FISH LADDER MODIFICATIONS FOR BOULEVARD LAKE DAM

(Photograph from NSSA website https://northshoresteelhead.com)

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EXECUTIVE SUMMARY

An analysis was completed of potential improvements for the existing fishway at Boulevard Lake Dam. The goal of the improvements is to enable quantification of the fish that swim upstream through the fishway, to enhance attraction flow at the fish ladder entrance, and preserve or enhance hydraulics favorable to passage through simple and cost-effective modifications to the existing fishway.

A three-tiered approach was developed. The first tier implements fish counters in the upper and lower pools along with some partial blockage of two weirs to direct fish through the fish counter in the lower pool. Low level orifices are recommended for the uppermost two pools in Tier 1 to improve hydraulics and provide a non-jumping option for upstream passage. Tier 2 adds a single floor-level orifice to the remaining weirs except for weir 5 which serves as a barrier to Lamprey passage. Tier 3 implements flash boards to partially block the remaining weirs, creating a uniform overflow width for most of the pools.

ACKNOWLEDGEMENTS

The authors are grateful to Frank Edgson and Scott McFadden of the North Shore Steelhead Association (NSSA) for their valuable insight, feedback, and contributions to this project. The authors also thank Dani Ramos-Espinoza and Cole Martin of InStream Fisheries Research, Inc for their insight and suggestions regarding fish counter installation and associated details.

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1 INTRODUCTION

The overall goal of this study is to identify and analyze low-cost modifications for implementation at the existing fishway at Boulevard Lake Dam on the lower reaches of the Current River near the City of Thunder Bay, Ontario. The fishway, located approximately 650 meters upstream from the mouth of the Current River where it enters Lake Superior, was installed in 1991 with the goal of passing migratory rainbow trout (steelhead) upstream past the dam (Beak, 1990). Ongoing rehabilitation of the dam, including installation of powered flow gates for the fish ladder and adjacent sluiceways, will enhance control of fishway flows. A recent hydraulic analysis of the existing fishway, which is a pool and weir-type fish ladder, indicated that the ladder can be operated at flow rates between 1 to 2.7 cubic meters per second (cms) to achieve hydraulics amenable to fish passage and recommended a target flow rate of 1.5 cms (Lyons & Weber, 2020). However, the study also showed that the overall design of the ladder was sub-optimal and improvements should be considered to improve fishway hydraulics, enhance attraction, and assess their efficacy. The present study focuses on simple cost-effective modifications that will enhance attraction flow and enable the installation of fish counters to collect biological data while maintaining or improving hydraulics within the fishway over a range of flow conditions.

1.1 Objectives

The objectives of this study are to:

- Identify the size and location of orifices and other modifications which are high gain and low cost.
- Determine basic hydraulics associated with the modifications for fishway flow rates of 0.4, 1.0, 1.5, 2.0 and 2.5 cms.
- Produce a report with recommended modifications and detailed drawings of the modifications.
- Include a brief assessment on the effect of the flash boards on attraction flow.

2 BACKGROUND

2.1 Dam operation

The dam is operated by the City of Thunder Bay according to the Boulevard Lake Dam water management plan which specifies seasonal flow and water level targets. The water management plan is subject to limits established by the 2018 Amended Permit to Take Water (PTTW) (Number 4321-6RVR23) issued by the Ontario Ministry of the Environment and Climate Change. For ecological reasons downstream of the dam, the minimum flow requirement through the dam is 0.4 cms. In the spring fish passage season, from April 1 to June 15, the minimum flow requirement is increased to 2.1 cms or the natural inflow to the lake, whichever is less (KGS, 2020).

2.2 Existing fishway design

The Boulevard Lake Dam fishway is a pool and weir-type fish ladder. Flow into the ladder has been historically controlled by stoplogs, but will be controlled by a powered overflow leaf gate which will replace the existing stoplogs as part of an ongoing refurbishment project scheduled to be completed in late 2021. The fish ladder has eleven stepped pools divided by notched overflow weirs with approximately 0.5-meter head drop between each weir (Figure 2-1, Figure 2-2, and Figure 2-3). The pools are numbered one to 11 sequentially from upstream to downstream. Shallow rectangular notches are formed in the top of downstream weirs in Pools 2 through 11, alternating between two and three notches per weir (Figure 2-4). Notch sizes are 0.6 meters wide by 0.1 or 0.15 meters deep. Pool slope and length varies between pools and pool width increases in the downstream direction. Key fish ladder dimensions and slopes are included in Table 2-1. Further detail and design features of the existing ladder were documented by Lyons and Weber (2020).

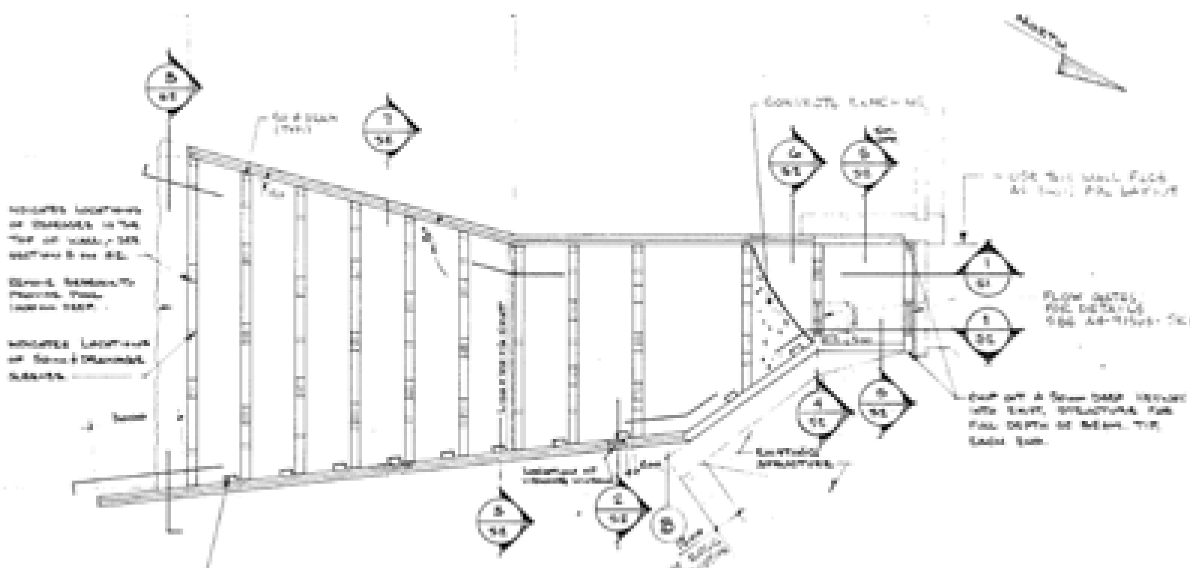


Figure 2-1. Fish ladder plan view (Proctor & Redfern, 1992)

