28}$ that passing over the dam. To apply the same ratio on the Penobscot, we will assume that one-half the water is passing over the dam; the volume passing through the fish-way must then be about 6,700 cubic feet per minute, which would perhaps run through an opening two feet deep and sixteen feet wide. Thus, we find that if it is to conform in relative capacity to the tested fish-ways on the American river nearest approaching the size of the Penobscot, or to the best foreign salmon-ladder of whose performance I am informed, it must discharge either 5,100 or 6,700 cubic feet of water per minute, and this will probably require passage-ways two feet deep and twelve or sixteen feet wide. I am far from affirming that such a scale is essential; but it is worthy of notice that in building fish-ways with passage-ways only two or three feet wide on rivers of the size of the Penobscot, we are departing widely from the proportion heretofore found sufficient, reducing the relative volume, in fact, 70 or 90 per cent., and diminishing in an unknown ratio the chances of fish finding the entrance.

A large number, perhaps the majority, of the salmon-rivers of the Eastern United States are circumstanced like the Penobscot; half or more of the water at the fish-season passing over the dam. Others, among which the Merrimack at several points is a conspicuous example, send the greater part of the water off into canals to feed mills. This circumstance, so far from being anything to regret, is of positive advantage, since it lessens the volume of water required in the fish-way.

Besides the necessity of a sufficient volume of water to attract fish into the fish-way, it must be deep enough and wide enough to afford them ample room for movement while ascending it. The latter desideratum may sometimes dictate the capacity of the structure in small streams; although, in rivers of considerable size, there can be no difficulty in this respect if due care is taken to meet the imperative demand for an *attractive discharge* of water. Salmon can, and sometimes will, pass through an opening much less than a foot square;* and if there be cases where so small an opening will discharge a flood duly attractive, these dimensions will suffice. Under the same limitations, the passage-ways of a fish-way designed for the use of alewives only may be reduced to six inches square, discharging not over 40 cubic feet of water per minute.

The dimensions given are adapted to the form of fish-way known as Smith's, and to those which, like it, afford a very free passage to the water. Of this kind are Foster's and the fish-ways in use in Maine rivers before his were introduced. Those devices which greatly retard the water, such as Brackett's, will require a corresponding enlargement of the openings.

In devising fish-ways for shad, an entirely different scale must be adopted. The lack of a sufficient volume of water is doubtless the prime reason why shad have never freely ascended any fish-ways, except the two remarkably wide ones constructed at Columbia on the Susquehanna River, which give passage to from 20,000 to 50,000 cubic feet of water per minute.

The wants of the fish alone fix the minimum capacity of the fish-way; but in determining the proper maximum, we must consult the interests of the owners of the water-power, who generally bear the burden of construction and maintenance, and who are therefore affected both by the cost of the structure and by the amount of water withdrawn by it from the use of the mills or canals. The cost, which is the most important point by far, will be considered in another place. Serious intrenchment on the water-supply is not likely to occur, for the following reasons: first, the amount of water required need not exceed one-fiftieth of the average volume of the river; secondly, the extensive use of the water for mills or navigation generally greatly reduces the volume passing over the dam and down the main channel by which the fish approach the fish-way, and warrants a corresponding reduction of the amount of water needed; thirdly, the period during which it is desirable to operate the fish-ways is at a date when there is generally an abundance of water in

* At Bucksport, salmon have passed in considerable numbers down through an opening eight inches wide and less than a foot deep in attempting to reach a spawning-ground in a brook.

the rivers, and a large amount going to waste, extensive milling-operations being rarely based on anything more than the *low run* of water.

3.—EASE OF ASCENT.

All the migratory fishes are capable of stemming a strong current. Were the fish-way a simple, straight sluice, so that the whole volume of water should pass through it without bend or break, a very high velocity would be permissible. Probably six or eight miles per hour would not be too swift. The Pennsylvania commissioners have erected a fish-way for shad of such a character, with a velocity whose maximum is estimated to be ten miles per hour.* This fish-way is over a dam only 5 feet high, and with a slope of 1 in 24. To construct a fish-way of this kind over a much higher dam would be impracticable, because with the same slope the velocity of the water would be accelerated in proportion to the increase of length, and would soon become excessive; and a more gentle slope would require a structure of too great size and cost. For economy's sake, both in respect to space and expense, it is deemed better to conduct the water down a steeper grade, (about 1 in 7, 10, or 15,) and correct the tendency to excessive velocity by repeated change of direction, which is generally effected, in the main, by numerous transverse partitions. Now, a column of water moving at the rate of ten miles per hour would acquire too great a momentum to admit of such control without breaking it up into a mass of tumbling spray, in which fishes would be utterly unable to direct their course. It is therefore necessary to greatly modify the velocity. In Brackett's fish-way it is brought down to the extremely low rate of about 100 feet per minute, which enables us to turn the water at right angles without breaking the surface. In Smith's and Foster's, it is twice as great. Probably the maximum permissible in any of the kindred styles is not above 250 feet per minute, or a little less than three miles per hour. Could a fish-way be devised with a grade of 1 in 10, in which the velocity should be greater without injuriously breaking the water, and should fish be found to ascend it as readily as in a more gentle current, it would have this important advantage over those employing a lower velocity, namely, it would discharge, in proportion to its size and cost, a greater amount of water, and would therefore be more attractive to fish.