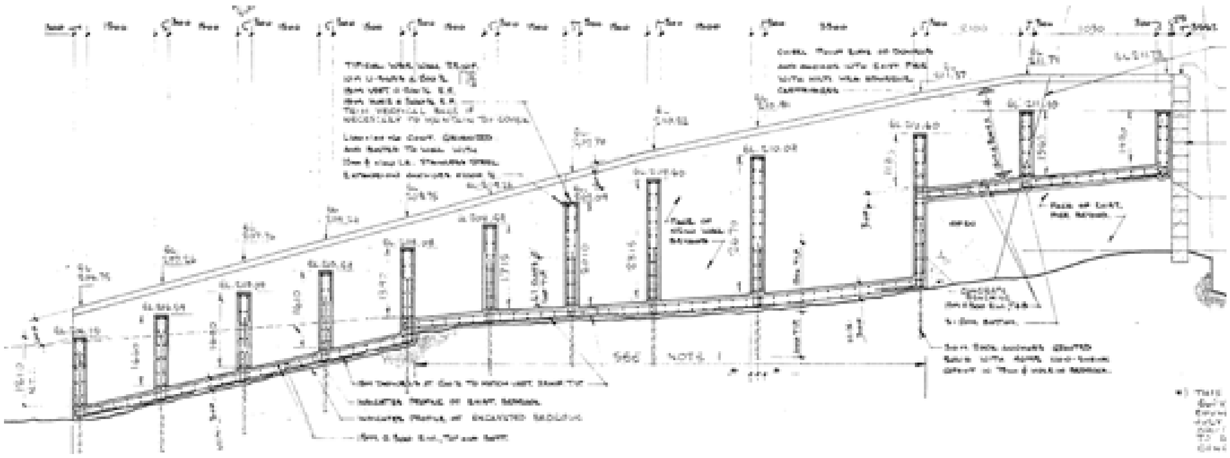


Figure 2-2. Fish ladder section view (Proctor & Redfern, 1992)

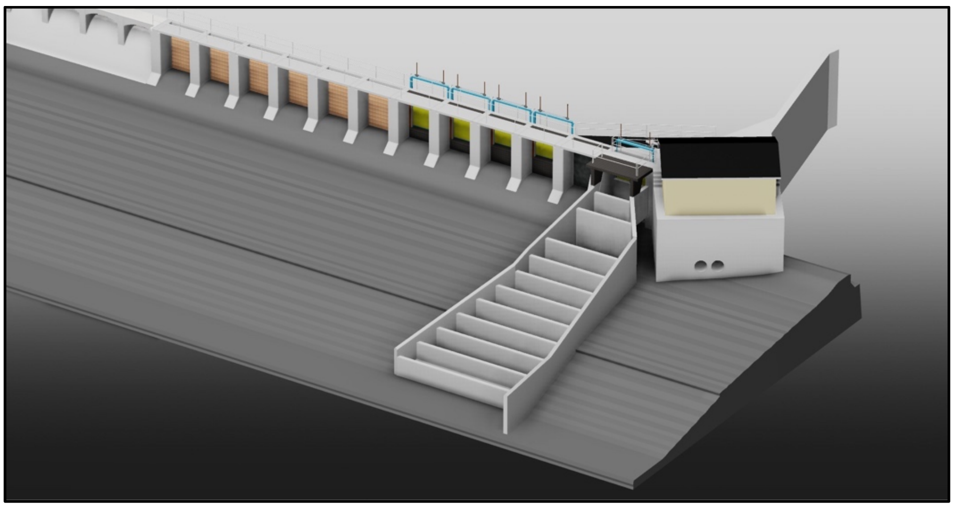


Figure 2-3. Fish ladder rendering (does not show weir notches) (credit: TBT Engineering)

Figure 2-4. Photograph looking upstream showing the fishway weirs and notches without flow (Source: https://northshoresteelhead.com/project/current-river/fishway-project/gal)

Table 2-1. Boulevard Lake Dam fish ladder pool dimensions and slopes (Lyons & Weber, 2020).

Pool No.	Pool Width (m)	Pool Length (m)	Weir Height (m)	Weir Elevation (m)	Pool Volume (m3)	Slope (%)
1	3.065	4.030	1.565	211.10	19.3	1%
2	4.746	2.100	1.183	210.60	11.8	24%
3	6.276	3.300	2.670	210.09	55.3	15%
4	6.495	1.800	2.315	209.60	27.1	27%
5	6.686	1.500	2.010	209.09	20.2	34%
6	7.280	1.500	1.715	208.59	18.7	33%
7	7.935	1.500	1.390	208.08	16.5	34%
8	8.633	1.500	1.610	207.59	20.8	33%
9	9.310	1.500	1.600	207.09	22.3	33%
10	9.986	1.500	1.660	206.59	24.9	33%
11	10.653	1.500	1.210	206.10	19.3	33%

Note: Pool width from 3D AutoCAD model provided by NSSA. Pool depth and length from Proctor & Redfern Drawing No. A1-91508-S1 Rev. 2, July 1991.

3 HYDRAULIC ANALYSIS

3.1 Hydraulic design parameters

There are no firm design criteria or parameters for the geometric or hydraulic design of pool and weir-type fish ladders, but recommendations and best practices can be found in several publications. In general, these are summarized as follows:

- Flow in each pool should be in the plunging flow regime (Katopodis, 1992).
- Flow depth over the weir should be between 0.15 and 0.30 meters (Bell, 1990).
- Energy dissipation in each pool should not exceed 192 Watts per cubic foot (Bell, 1990).
- Pool size should be a minimum of 2.44 meters long, 1.83 meters wide, and 1.52 meters deep (NMFS, 2008).
- Orifice dimensions should be at least 0.381 meters high by 0.305 meters wide (NMFS, 2008).
- Attraction flow velocities are recommended to be at least 1.2 meters/sec (Clay, 1961).

Whether these criteria are met for a specific fish ladder is primarily a function of the pool geometry and fishway flow rate. As such, the amount of inflow, the entrance geometry, the head pool elevation, the size and shape of each pool, the slope, and the outflow characteristics will all influence whether these criteria can be met inside the ladder pools. Because the geometry of each fish ladder pool is unique at Boulevard Lake Dam, the criteria will be met or exceeded at unique flows in each pool. Most of the fish ladder pools do not meet the minimum length recommendation.

3.1.1 Flow regime

The flow in the fish ladder pools will be in the plunging or streaming flow regime (Figure 3-1) as determined by the pool geometry and the total inflow to the fish ladder. For plunging flow, the depth over the weir is a function of flowrate and weir width, and can be calculated from the traditional weir equation. For streaming flow, the depth over the weir is also a function of the pool slope and length and can be calculated from a modified weir equation. The plunging, streaming, and transitional flowrates can be calculated from the following equations (Katopodis, 1992; Rajaratnam et al., 1988):

$$Q_{plunging} = \frac{Q_w}{(2/3)Bh^{1.5}\sqrt{2g}} = 0.62 \qquad (3\text{-}1)$$

$$Q_{streaming} = \frac{Q_w}{Bd^{1.5}\sqrt{gS_o}} = 1.5\sqrt{L/d} \qquad (3\text{-}2)$$

$$Q_{transitional} = \frac{Q_w}{BS_oL^{1.5}\sqrt{g}} = 0.25 \qquad (3\text{-}3)$$

Where

Q_w is flow rate over the weir (m^3/sec),

B is weir width (meters),

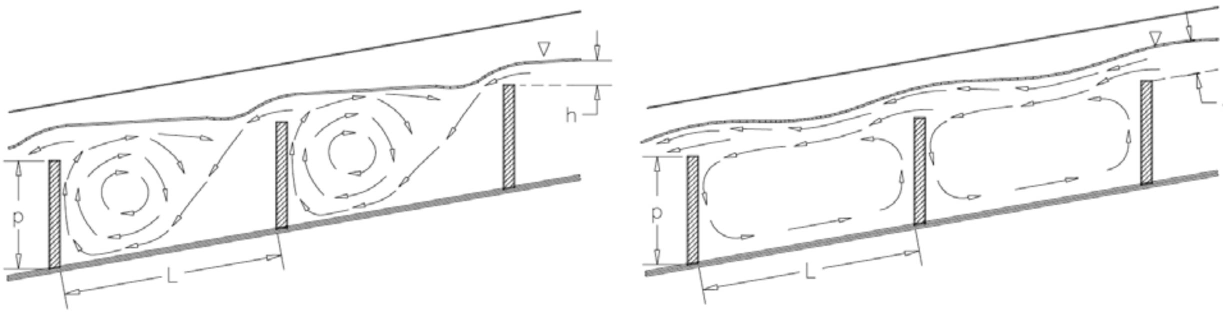
h is head on the weir (meters),

d is depth of flow over the weirs (meters),

g is the gravitational constant (9.81 meters/sec^2),

S_o is slope between weirs (%), and

L is length between weirs (meters).