In devising means for reducing the velocity of the water, I think too little weight has been given to the friction of the sides and bottom. Any one who will compare the motion of water in an ordinary stony brook, or a trench fish-way with that in a fish-way built of timber or cut stone, will be struck with the difference in the flow; in the former a much steeper grade can be introduced without producing a dangerous or unmanageable velocity. The cause of the difference is to be sought for in the conformation of the sides and bottom, particularly of the latter. In

* Report of the State [Pennsylvania] Commissioners of Fisheries for the year 1873. Harrisburg, 1874.

the brook, not only is the shore-line exceedingly irregular, but the bottom is, for the most part, formed of small bowlders, or, if of ledge, abounds in inequalities bristling with projections like a rasp, and acting on the water in a manner aptly likened to the action of the rasp on wood or metal. In the fish-way, great pains are commonly taken to have even surfaces. These, particularly when coated with slime, as they become after a while, are as smooth and slippery as glass, presenting a minimum of resistance to the descending water, which rushes across the parts with unchecked velocity against the partition-walls. It may therefore be of great service to give an artificial unevenness to the floor and sides of the fish-way. Large timbers crossing the floor at right angles to the current will be very efficient; but there is danger that at low stages of the water they may produce a succession of little cascades, to the great disadvantage of such fishes as alewives. Still, they may be introduced far enough apart to admit of sloping boards on the lower side. Another mode, applicable to both sides and floor, is to stud them with sawed strips of timber, say one or two inches in thickness and width, nailed on several inches apart at right angles to the current.*

A fish-way must be free from all such false or complicated currents as would mislead or perplex the fish. It is not to be supposed that they are guided by any knowledge of localities or directions, but simply by the downward motion of the water. To make head against the current is their steady aim, no matter whether it leads them directly forward or to right or left, so long as the turns in the course are not too sharp for their flexible bodies to follow. A path that appears very crooked to us may be straight enough to them, and is just as good as a straight path so long as it leads them constantly upward. In an eddy, the fish may go round and round in the same circle at a great expense of time, and a slight expense of strength too, but effecting nothing in progress. A similar waste of time and energy occurs in following up a side-current which is closed above by some impassable barrier. It is well known that in fish-ways consisting of series of pools, with narrow passage-ways from pool to pool, the greater part of each pool is occupied by a large eddy, wherein certain migratory fishes, notably alewives, collect in great numbers, and lie stemming the gentle current, or carelessly revolving with it, small numbers at each revolution leaving the main body and shooting up into the next pool above. It is not an easy matter to determine their motives in pausing so long in their upward journey. Experts entertain diverse views. The late N. W. Foster, when his attention was called to the matter, replied that such idling was in perfect keeping with the behavior of the fish when passing natural obstructions, and was not to be regarded as in any degree objectionable. Others say that the fish do not know which way to go, and that they

* I am indebted for this suggestion to Mr. E. A. Brackett, of Massachusetts. I do not know whether the device has been tested, but it certainly appears to be a practicable mode of reducing the velocity.

sometimes lie there in perplexity, until, wearied by exertion, drunk and giddy from the continual whirling, they abandon the attempt and fall back out of the fish-way. That the fish will sometimes be so perplexed as to back out of the fish-way is sufficiently plausible to warrant the avoidance of the causes that lead to it, even at considerable cost. It is also quite likely that fishes, like other creatures, are capable of being made dizzy by continual whirling; but I can hardly think it possible that this ever occurs in the pools of any well-proportioned fish-way of any of the styles that have been in vogue in the United States during the last ten years. Nor does it appear likely that the expenditure of strength in stemming eddies is ever sufficient to be of great moment. The loss of time, however, is a serious matter. While in a fish-way, as well as below any barrier, fish are liable to be turned back by fright, or, in the case of alewives, by the approach of night, and delayed perhaps for many days in their journey, and exposed so much longer to the various mischances that beset them. The quicker, therefore, they can be got through the fish-way and past the obstruction the better.

It was formerly supposed that fishes required frequent opportunities for rest, and no plan was thought complete which did not include a number of pools for that purpose. The general tendency of the results of more recent study is to the conclusion that no such resting places are necessary; the fishes being capable of long-continued exertion, and accomplishing the ascent with much greater speed and certainty when kept close at their task than when allowed to idle along in pools and eddies.

Thus it appears that eddies are of no value as resting-places, because they are not needed, and that they are probably, to a certain extent, positively injurious by delaying the advance of the fish. They may therefore be dispensed with, not only without detriment but probably with advantage. Taking this view of the case, our aim will be to produce a simple and uniform flow of water. Perfection in these respects is neither practicable, nor, as many instances prove, necessary. There are not wanting instances of fish-ways with large and strong eddies that worked admirably; and even in the best elaborated fish-way that has yet been introduced, the eddying and swirling of the water is not entirely obviated.

D—DEVICES WHICH ARE IN USE OR HAVE BEEN PROPOSED.

Fish-ways may be classified with reference either to their details or their general arrangement.

With reference to details they may be grouped thus:

Gap.

Trench, ditch, or "Cape Cod" fish-way.

Oblique groove:

1. Single groove.
2. Brewer's.

Step:
1. Box or "pool" fish-ways:
   (*a*) Overflowing, (old style.)
   (*b*) With passage-way cut down to floor, (Smith's.)
   (*c*) With passage-way submerged, (Cail's.)
2. With contracting galleries, (Pike's.)
3. With transverse sloping floors, (Steck's.)

Inclined plane, without steps:
1. Plain, (Pennsylvania.)
2. With partitions at right angles:
   (*a*) Common style, ("rectangular compartment.")
   (*b*) Brackett's.
3. With oblique partitions:
   (*a*) Foster's.
   b) Swazey's.

With reference to general arrangement they may be again classified thus:

1. Extended.
2. Reversed.

These two forms have been applied to most of the step and inclined-plane fish-ways, and can be adopted with any of them.

3. Spiral, (Cail's; Pike's, &c.)

This form is an essential feature of Pike's, and may be combined with the details of most of the step and inclined-plane fish-ways.

1.—GAP.

The simplest form of fish-way is a gap in the dam. This appears to have been much in use in British rivers, where it receives the name of "Queen's gap." In low dams, it answers well for salmon. In America, it has occasionally been resorted to for alewives; and in dams built of plank, it can be made by the simple removal of one or two perpendicular planks, forming an opening quite to the bottom of the stream, and, if circumstances be favorable and the height be not great, it works well and saves the expense of a permanent structure. The only instance of a permanent gap-fish-way that I have seen is at Milltown, on the Saint Croix, where wing-dams are built from either shore obliquely up the stream, and separated at their upper ends by a space several feet wide. Where circumstances permit a dam to be built in this way, it forms the best fish-way that could be devised.

4.—TRENCH, OR CAPE COD FISH-WAY.

When a dam is too high to admit of the use of the gap, a more elaborate contrivance is necessary. The rudest, and in some cases the easiest to build, is what may be styled the trench-fish-way, in which a sufficient stream of water is conducted around the dam over the ground, in a trench or in a natural crevice or ravine, the velocity of its flow being moderated by the unevenness of the bottom and sides, by turns in its direction, or by rude walls of stone, crossing it at convenient points. It commonly assumes the form of a series of pools, gently flowing or eddying, connected by short runs of swift water. In operation, it is when well located, very successful, and being at the same time cheap, is perhaps to be preferred to any other form, where the facilities exist for its construction, and there is no special reason to grudge the extra volume of water that it requires over the more artificial kinds. A good many fish-ways of this form have been in use in New England. In Massachusetts it has received the name of "Cape Cod fish-way." In Maine the most notable is at Damariscotta Falls. Damariscotta River is frequented by alewives, affording no suitable breeding-grounds for salmon or shad. Tradition says that in its natural state not even alewives entered it in any greater numbers than might be supposed to straggle in from the neighboring Pemaquid river. They could not surmount the fall, which is about fifty feet high, rushing down over a rugged ledge. About 1806 the inhabitants built a fish-way, consisting of 20 or 30 pools, in a crevice of the ledge. The alewives rapidly increased, and have yielded large annual returns down to the present time. A few years since the catch was estimated at 1,200,000, which was said to be considerably below the former yield. There are several places in this fish-way that are more difficult for the fish to ascend than any Foster fish-way that I ever saw, yet it seems to meet the wants of the alewives.

At Brooksville, Me., there is a trench-fish-way around a dam 18 feet high, which has a pretty steep grade, without pools or considerable bends, yet it is quite effective. Alewives are the only fish ascending it, and they accomplish the ascent without difficulty.

3.—OBLIQUE GROOVE.

The single oblique groove leading in a straight line down the face of a dam from its apex to the water below has been tried in the British islands and found utterly useless. Its faults are thus described by Mr. Samuel U. Roberts, of Galway, Ireland:

"The velocity of the water which enters the groove at the apex of the weir increases in its descent down the inclined plane of the groove, its depth becomes proportionately diminished, and it is utterly impossible that any salmon can pass up it. It is true that when water is flowing over the apex of the weir, additional water will be gathered in the groove, where it is formed diagonally across the apron of the weir; but this water enters the groove at *one side only*, and the fish is compelled to swim against the current diagonally, which is unnatural. Any large quantity of water discharged over the apex of the weir will sweep fish out of the groove; while in dry weather, the thin, rapid stream of water on the lower portion of the groove will render it impossible for any fish to ascend."

The two devices patented by J. D. Brewer, (Plate XXII, fig. 6, first device; Plate XXXII, same in operation; Plate XXXIII, second device,) of Pennsylvania, are combinations of oblique grooves sunk in an inclined plane, and conducting streams of water in a zigzag course down to the water below. The first* provides for a single simple stream, turned by very sharp angles. In the second, the stream is divided at regular distances into two, which, after running out to the opposite sides of the fish-way, are brought again together in the center. Both are designed to be used at various stages of water, even when a considerable volume is pouring over them. In the latter case, the tendency will be toward a violent rotary motion in the grooves; and at all stages of water there is danger of the velocity of the current and the violent boiling of the angles being too hard for fish to encounter.

4.—STEP-FISH-WAYS.

The peculiarity of all the devices grouped under this head is a level floor to each division of the fish-way, the descent being accomplished by a succession of falls or steps. The common form of the divisions is nearly square, but in Steck's and Pike's they are long and narrow. What is commonly known as the old "pool" fish-way (Plate XXII, Fig. 4) consists of a number of boxes, placed in a series below the apex of the dam in such a way that the water pours over the top of each box into the next below it in a succession of cascades. The width of the sheet is equal to the length of one whole side of a box. This device has been tried in various British rivers, but has proved unsatisfactory. In America it has been tried, and, wherever tested, found radically defective. When the water is high, its motion in the boxes becomes so violent that no fish can stay

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* *Brewer's Improvement in Chutes and Fish-ways.—United States Patent-Office,—James D. Brewer, of Muncy.*

(Specification forming part of letters-patent No. 126257, dated April 30, 1872.)