(a) plunging flow regime (b) streaming flow regime

Figure 3-1. Typical pool and weir fish ladder hydraulics and flow equations (Katopodis, 1992)

3.1.2 Flow depth over weirs

Because of the varying weir lengths throughout the ladder, flow depth over the weirs varies in each pool for a given flowrate. Flow depth will be the deepest over the narrowest weirs and shallowest over the widest weirs. Flow depth for a given flow rate and weir width can be calculated by solving Equation 3-1 for head *h*:

$$h = \left(\frac{Q}{(2/3C_d B\sqrt{2g}}\right)^{2/3} \qquad (3\text{-}4)$$

Where

Q is fish ladder flow rate (m^3/sec),

C_d is the weir coefficient (0.62),

B is weir width (meters), and

g is the gravitational constant (9.81 meters/sec^2).

3.1.3 Pool energy

To allow adequate resting opportunity in each pool, the maximum flowrate can be calculated for a known pool volume and energy head drop into the pool from the following equation (NMFS, 2008):

$$Q_{max} = \frac{VE}{\gamma h} \qquad (3\text{-}5)$$

Where

Q_{max} is fish ladder flow rate (m^3/sec), *V* is pool volume (m^3),

E is energy dissipation rate (watts/m^3),

γ is unit weight of water (9807 N/m^3), and

h is energy head drop between pools (m).

3.1.4 Hydraulics of the existing design

The hydraulics of the existing design were extensively evaluated in by Lyons and Weber (2020). Based on their evaluation, the flow regime in Pools 2 to 11 is plunging for flows below 2.7 cms, begins to transition from plunging to streaming at 2.7 cms in Pool 2 first, and is fully transitioned to streaming flows in the entire ladder around 5 cms. Flow depth over the weirs was shown to vary due to the progressive lengthening of the weirs in the downstream direction. For a flow of 0.4 cms, the flow depths were estimated to range from 0.07 to 0.17 meters, with increased depths at the notches. Individual pools of the Boulevard Lake Dam fish ladder exceed the recommended energy dissipation threshold at flows between 0.5 and 2.2 cms, with most of the pools exceeding the recommended value at flows greater than 0.7 to 1.0 cms. To achieve 1.2 m/sec velocity exiting the pool, the fishway currently needs to be operated at approximately 2 cms or above.

3.2 Modifications

Modifications under consideration were selected based on their likelihood of creating the most improvement without major structural changes. Therefore, the recommended modifications may not represent the highest achievable fish passage efficiency that is possible at Boulevard Lake Dam, but are aimed toward increasing fish passage efficiency of the existing structure, and quantifying the number of fish entering and passing the fishway so that operators can begin to better understand the efficacy of fish passage at the dam. Modifications that would require extensive civil work or reconstruction such as altering the fish ladder slope, pool width, pool length, drop between pools, fishway type or location are beyond the scope of this study.

3.2.1 Orifices

Many pool and weir-type fish ladders include submerged openings to provide a non-jumping option for upstream passage. For adult migrants, the minimum recommended orifice size is 0.381 meters tall by 0.305 meters wide (NMFS, 2008). Adding orifices in the Lake Boulevard fish ladder may improve overall passage rates by providing a non-jumping option or by improving hydraulics within individual pools for certain flow conditions. For a given fishway flow rate, adding a submerged orifice will decrease the amount of flow that would otherwise overtop the weir, thereby increasing the flowrate at which that pool transitions from plunging to streaming, which may be beneficial to passage.

3.2.2 Flash boards

Flash boards were suggested conceptually by Lyons and Weber (2020) as a cost-effective means to alter weir length and create more uniform hydraulics within the fish ladder. Reducing weir length, especially on the lower pools, would increase the flow depth across the weir and thereby create a stronger flow signature to attract fish to the entrance and trigger upstream jumping. Flash boards could also be used to block plunging flow and inhibit jumping at certain locations.

3.2.3 Fish counter

There is currently no means of determining the number or size of fish that utilize the Boulevard Lake Dam fishway. An option under consideration is installation of a resistivity-type fish counter in Pools 1 and 11. This type of fish counter is based on the principle that a difference in electrical conductivity exists between the water and body of the fish. Analysis of the data collected by these counters allows the quantification of the number and size of fish that enter and pass the fishway. Multiple electrodes in each counter (generally three to five) also enable the determination of direction that each fish passes through the counter. The main advantages of this type of counter is that they are simple to operate, relatively inexpensive, and can usually be installed in existing structures without major modifications. A disadvantage is the potential to be blocked by debris or to register false counts due to debris passage, however, this could be mitigated by installation of an unerwater video camera. Consequently, tube counters require routine inspection and clearing of debris as needed. An example illustration of installed resistivity tube counters is shown in Figure 3-2 and a view inside a tube counter showing the three electrodes (dark rings) is shown in Figure 3-3.

Figure 3-2. Resistivity-type fish counters at unknown installation (Source: https://instream.net/services/electronic-fish-counters/)

Figure 3-3. View through a resistivity-type fish counter (photo credit: Frank Edgson).

Installation of a resistivity tube fish counter *between* two cells may affect the hydraulics of the inter-connected pools by creating a new flow path between pools. All or a portion of the flow will pass through the tube depending on the tube diameter, the fishway flow, and the head differential between the pools. Excess flow would be conveyed over the weir or other flow paths. To be effective, fish must be directed to the tube and alternate passage routes should be eliminated or blocked. Alternately, the installation of a fish counter *within* a pool can be achieved by dividing the pool with a porous wall or rack with sufficient bar spacing to allow flow to pass but block fish and only allow fish to pass the fish counter tube.

3.3 Recommended modifications

A number of modifications and configurations have been considered. The recommended modifications are intended to provide changes that can be implemented in three tiers, building on modifications from the previous tier with a goal of improving fish passage with each tier. The modifications are illustrated in Figure B-1 and described in more detail in the following sections.

3.3.1 Tier 1 modifications

Tier 1 includes the following fishway modifications:

- fish counters and exclusion panels installed in pools 1 and 11,
- partial weir blockage (i.e., flash boards) in pools 10 and 11,
- two low-level orifices in the weir between pools 1 and 2, and
- two low-level orifices in the weir between pools 2 and 3.

The recommended fish counters are resistivity-type tube fish counters manufactured by InStream Fisheries Research, Inc. (InStream) and discussed earlier in the report. Each counter would be installed in a porous wall or rack, referred to as an exclusion panel, inside the pool, allowing flow to pass through the porous wall and fish counter tube but requiring fish to pass through the counter. The counters being considered are approximately 0.46 meters in diameter with length varying based on the size of fish to be counted. Consultation with InStream indicated a 1.0-meter long tube would be appropriate for the largest fish of approximately 70 centimeters in length expected in the fishway.