To all whom it may concern:

Be it known that I, James D. Brewer, of Muncy, in the county of Lycoming, and State of Pennsylvania, have invented certain new and useful improvements in chutes for the passage of fish; and I do hereby declare that the following is a full, clear, and exact description thereof, reference being had to the accompanying drawing and to the letters of reference marked thereon, which form a part of this specification.

The nature of my invention consists in a series of isosceles or equilateral triangles extending from the opposite side-walls of the chute of a dam, and laid in the bottom thereof so as to form a zigzag course, and leaving an open space for the passage of fish up and down said chute.

In order to enable others skilled in the art to which my invention appertains to make and use the same, I will now proceed to describe its construction and operation, referring to the annexed drawing, in which is represented a perspective of my chute.

A represents the bottom, and B B the side-walls of the chute of a dam. On the bottom A, and extending from the side walls B B, are laid a series of isosceles or equilateral triangles, C C, forming a zigzag course, and leaving an open space, *a*, of about twelve inches wide, more or less, for the passage of the fish up and down the chute. The triangles C C are laid on two stringers, which extend up and down the chute, and in them a moment, and with low water the sheet pouring over the rim of each box is so thin as to deter fish from attempting the passage. To leap from box to box would be easy enough for salmon and not beyond the power of alewives, but neither of these fishes is *willing* to leap an obstruction. Probably salmon never leap a fall until all other means of passing have been tried many times in vain, and perhaps, as has been before remarked, many of them will never leap. The fish-way built at Lowell, on the Merrimack, in 1866, was after the box-pattern, arranged very nearly as in the illustration of the box fish-way. It was very solidly built, with boxes about twelve feet square. Its location was such that the amount of water entering it could not be regulated, and consequently it was frequently useless, either from floods or drought. At another place in Massachusetts a fish-way of this kind was fairly tested in the presence of a multitude of alewives. "At the Mystic Water-Power Company's dam in West Medford," say the Massachusetts commissioners,* "was a step-fish-way, consisting of a number of deep boxes, each communicating with that above by a little fall. Nothing could be easier than this ascent. The alewives swarmed in thousands at the foot of the dam. A few would jump the first and second, and even the third fall. Beyond this not one would go; nay, they would turn about and come down again."

5.—SMITH'S FISH-WAY.

Poor as the "pool" fish-way is, it is easily altered into a very efficient form. It is only necessary to cut a narrow passage through the wall

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the triangles are secured to said stringers by means of iron bolts or clamps. The triangles and bottom of the chute are to be paved with stone or other suitable material.

By means of this arrangement, fish are enabled to pass up streams obstructed by dams or slight vertical falls, or natural vertical obstructions, when not too elevated.

In addition to this, it will be found that water running through a chute of this kind will have a tendency to keep crafts descending the chute in the center, and thus secure to them a safer passage in their descent. In the present chutes, the force of water confined in a narrow space has a tendency to raise in the middle, and thus throw a raft or ark or other craft out of the center to one side or other, and sometimes obliquely across the chute. It also breaks the force of the water, and thus protects the bottom of the chutes, and will have a tendency to prevent them from bursting up or being washed out and forming breakers, so destructive to lumber-rafts and even the lives of watermen.

I am aware of the existence of Daniel Steck's patent of June 26, 1866, and do not claim anything contained therein; but—

What I do claim, and desire to secure by letters patent, is—

A series of isosceles or equilateral triangles, extending from the opposite side-walls of the chute of a dam, and laid and secured in the bottom thereof, substantially in the manner and for the purposes herein set forth.

In testimony that I claim the foregoing as my own I affix my signature in the presence of two witnesses.

JAMES D. BREWER.

Witnesses:

WM. BRINDLE.

J. M. M. GERNERD.

* Report of the [Massachusetts] Commissioners of Fisheries for the year ending January 1, 1870, p. 4.

which separates pool from pool for the water to flow through, instead of pouring over the top of the wall, and we have a device by which salmon and other fish can pass from the bottom to the top by swimming instead of leaping. This improvement was made in Scotland about 1840, by Mr. James Smith, of Deanstone. His fish-way appears to have had compartments, or pools, nearly square, two or three feet deep, with level floors, a step from each pool to the next, and passages about one-fifth the width of the pools, opened at opposite corners. This form was remarkably successful, and became the means of repeopling many rivers.

The salmon-ladder at Galway, on the river Corrib, (Plate XXII, Fig. 1; Plate XXVII, Fig. 1,) perhaps the most successful known, is constructed after this pattern. The weir crosses the river obliquely, is only 5 feet high, but quite impassable. The fish-way is located at its upper angle, is 46 feet long, divided into five pools nearly 10 feet square, which are connected by narrow passes; the inlet is two feet square, and the average depth of water in the pools is 14 inches. The volume of water flowing down the river Corrib, at Galway, during the summer, is 120,000 cubic feet per minute. Of this total, 100,000 cubic feet are led off to the mills and canals, 19,280 cubic feet pass over the dam, and 720 cubic feet per minute pass through the fish-way, which thus consumes $\frac{1}{160}$ of the total volume of the river, and about $\frac{1}{28}$ of the amount that passes to waste down the main channel. In 1853, the year when this fish-way was first opened, the catch of salmon in the river was only 1,603. In 1864, it had risen to 20,512. The latter year 40,000 salmon are estimated to have passed up through the fish-way. Mr. Roberts says, "It is not unusual to count the salmon passing up at the rate of 140 or 150 per hour, and I have no doubt but that at night they ascend in much larger numbers."*