The purpose of partial weir blockage by flash boards in pools 10 and 11 is to alter the flow entering and exiting pool 11 and to inhibit fish from jumping over the blocked portions of the weirs. The weir blockage will require the fish to swim through the fish counter after entering pool 11 but before jumping to pool 10. By eliminating the plunging flow between pools 10 and 11 downstream of the fish counter, the fish in pool 11 won't be able to jump into pool 10 until after they've passed through the fish counter. Likewise, the flashboard on pool 11 blocks plunging flow into the tailrace upstream of the fish counter so that fish will only enter pool 11 from the river on the downstream side of the counter. The weir blockage on pool 11 will also concentrate fishway flows to the left bank (looking downstream) side of the pool where it enters the river along the left shoreline, increasing velocity exiting the ladder and enhancing the flow signature in the tailrace.

Pools 1 and 2 are the narrowest pools in the fish ladder and transition from plunging to streaming flows at lower flows than the other pools. The low-level orifices added between pools 1, 2, and 3 allow some of the fishway flow to pass between pools without flowing over the weirs, thereby decreasing the flow depth over the weirs and causing the flow to transition from plunging to streaming at a higher total flow. Secondarily, they also provide a non-jumping passage route for fish near the upstream end of the ladder, where fish have already expended significant energy passing the lower pools. Tier 1 modifications are illustrated in Appendix B (shaded blue).

3.3.2 Tier 2 modifications

Tier 2 modifications keep all modifiations from Tier 1 and add a single orifice in each downstream weir wall of pools 3, 4, 6, 7, 8, 9, 10, and 11. The weir between Pools 5 and 6 serves as a lamprey barrier, so no orifice is installed in weir 5. The orifices provide a non-jumping option in every pool (except 5) with the intent to increase overall fish passage efficiency, especially for coaster brook trout, widely believed to be less capable jumpers compared to rainbow trout. The orifice between Pools 10 and 11 is installed upstream of the fish counter to insure fish cannot bypass the counter. Likewise, the orifice installed between Pool 11 and the river should be installed downstream of the counter for the same reason. The orifices also increase transitional flows in all pools while simultaneously lowering flow depth over the weirs. This is favorable to fish passage as it allows higher flows in the ladder before the transition from plunging to streaming occurs. Flow depths over the weirs are generally within the recommended range (0.15 to 0.30 m) for fishway flows of 1.0, 1.5, and 2.0 cms. Tier 2 modifications are illustrated in Appendix B (shaded magenta).

3.3.3 Tier 3 modifications

Tier 3 modifications keep all modifications from tiers 1 and 2 but add flashboards to partially block weirs 3, 4, 5, 6, 7, 8, and 9 to make equal overflow widths in each pool. This creates uniform overflow width between pools from pool 2 through 9. Pools 10 and 11 remain unchanged due to the flash boards already installed for the fish counter in tier 1. Pools 1 and 2 do not get flash boards because they are already narrower than the other pools. Fish ladder pools are traditionally designed to be constant width, length, depth, and slope along the length of the ladder and provide equal flow width along the length of the ladder and therefore more uniform hydraulics between pools. By creating uniform weir width, flow patterns become more uniform and overall fish passage efficiency may increase. The narrower overflow sections cause transition flows to decreases in pools 3 to 9 due to narrowing of the weirs, however, the transition flows are still approximately 2.5 cms or higher, so the performance will still be acceptable for fishway flows below 2.5 cms. Likewise, flow depths over the weirs increase and fall within the recommended range (0.15 to 0.30 m) for fishway flows of 1.0 and 1.5, which may be helpful for passage. For fishway flows of 2.5 cms, the pool depths begin to approach the top of the flashboards and may result in in intermittent overtopping which should be avoided. Tier 3 modifications are illustrated in Appendix B (shaded green).

3.3.4 Pool hydraulics

The pool hydraulics associated with Tiers 1, 2, and 3 modifications have been calculated for fishway flows of 0.4, 1.0, 1.5, 2.0, and 2.5 cubic meters per second (cms). Tabulated values of total fishway flow rate (Q), head on the weir (h), weir flow rate (Q_{weir}), orifice flow rate ($Q_{orifice}$), and velocity through the orifice ($V_{orifice}$) are provided in Appendix A, Tables A-1, A-2, and A-3.

The calculations for orifice flow rate and head on the weir assume orifice sizes of 0.381 meters tall by 0.305 meters wide which are the recommended minimum size for adult migrants (NMFS, 2008). The reported orifice flow rate value is the total flow rate of all orifices installed between a single weir (one or two orifices). Orifice flow rates generally range from 0.2 to 0.25 cms per orifice regardless of fishway flow rate. Orifice velocities range from 1.7 to 2.5 meters per second which is well below the burst speed of adult migrants (Bell, 1990). The narrow range of velocity values over the relatively wide range of fishway flow rates is due to flow and velocity through the orifices being a function of head differential across the orifice, which changes relatively little with fishway flow rate. Weir widths and transitional flows for the existing configuration and those for Tiers 1, 2, and 3 modifications are provided in Table 3-1 and Table 3-2.

Table 3-1. Weir widths for the existing fishway and for each tier.

Pool No.	Weir Width (m)			
	Existing	Teir 1	Tier 2	Tier 3
1	3.07	3.07	3.07	3.07
2	4.75	4.75	4.75	4.75
3	6.28	6.28	6.28	4.75
4	6.50	6.50	6.50	4.75
5	6.69	6.69	6.69	4.75
6	7.28	7.28	7.28	4.75
7	7.94	7.94	7.94	4.75
8	8.63	8.63	8.63	4.75
9	9.31	9.31	9.31	4.75
10	9.99	4.99	4.99	4.99
11	10.65	5.33	5.33	5.33

Table 3-2. Transitional flows for the existing fishway and for each tier.

Pool No.	Transitional Flow (cms)			
	Existing	Tier 1	Tier 2	Tier 3
1	0.19	0.64	0.64	0.64
2	2.69	3.14	3.14	3.14
3	4.55	4.55	4.77	3.68
4	3.34	3.34	3.57	2.66
5	3.27	3.27	3.27	2.32
6	3.49	3.49	3.71	2.50
7	3.88	3.88	4.10	2.54
8	4.06	4.06	4.28	2.45
9	4.46	4.46	4.69	2.50
10	4.79	2.39	2.62	2.61
11	5.01	2.50	2.72	2.73

3.3.5 Attraction flow

The weir blockage in pool 11 will concentrate the flow over half the weir length compared to the existing configuration, thereby approximately doubling the exit velocity. The flow velocity exiting the plunge pool immediately downstream of the fishway was previously estimated to be between 0.24 and 1.52 meters per second for fishway flows of 0.4 to 2.5 cubic meters per second (Lyons and Weber, 2020). Doubling these values results in flow veloicites of approximately 0.5 to 3.0 meters per second. A fishway flow of 1.0 cubic meters per second will result in an attraction flow velocity of approximately 1.2 meters per second which is the minimum recommended attraction flow velocity by Clay (1961). A fishway flow 1.5 cubic meters per second will result in an attraction flow velocity of approximately 1.8 meters per second. A fishway flow of 2.0 cubic meters per second will result in an attraction flow velocity of approximately 2.4 meters per second which is the maximum recommended attraction flow by Clay (1961) and is only recommended to be exceeded for very short distances.

3.3.6 Installation notes

The fish counters and associated fish fences will be designed and installed by InStream. InStream provided guidance to the authors for placing the fish counters in Pools 1 and 11. They stressed the importance keeping the counters submerged but noted that placing the counters at the bottom of the pools the counters will remain submerged at all times. They also noted that excessively bubbly flow inside the counters can cause noise in the data. Given the pool depth and proximity of the plunging flow, bubbles are not anticipated to be an issue. If issues with bubbles do arise, it may be possible to shift the counters along the floor to a location with fewer bubbles at depth. InStream also suggested angling the exclusion panel in Pool 1 to create more room for fish between the ends of the fish counter and the pool walls. The exclusion panel is rotated 30 degrees relative the to the weir face (Figure B-1).

The dimensions for Pools 1 to 11 shown in this report may not be accurate and should be confirmed with field measurements prior to fabrication of any components. Installing the exclusion panels and flash boards will require drilling into the concrete walls and/or weirs. Structual details including rebar detail from the original installation is provided in Figures B-7 and B-8 as a reference for installers. The drawing notes indicate that the overflow weirs are reinforced with 15M (16 mm diameter) vertical rebar spaced 200 mm on center and 15M horizontal rebar spaced 300 mm on center. The top of weirs are reinforced with 10M (11.3 mm diameter) U-bars spaced at 200 mm on center. The authors cannot confirm if the drawings accurately represent as-built rebar size and spacing. Based on the rebar spacing, contractors should expect to encounter rebar when cutting orifices and/or drilling holes for fasteners.

Weir blockage can be achieved by bolt-on boards or non-porous panels. The flash boards are recommended to be solid wood or aluminum panels with vertical steel supports that extend along the upstream face of the weir. The structural design of the flashboards is beyond the scope of this report, but the flashboards should be designed to withstand the hydrostatic force of water plus a factor of safety to account for flow energy and debris strikes. Representatives of InStream Fisheries Research, Inc. indicated they can design and fabricate the bolt-on blockage panels if desired.

4 SUMMARY

This study recommends a series of fishway modifications to begin monitoring fish and potentially enhance upstream passage at Boulevard Lake Dam. A number of modifications implemented in three tiers were identified that can be accomplished with minor changes to the fishway. All modifications except creating the low-level orifices can be implemented by bolting on pre-fabricated panels or screens. The hydraulics associated with each tier were quantified and show that the fish ladder can be operated in a manner that produces flow patterns amenable to passage at flows of 1.0, 1.5. and 2.0 cms.

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6 ABOUT THE AUTHORS

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Larry earned a Ph.D. from the University of Iowa in civil and environmental engineering in 1993 and received his professional engineering license in Iowa in 1996. He is an independent consultant but also currently is the Edwin B. Green Chair in Hydraulics and a full professor in the Department of Civil and Environmental Engineering at the University of Iowa.

From 2004 to 2017, Larry served as the Director of IIHR – Hydroscience & Engineering, the nation's oldest academic research program focused on hydraulics, hydrology, and fluid mechanics. He has extensive knowledge in community resilience and planning; flooding; flood mapping; flood mitigation; river hydraulics; fate and transport of nutrients; hydropower; coupling individual-based ecological and fluid mechanics models; fish passage facilities; environmental hydraulics; hydraulic structures; and river restoration and sustainability. Through these research programs, Larry's impact has ranged from theoretical numerical model development and scientific discovery (as demonstrated in over 60 peer-reviewed scholarly publications) to the broad application of numerical models and systems-level design approaches to solve complex large-river ecological challenges (as demonstrated in over 200 conference papers and engineering research reports for contracted projects).

Larry's current area of focus range from fish passage to large-scale water resources projects, includes coupling computational fluid dynamics models to community and individual-based behavioral models to further understand fish behavioral decisions in the immediate vicinity of passage facilities. These models have been applied to natural river reaches and hydraulic structures both for fundamental advancement of scientific understanding of fish swim path selection and for practical application to the design of successful fish passage facilities.

Troy Lyons, Ph.D., P.E.

Troy earned an M.S. in civil and environmental engineering in 2002, his professional engineering license in Iowa in 2007, and a Ph.D. in civil and environmental engineering in 2021. He is an independent consultant but also a research engineer and the Director of Engineering Services at IIHR – Hydroscience & Engineering at the University of Iowa.

Troy's research has focused on the design and optimization of hydraulic structures, primarily related to dams, fishways, drop structures, gates, storm water conveyance structures, and deep tunnels. He has extensive experience in hydraulic modeling of rivers and streams, design of hydraulic structures, and hydraulic field data collection. His work has included projects on many rivers, including the Columbia, Snake, Mississippi, Missouri, Ohio, Des Moines, and Ohio rivers, among others. Troy has expertise in evaluating and modeling engineered and natural riverine environments including investigating the performance of hydraulic structures and their impacts on river flow patterns, the effects of bed roughness on water surface slope, sediment transport and deposition, design and optimization of fish passage structures at hydropower installations, modifications of spillway designs to reduce levels of total dissolved gas, and investigations of erosion potential downstream from spillways. Nearly all of Lyons' research has been applied to practice for federal, state, and private projects.

APPENDIX A: FISHWAY HYDRAULICS

Table A-1. Tier 1 fishway hydraulics.

Pool 1: two orifices

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	---	---	0.40	1.72
1.00	0.21	0.54	0.46	2.00
1.50	0.32	1.02	0.48	2.05
2.00	0.42	1.51	0.49	2.09
2.50	0.50	2.01	0.49	2.13

Pool 2: two orifices

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.01	0.00	0.40	1.71
1.00	0.16	0.57	0.43	1.85
1.50	0.25	1.06	0.44	1.89
2.00	0.32	1.55	0.45	1.92
2.50	0.38	2.05	0.45	1.95

Pool 3: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.11	0.40	---	---
1.00	0.20	1.00	---	---
1.50	0.26	1.50	---	---
2.00	0.31	2.00	---	---
2.50	0.36	2.50	---	---

Pool 4: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.10	0.40	---	---
1.00	0.19	1.00	---	---
1.50	0.25	1.50	---	---
2.00	0.30	2.00	---	---
2.50	0.35	2.50	---	---

Pool 5: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.10	0.40	---	---
1.00	0.19	1.00	---	---
1.50	0.25	1.50	---	---
2.00	0.30	2.00	---	---
2.50	0.35	2.50	---	---

Pool 6: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.10	0.40	---	---
1.00	0.18	1.00	---	---
1.50	0.23	1.50	---	---
2.00	0.28	2.00	---	---
2.50	0.33	2.50	---	---

Pool 7: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.09	0.40	---	---
1.00	0.17	1.00	---	---
1.50	0.22	1.50	---	---
2.00	0.27	2.00	---	---
2.50	0.31	2.50	---	---

Pool 8: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.09	0.40	---	---
1.00	0.16	1.00	---	---
1.50	0.21	1.50	---	---
2.00	0.25	2.00	---	---
2.50	0.29	2.50	---	---

Pool 9: no changes

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.08	0.40	---	---
1.00	0.15	1.00	---	---
1.50	0.20	1.50	---	---
2.00	0.24	2.00	---	---
2.50	0.28	2.50	---	---

Pool 10: 1/2 weir width

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.12	0.40	---	---
1.00	0.23	1.00	---	---
1.50	0.30	1.50	---	---
2.00	0.36	2.00	---	---
2.50	0.42	2.50	---	---

Pool 11: 1/2 weir width

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.12	0.40	---	---
1.00	0.22	1.00	---	---
1.50	0.29	1.50	---	---
2.00	0.35	2.00	---	---
2.50	0.40	2.50	---	---

Table A-2. Tier 2 fishway hydraulics.