Two other successful Smith fish-ways exist at Ballysodare (Plate XXVII, Fig. 2) and Collooney, in the county of Sligo, Ireland. Both of them, being very long, are reversed, so that the lower end in each case is brought close to the fall. At Ballysodare, the fall is 19¼ feet; the fish-way is 174 feet long, divided into 15 pools, each of which is 10 feet wide and 11 feet long, with an inlet 10 inches wide and 2½ feet deep in ordinary. The fish-way at Collooney closely resembles the above. The obstructions on this river were natural and precipitous, and shut salmon out of the river completely. After the ways were built, salmon ascended freely, in very small numbers at first, but increasing so fast, that eleven years later 10,000 were caught in a single season. The Smith fish-way is undoubtedly good enough for salmon; it is, perhaps, liable to be difficult for alewives, but the addition of a slope, instead of an abrupt fall at each step, would go far toward making it easy for them.

6.—CAIL'S FISH-WAY.

This is a recent invention of Mr. Richard Cail, mayor of Newcastle-on-Tyne, England. It differs from Smith's in having the passes entirely

* Fourth report of the Commissioner of Fisheries of the State of Maine for the year 1870, p. 41. (See illustration.)

submerged, opening 12 or 14 inches square at the bottom of each pool, and midway of its width instead of at one side. The inlet is made larger than any of the subsequent passages, so that the pools are kept full. The dimensions adopted by Mr. Cail are as follows: Pools at least 6 feet square; bottom of first pool 4 feet below the crest of the dam; each of the subsequent pools successively 18 inches lower than the one that precedes it; inlet 14 inches square; other passages 12 inches square. With pools 3 feet deep the passes are nearly 2 feet under water. The theory of the inventor is that the water in each pool acts as a cushion to the inflowing column, retarding its velocity sufficiently for practical purposes. This device* has been tried at Dinsdale, and pronounced successful with salmon. Judging merely from the plans and descriptions, it does not appear to have any advantage over Smith's and similar contrivances. Though fully satisfactory with salmon, its success with alewives would be doubtful.

7.—PIKE'S FISH-WAY.

This (Plate XXIX, fig. 1, perspective view; fig. 2, ground-plan) is the invention of Robert G. Pike, esq., of the board of commissioners on inland-fisheries of the State of Connecticut. It differs from any yet described in having long, narrow galleries instead of short pools. The floors are level, and the descent accomplished by easy steps of 3 inches each. The velocity of the current is checked by change of direction and by the convergence of the sides of the galleries. For the sake of economy in space and material, the galleries are built side by side, without waste-space, and arranged in a sort of spiral. In regard to dimensions, Mr. Pike writes as follows:

"I propose to build fish-ways upon this plan, (for falls of 3 to 8 feet height,) with passage-ways 2½ feet wide, narrowing to 18 inches; the sides to be 2 feet or 30 inches high, and the fall not *less* than 1 in 25 or 30. The saving of material in this form of fish-way is not far from 35 per cent., to say nothing of the extensive masonry and cob-work usually required in long fish-ways."

"In making one circuit of a fish-way of the above dimensions, the water traverses 7 galleries, having a total length of 68 feet, and falls over 14 steps of 3 inches each, which gives it a total fall of 3½ feet to each circuit. Having reached the end of the circuit, the water passes *under* the point of beginning, and pursues its course through a second circuit, which is precisely like the first. Between the several floors of the spiral there is thus a space of 3½ feet, of which about one foot can be left open in the outer walls for the admission of light. The inner galleries are lighted by smaller apertures. The compactness, economy, and easy grade attained by this device are remarkable, and I think entitle it to be considered the most valuable contribution to the science of fish-ways since the invention of Smith."

* See illustration.

8.—STECK'S FISH-WAY.

The invention of Daniel Steck, (Plate XXII, fig. 2,) of Pennsylvania, differs from Smith's in having the partition-walls placed very near together, giving long and narrow pools running across the fish-way, and in having the floor of each pool slope upward from the entrance to the outlet. The advantages of this plan are, first, that it enables the builder to accomplish the descent in a much shorter distance, thus bringing the foot of the fish-way nearer the dam; and, secondly, that it avoids eddies, the pools being too narrow to permit them. The disadvantages are that it requires the occupancy of a great breadth of the dam, and that, when the supply of water is scanty, the fall at each step will be an impediment to fish.

9.—INCLINED-PLANE FISH-WAYS.

The fundamental distinction of these from the step-fish-ways is that the descent is accomplished by a general inclination of the floor instead of steps. The fish-ways of this class requiring notice are the Pennsylvania style, the common rectangular, Brackett's, Foster's, and Swazey's. All except the first named are built with compartments to check the velocity of the current.

10.—THE PENNSYLVANIA FISH-WAYS.

These are two structures built by the State of Pennsylvania in the dam at Columbia on the Susquehanna River. They are both perfectly plain open sluices, entirely beyond precedent in dimensions and ease of grade, and distinguished from all the common styles by being located in and above the dam, instead of projecting in front of it, so that to the ascending fish the entrance to the fish-way appears as a simple gap in the dam.

The first (Plate XX, fig. 3, plan in outline; fig. 4, profile in same) was built in 1866, at a point 1,500 feet from the right bank of the river; the total length of the dam being 6,800 feet, and the height of the fall about 6 feet. The fish-way is 45 feet long, 20 feet wide at the upper end, and 40 feet wide at the lower end. The widening of the floor is effected by offsets, with the design of affording resting-places for fish; (this feature was omitted from the later plan.) The grade is 1 in 15. The outlet is on a line with the face of the dam. Both fish-way and dam are of heavy crib-work, filled with stone and furnace-cinder.

Uncertainty existing as to the success of this structure, a still larger one (Plate XX, fig. 1, plan in outline; fig. 2, profile in same) was built in 1873, at a point 2,500 feet from the left bank, where it was thought that shad congregated when stopped by the dam. The new fish-way is of a uniform width of 60 feet, is 120 feet long, and has a grade of 1 in 35. Colonel James Worral, the engineer who designed both fish-ways, estimates the velocity of the current in this one to be less than 10 miles per hour.

The large size of these fish-ways is demanded by the peculiar character of the shad, for the use of which they are designed. They are of too costly a character to be used on high dams, even if it were possible to conduct a body of water down a long open plane like this without the attainment of too great velocity. The fish-way of 1866 may have given passage to some shad, but has not met the expectations of its builders. That of 1873 has had one season's trial without fully establishing the fact of its success.

11.—THE COMMON RECTANGULAR FISH-WAY.

This (Plate XXXI, in operation) is apparently the original style of the inclined-plane fish-way. The partitions are run at right angles with the sides of the fish-way, making rectangular compartments, (commonly square,) with passage-ways one-eighth or one-fourth the width of the fish-way, cut quite down to the floor, and placed alternately against the right and the left side. This is very closely like Smith's in form and action, being in the latter respect almost identical when well supplied with water. In case of a scanty supply of water, the advantage is with the inclined plane, particularly for such fish as alewives. This device was in common use in the eastern part of Maine for many years previous to Mr. Foster's improvements, which were made about 20 years ago, and is probably of as early origin as Smith's. When well proportioned and located, it is very successful with both salmon and alewives. Among the various modifications introduced, the following deserve notice:

First, to avoid the violent swirling of the water, which takes place when the floor is an interrupted plane, the bottom of each passage-way is blocked up a certain distance above the floor, resulting in an increase of the depth of water in the compartments without increasing the volume flowing, and making a perpendicular fall at each passage-way. In the latter result lies the only disadvantage, and this can be overcome by placing against the lower side of the blocking an inclined plane, which shall support the descending body of water. It should be remarked that the blocking of the passage-ways turns the structure into a step-fish-way, and that the same mode of overcoming the difficulty of the perpendicular fall may be applied to any step-fish-way.

Secondly, to check the force of the water across the pool, and thereby prevent a difficult cross-current in the passage-way, an arm is attached to the upper side of each partition-wall and at right angles with it. This modification has been many years in use at Warren on the Saint George River.

Thirdly, to avoid the large eddies and accompanying waste of space caused by the large compartments, the partitions are placed nearer together. When the distance between the partitions is equal to the width of the passage-ways, the latter being, say, one-third or one-fourth the width of the fish-way, eddies are almost wholly avoided, and the economy of space is so great that a grade much steeper than ordinary can be adopted. A combination of this and the first modification is strongly recommended.

12.—BRACKETT'S FISH-WAY.

Invented and patented by E. A. Brackett,* (Plate XXI, fig. 6, plan; Plate XXII, fig. 5, illustration for patent; Plate XXIII, fig. 1, plan of fish-way at South Hadley Falls, Mass.; fig. 2, elevation of same; Plate XXV, plan of fish-way at Brownville, Me.; Plate XXVIII, perspective view,) of the board of commissioners on inland-fisheries of Massachusetts. The distinctive features of this fish-way are the form and arrangement of the partitions and arms, in the device of which the moderation of the velocity of the current has been the main thing aimed at. The most complete success has been attained. The water flows very gently, without breaking or forming strong eddies; and alewives and other fishes ascend it with the utmost ease, passing almost without hesitation through its whole length. Fish-ways of this pattern have been introduced very extensively in Massachusetts and several other New England States. When salmon are the only fish to use it, a very steep grade, say 1 in 6 or 7, could probably be adopted to advantage; but as ordinarily built, in alewife-rivers, the grade adopted is about 1 in 10. The style of arrangement will be readily understood from the illustrations.

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* *Brackett's improvement in fish-ways.—United States Patent-Office.—Edward A. Brackett, of Winchester, Mass.*

(Specification forming part of letters-patent No. 132349, dated October 22, 1872.)

To all whom it may concern:

Be it known that I, Edward A. Brackett, of Winchester, in the county of Middlesex, and commonwealth of Massachusetts, have invented certain improvements in fish-ways, of which the following is a specification:

The nature and purposes of a fish-way, so called, are, as is well known, to enable fish to overcome the obstacles of a dam and to ascend streams which would otherwise be inaccessible; and the primary object of this invention is to provide a means whereby the otherwise rapid current of the fish-way may be reduced to a sluggish stream of uniform or practically uniform speed throughout, whereby fish may ascend or descend, or rest at their leisure. My improvements consist, first, in extending a fish-way up stream through a dam, and so as to extend some distance above the latter, and in providing said fish-way above the dam with a series of water-inlet ports of various heights in order to accommodate the various stages of water and avoid the great pressure which would otherwise result from high water or a flood; and, secondly, the nature of these improvements consists in the construction of the trough or chute of a fish-way by means of an oppositely-arranged series of abutments or bulk-heads, or their equivalents, whereby the original current is diverted into a circuitous or sinuous course, and a series of eddies produced, which retard the speed of said current to any desired extent, substantially as hereinafter stated.