Pool 1: two orifices

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	---	---	0.40	1.72
1.00	0.21	0.54	0.46	2.00
1.50	0.32	1.02	0.48	2.05
2.00	0.42	1.51	0.49	2.10
2.50	0.50	2.01	0.50	2.13

Pool 2: two orifices

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.00	0.00	0.42	1.79
1.00	0.16	0.56	0.44	1.90
1.50	0.24	1.05	0.45	1.94
2.00	0.32	1.54	0.46	1.96
2.50	0.38	2.04	0.46	1.99

Pool 3: one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.06	0.18	0.22	1.91
1.00	0.17	0.78	0.22	1.92
1.50	0.23	1.28	0.22	1.92
2.00	0.29	1.78	0.22	1.92
2.50	0.34	2.28	0.22	1.93

Pool 4: one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.06	0.19	0.21	1.83
1.00	0.16	0.78	0.22	1.86
1.50	0.23	1.28	0.22	1.87
2.00	0.28	1.78	0.22	1.88
2.50	0.33	2.28	0.22	1.88

Pool 5: no orifice due to Lamprey barrier

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.10	0.40	0.00	---
1.00	0.19	1.00	0.00	---
1.50	0.25	1.50	0.00	---
2.00	0.30	2.00	0.00	---
2.50	0.35	2.50	0.00	---

Pool 6: one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.06	0.18	0.22	1.92
1.00	0.15	0.78	0.22	1.93
1.50	0.21	1.28	0.22	1.93
2.00	0.26	1.77	0.23	1.94
2.50	0.31	2.27	0.23	1.94

Pool 7: one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.05	0.18	0.22	1.92
1.00	0.14	0.78	0.22	1.93
1.50	0.20	1.28	0.22	1.93
2.00	0.25	1.78	0.22	1.94
2.50	0.29	2.27	0.23	1.94

Pool 8: one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.05	0.18	0.22	1.91
1.00	0.13	0.78	0.22	1.92
1.50	0.19	1.28	0.22	1.92
2.00	0.23	1.78	0.22	1.93
2.50	0.27	2.28	0.22	1.93

Pool 9: one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.05	0.18	0.22	1.87
1.00	0.13	0.79	0.21	1.78
1.50	0.18	1.30	0.20	1.73
2.00	0.22	1.80	0.20	1.68
2.50	0.26	2.31	0.19	1.64

Pool 10: 1/2 weir width, one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.18	0.22	1.92
1.00	0.19	0.78	0.22	1.94
1.50	0.27	1.27	0.23	1.94
2.00	0.34	1.77	0.23	1.95
2.50	0.40	2.27	0.23	1.96

Pool 11: 1/2 weir width, one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.16	0.24	2.03
1.00	0.18	0.74	0.26	2.23
1.50	0.25	1.23	0.27	2.34
2.00	0.31	1.72	0.28	2.44
2.50	0.37	2.21	0.29	2.52

Table A-3. Tier 3 fishway hydraulics.

Pool 1: two orifices

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	---	---	0.40	1.72
1.00	0.21	0.54	0.46	2.00
1.50	0.32	1.02	0.48	2.05
2.00	0.42	1.51	0.49	2.09
2.50	0.50	2.01	0.49	2.13

Pool 2: two orifices

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.00	0.00	0.41	1.76
1.00	0.16	0.57	0.43	1.84
1.50	0.25	1.07	0.43	1.85
2.00	0.32	1.57	0.43	1.86
2.50	0.38	2.07	0.43	1.86

Pool 3: one orifice, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.08	0.18	0.22	1.90
1.00	0.20	0.78	0.22	1.91
1.50	0.28	1.28	0.22	1.91
2.00	0.35	1.78	0.22	1.91
2.50	0.41	2.28	0.22	1.91

Pool 4: one orifice, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.08	0.19	0.21	1.81
1.00	0.20	0.79	0.21	1.84
1.50	0.28	1.28	0.22	1.85
2.00	0.35	1.78	0.22	1.86
2.50	0.41	2.28	0.22	1.86

Pool 5: no orifice due to Lamprey barrier, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.13	0.40	0.00	---
1.00	0.24	1.00	0.00	---
1.50	0.31	1.50	0.00	---
2.00	0.38	2.00	0.00	---
2.50	0.44	2.50	0.00	---

Pool 6: one orifice, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.18	0.22	1.91
1.00	0.20	0.78	0.22	1.91
1.50	0.28	1.28	0.22	1.91
2.00	0.35	1.78	0.22	1.91
2.50	0.41	2.28	0.22	1.91

Pool 7: one orifice, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.18	0.22	1.91
1.00	0.20	0.78	0.22	1.91
1.50	0.28	1.28	0.22	1.91
2.00	0.35	1.78	0.22	1.91
2.50	0.41	2.28	0.22	1.91

Pool 8: one orifice, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.18	0.22	1.91
1.00	0.20	0.78	0.22	1.91
1.50	0.28	1.28	0.22	1.91
2.00	0.35	1.78	0.22	1.91
2.50	0.41	2.28	0.22	1.91

Pool 9: one orifice, partially blocked weir

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.18	0.22	1.92
1.00	0.20	0.78	0.22	1.92
1.50	0.28	1.28	0.22	1.93
2.00	0.35	1.78	0.22	1.93
2.50	0.41	2.28	0.22	1.94

Pool 10: 1/2 weir width, one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.18	0.22	1.92
1.00	0.19	0.78	0.22	1.94
1.50	0.27	1.27	0.23	1.94
2.00	0.34	1.77	0.23	1.95
2.50	0.40	2.27	0.23	1.96

Pool 11: 1/2 weir width, one orifice

Q (cms)	h (m)	Q_{weir} (cms)	$Q_{orifice}$ (cms)	$V_{orifice}$ (m/s)
0.40	0.07	0.16	0.24	2.03
1.00	0.18	0.74	0.26	2.23
1.50	0.25	1.23	0.27	2.34
2.00	0.31	1.72	0.28	2.44
2.50	0.37	2.21	0.29	2.52