In the drawing [Plate XXII, fig. 5] accompanying this specification, I have represented, in Fig. 1, a vertical section; in Fig. 2, a side-elevation; and, in Fig. 3, a plan of my improved "fish-way."

In these drawings, A is supposed to represent the location of the dam of a river or stream into which a fish-way is to be introduced.

In carrying out the purpose of my invention, I provide a rectangular oblong trough, or box, B, closed at the sides and ends, with the exception of one or more water-discharge ports, *a*, at its lower or down-stream end, and several water-inlet or supply

13.—FISH-WAYS WITH OBLIQUE PARTITIONS.

Foster's improvement (Plate XXI, fig. 3, plan; fig. 4, same, modified as built on Penmaquan River, Maine; Plate XXIV, fig. 1, location of fish-way at Union Mills, Saint Croix River; fig. 2, plan of same; fig. 3, side-elevation of same; fig. 4, cross-section showing shape of passage-ways; Plate XXX, fish-way closed) consisted in oblique partitions crossing

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ports, *b*, b^1, b^2, &c.; at its upper end, the trough or box being placed within the stream in a sloping position and projecting through and extending somewhat above the dam, as shown in the drawing; the slope of the said trough or box being varied with circumstances, the character of the stream, and the velocity to be imparted to the current passing through it. The inlet-ports *b*, b^1, b^2, before named, are placed at different points, up and down, of the stream, and consequently admit water to the trough at different altitudes; the port *b* being the highest and receiving the water at the high stage, and the port b^2 being the lowest of the series and receiving water when it will not enter the upper one.

Having thus seen how I control and regulate the admission of water to the chute B, I will now explain how I guide its course through the same, and in so doing carry out the primary object of my invention—that of retarding artificially the rapidity of the current. To this end I dispose within the chute or box A, and generally throughout its length, a series of abutments, *d*, *d*, *d*, &c., disposed at regular or irregular distance asunder and extending partially across the width of the chute, the abutment of one side being disposed opposite the recess formed by the two opposite adjacent abutments. The abutments *d* are not limited in number nor arbitrarily in position, but are arranged substantially as stated. Each abutment, or deflector, *d*, is formed with one or more bends or wings, *e*, *f*, &c., which extend longitudinally or thereabouts of the length of the chute, in order that the current of water intercepted by the abutment shall be compelled to take an upward or return movement for a short distance before passing to the next ensuing abutment to be again intercepted and diverted. In this manner, the current of water entering the head of the chute is continually interrupted and diverted from a direct course, a series of eddies being the result, following each other in such rapid succession as to retard the current throughout the entire chute. As the only head-way the water can attain is in passing from one abutment, or deflector, to another, and as these may be so near to each other as to almost entirely reduce the stream to a continuous series of eddies, the water makes its exit from the chute at about the same velocity with which it courses through the upper part thereof, and this velocity may, of course, be increased or diminished, according to the number of deflectors.

In a chute, or fish-way, constructed essentially as above described, the fish encounter very little resistance to their passage, and the eddies allow them to remain at rest at any time. In fact, in fish-ways now in actual use on this principle, thousands of fish are found in the proper season to be both ascending and descending the chute at the same time.

Claims.

1. In a fish-way which is extended through the dam of a water-course and some distance above the same, as described, I claim the ports *b*, b^1, b^2, arranged substantially as shown, whereby the water is admitted through one or more, according to conditions in its height, as set forth.

2. In a fish-way provided with a series of deflectors, *d*, for causing the water to take a sinuous course through the same, I claim the wings *e*, *f*, formed on or attached to said deflectors, substantially as and for the purposes herein set forth.

E. A. BRACKETT.

Witnesses:

W. E. BOARDMAN.
E. G. PINKHAM.

the fish-way completely, as in the rectangular style, with a passage-way at the upper end of each partition, on alternate sides of the fish-way. This was at first thought to be an important improvement, but is now regarded with less favor. Its action does not differ greatly from that of the common rectangular fish-way, while the obliquity of the partitions interferes with the introduction of arms like those in Brackett's and some other styles, and with its adaptation to the reversed and spiral arrangements. A good many of these have been built in Maine, and quite a number are now in successful operation.

A better device than Foster's is one recently invented (Plate XXI, fig. 1, plan; fig. 2, same, with additions, by C. G. Atkins) by Mr. Alfred Swazey, of Bucksport, Me., in which the passage-ways are all near the center of the fish-way, but discharge the water into two series of pockets arranged on each side. The movement of the water in a model four feet wide is admirable.

14.—GENERAL ARRANGEMENT.

Of the three modes of general arrangement mentioned above, namely, the *extended*, the *reversed*, and the *spiral*, the first being the simplest, has been most generally adopted. The disadvantages attending it have been considered sufficiently under the head of *location*. Though on low dams and in exceptional cases it proves quite satisfactory, it is utterly unfitted for the majority of cases; and to its use in locations where it carries the mouth of the fish-way to a great distance from the dam, I attribute a large share of the failures that have occurred.

The *reversed* form is far superior to the extended when applicable, as it generally is. Considering only the question of its adaptation to the requirements of the fish, it is fully equal to the spiral. But when the questions of economy of space and material are brought into consideration, it is found that the reversed form has no advantage over the extended, and that both these are far inferior in these respects to the spiral, which is the *ne plus ultra* of fish-ways.

The spiral form may be given to almost any of the step and inclined-plane fish-ways, but to some with greater facility than others. The easiest to adapt are the rectangular plans, such as Smith's, Cail's, Brackett's, and the common rectangular. So far as I know, only three styles of spirals have thus far been devised, namely, Pike's, Cail's, and an adaptation of the rectangular-compartment fish-way. Pike's is originally and essentially of this form. It is described above among the step-fish-ways, and illustrated in plan and perspective, (Plate XXIX, figs. 1 and 2.) Cail's spiral* is an adaptation of his step-fish-way described above. Each circuit consists of 4 pools, arranged in a large square; the descent from pool to pool being 18 inches, a descent of 6 feet is accomplished in a single circuit. The dimensions proposed by Mr. Cail (for small rivers, I suppose) are as follows: pools, 6 feet square and 3 feet deep; inlet, 14 inches square;

* See illustration.

passes, 12 inches square. The spiral arrangement occupies an area on the ground of only 12 feet square. This, it should be repeated, is not fitted for use in alewife-rivers. The third style of spiral referred to is an adaptation of the common rectangular,* devised by myself for several dams on the Presumpscot and Machias Rivers. It may be described as a series of reversed fish-ways, piled one on another; the two arms of a reversed fish-way constituting a circuit. By running forward 15 feet, reversing, and running back the same distance, we accomplish a descent of 3 feet, which enables us to repeat the circuit immediately under the first floor. Thus, whatever the height of the dam, the area occupied by the fish-way is no larger than for one only 3 feet high.

A similar statement might be made in reference to other styles of spirals. The saving in ground-area over the extended and reversed arrangements is, therefore, for a dam 6 feet high, one-half; for a dam 9 feet high, two-thirds; for a dam 12 feet high, three-fourths, and so on. This saving frequently enables us to occupy a very eligible site, which would be too small for any form but the spiral. The economy of material is not so remarkable, but still it is a very important item. Mr. Pike estimates the saving in his form to be 35 per cent.

The advantage of the spiral with reference to the location of the outlet (or lower end) has already been alluded to. There is little danger of getting it too far from the dam, on whatever side the water be discharged. Still there will in most cases be a choice in favor of this or that side, according to the peculiar features of the site.

E—SUBSIDIARY CONSIDERATIONS.

1.—PROTECTION AGAINST FLOODS.

The most of our rivers are subject to destructive floods, which, besides the force of the water, assail all exposed structures with floating ice and logs. It is, of course, essential that a fish-way be shielded from dangers of this sort. The first aim should be to select a site where protection is already secured. Frequently, however, it is necessary to place the fish-way in the open river. It may then be protected by a pier, or, if that be impracticable, a narrow fish-way can be covered with stout plank so that floods may sweep over it without injury. As the latter plan involves the entire abandonment of all attempts to regulate the supply of water in the fish-way while the flood continues, it should not be resorted to when it is practicable to secure a position that admits of constant access and regulation.

2.—MATERIAL AND COST.

Little need be said in respect to material. By the laws of most of the States where fish-ways are needed, it devolves upon the owner o the dam to build and maintain a fish-way. The question of material and

* See illustration.

mode of construction (providing the requisite form be secured) may, in general, be with safety left to him, who may be supposed to best consult his own interests in those matters. It may, however, be remarked that, except in a few instances, wood is the most economical material, and, where facilities exist for wetting the structure occasionally, perhaps every day or two during the drought, it will not decay for a great many years. In the construction of spirals, wood is the only material that can now be economically used; and that form offers peculiar facilities for preservation from rot by water-soaking.

The cost of a fish-way depends so largely on the site and on the cost of material and labor in the vicinity that no general estimate can be made. The cost of extended and reversed fish-ways varies more than that of the spirals, on account of the great variation in the amount of work required in the foundation. A few instances may be mentioned.

The fish-way at Union Mills, on the Saint Croix, (Plate XXIV, figs. 1, 2, 3, and 4,) being about 70 feet long, 8 feet wide inside, of the Foster pattern, built of solid timber, with walls about one foot thick, with an extensive foundation of crib-work, in deep water, and the whole strong enough to resist the heaviest freshets with logs and ice, cost $600.

A fish-way at Pembroke, on the Pennaquan River, about the same length, 70 feet, 8 feet wide, of lighter material, being not exposed to great floods, was built for less than $100.

The estimates of experts on the cost of the execution of several plans at Augusta on the Kennebec have ranged from $1,500 to $3,000. The dam is about 18 feet high, and the river is subject to great floods.

A stone fish-way has been built at Brunswick on the Androscoggin for $1,100. It is 180 feet long, and 10 feet wide inside, to pass over a dam 18 feet high. To secure its inclined floor, a considerable amount of excavation of rock was required. The walls are about two feet thick and the partitions about one foot, both laid in cement.

A spiral fish-way has been devised for the dam at Cumberland Mills on the Presumpscot, over a dam about 10 feet high. The ground-plan inside the walls is 24½ feet long and 15 feet wide. It is to be built of pine timber and plank, worth $20 per thousand feet; and the engineer of the mills, Mr. John Warren, estimates its cost at $365.

The fish-ways at Lowell and Lawrence, on the Merrimack, cost about $3,000 and $9,000, respectively; and that at Holyoke, on the Connecticut, a still larger sum.

The fish-way of 1873, at Columbia, on the Susquehanna, being a simple inclined plane, 120 feet long and 60 feet wide, with a heavy guard-crib on either side, cost $11,053.

The general introduction of the spiral form will greatly reduce the cost of constructing fish-ways over such high dams as those at Lawrence and Holyoke, where a large part of the expense is incurred in the foundation.