APPENDIX B: DRAWINGS

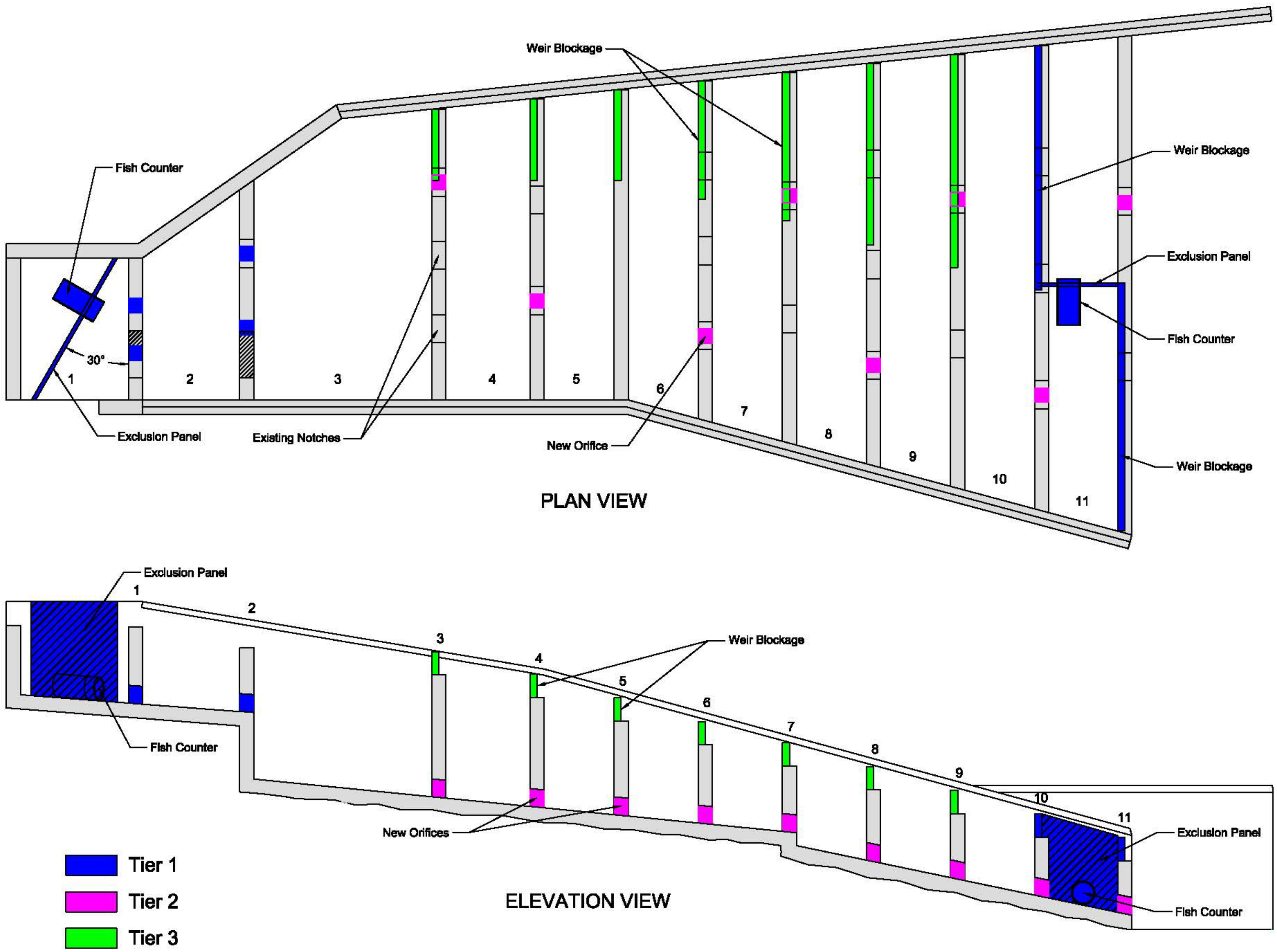


Figure B-1. Lake Boulevard fishway modifications.

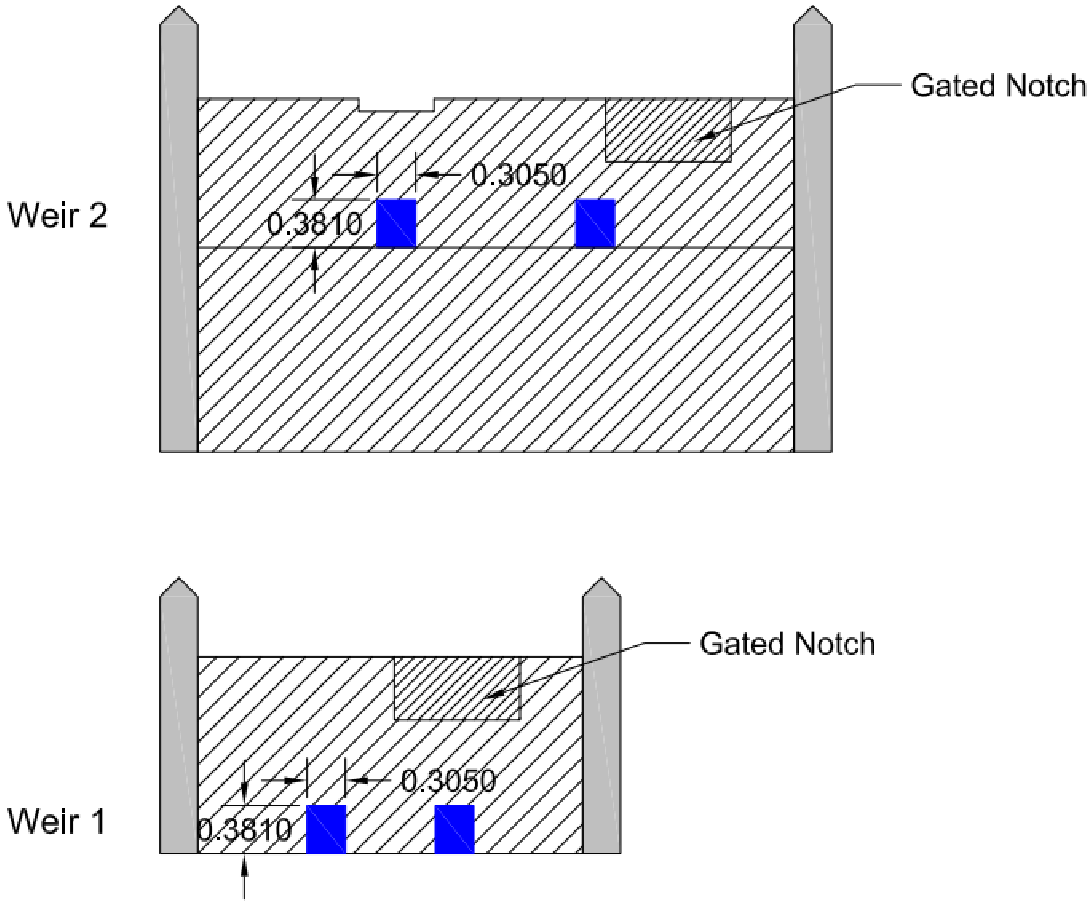


Figure B-2. Weir 1 and 2 details (looking upstream).

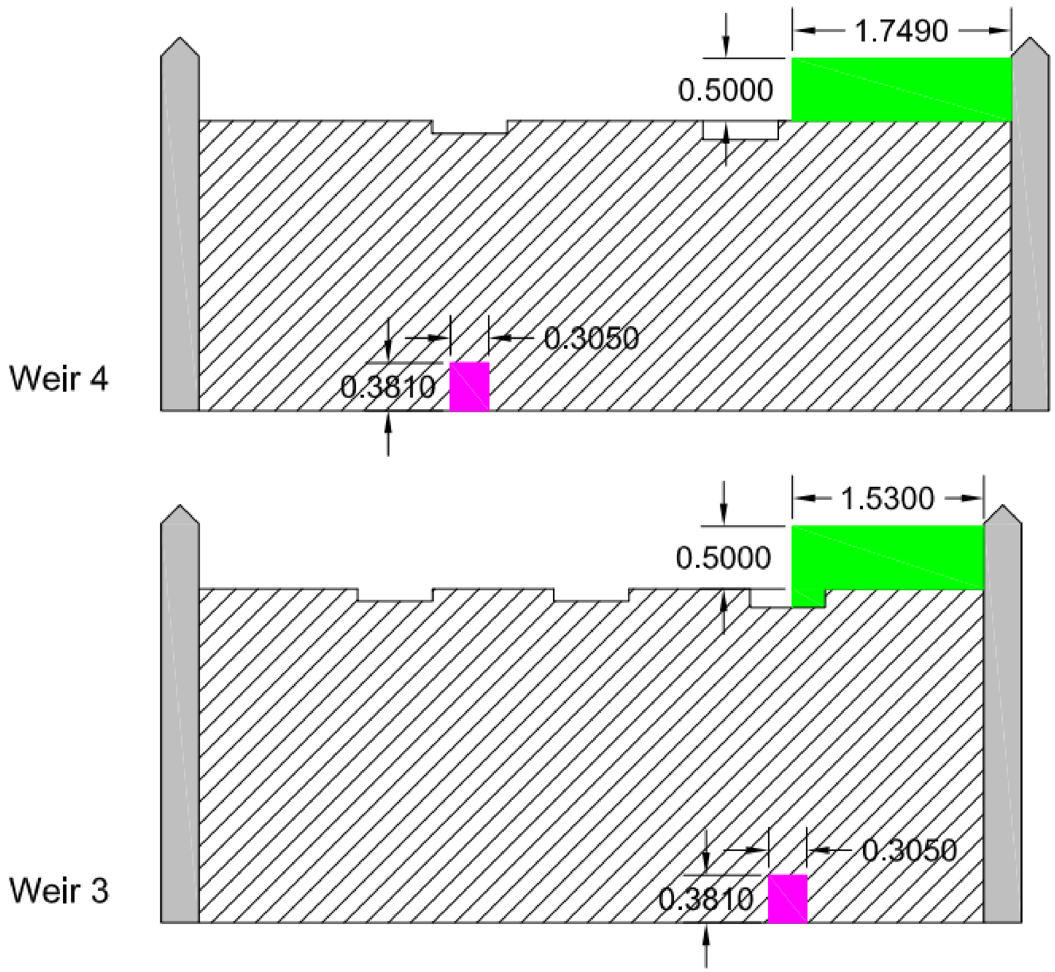


Figure B-3. Weir 3 and 4 details (looking upstream).

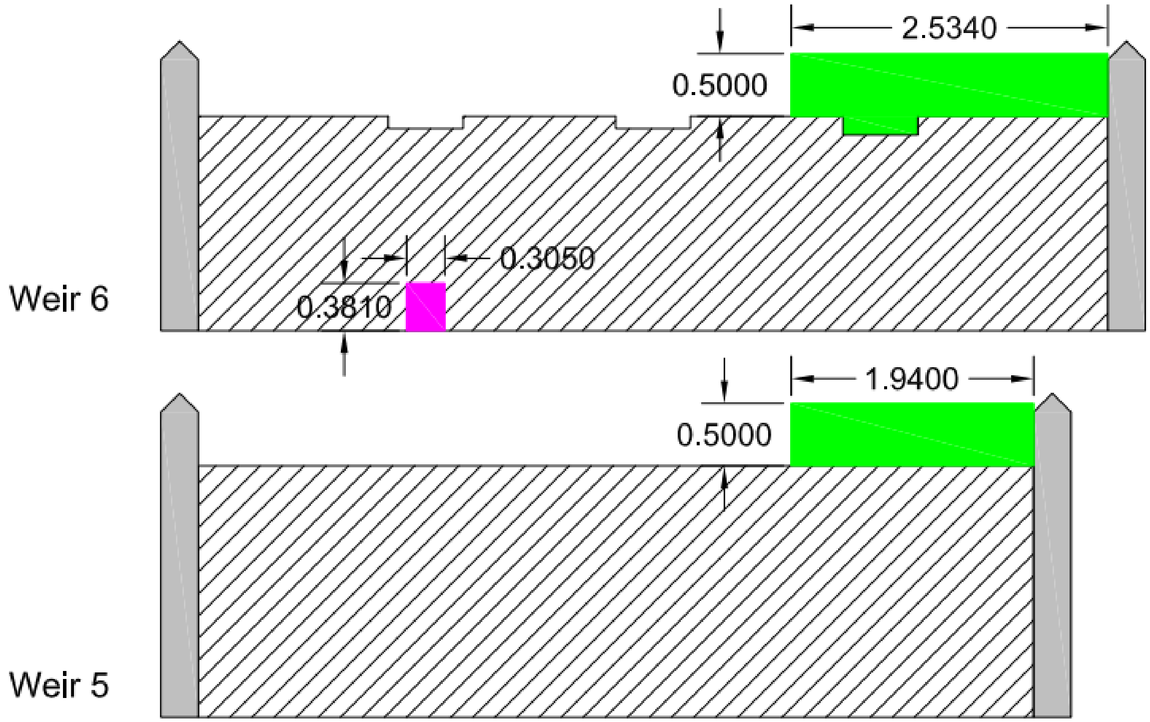


Figure B-4. Weir 5 and 6 details (looking upstream).

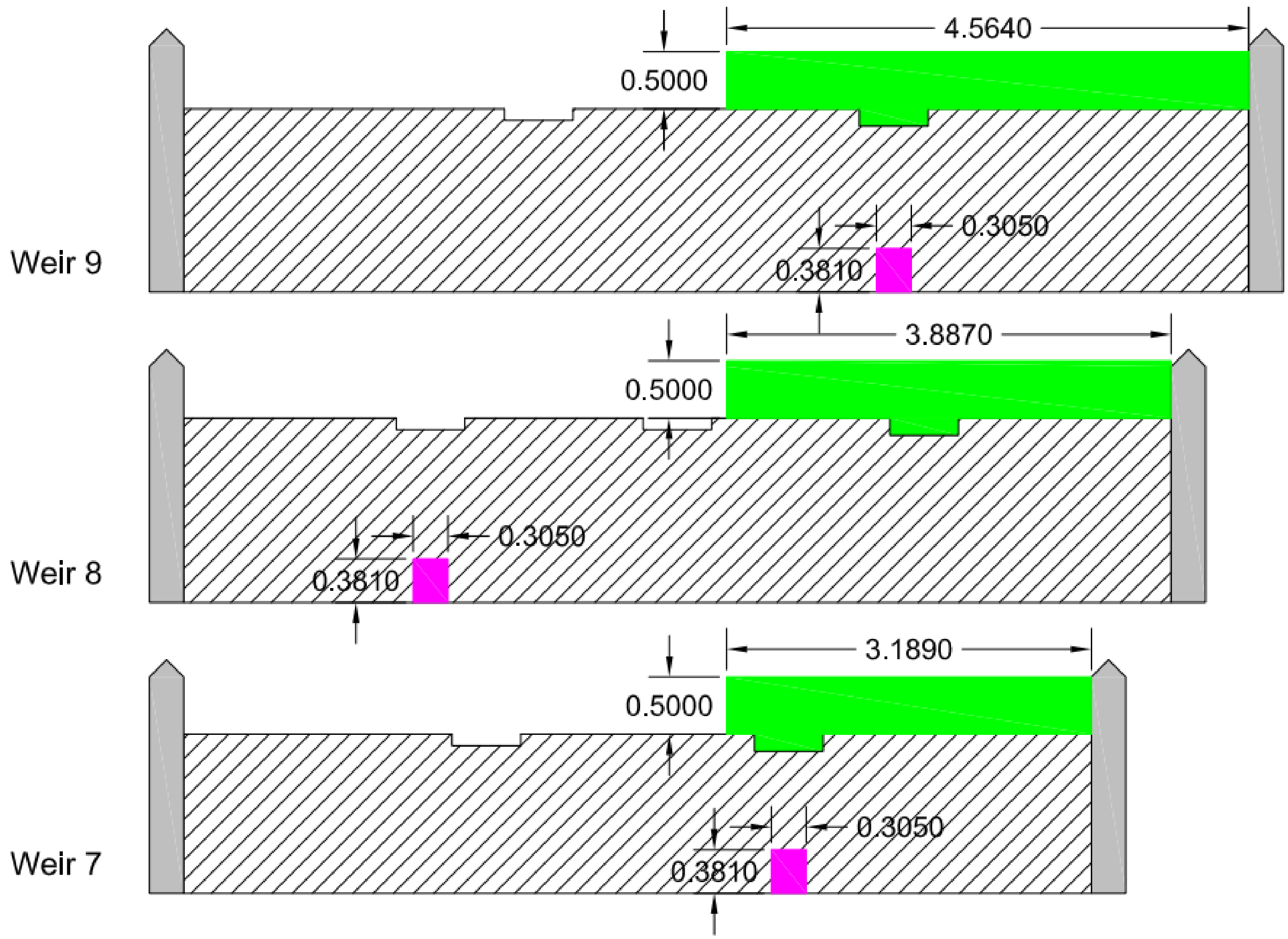


Figure B-5. Weir 7, 8 and 9 details (looking upstream).

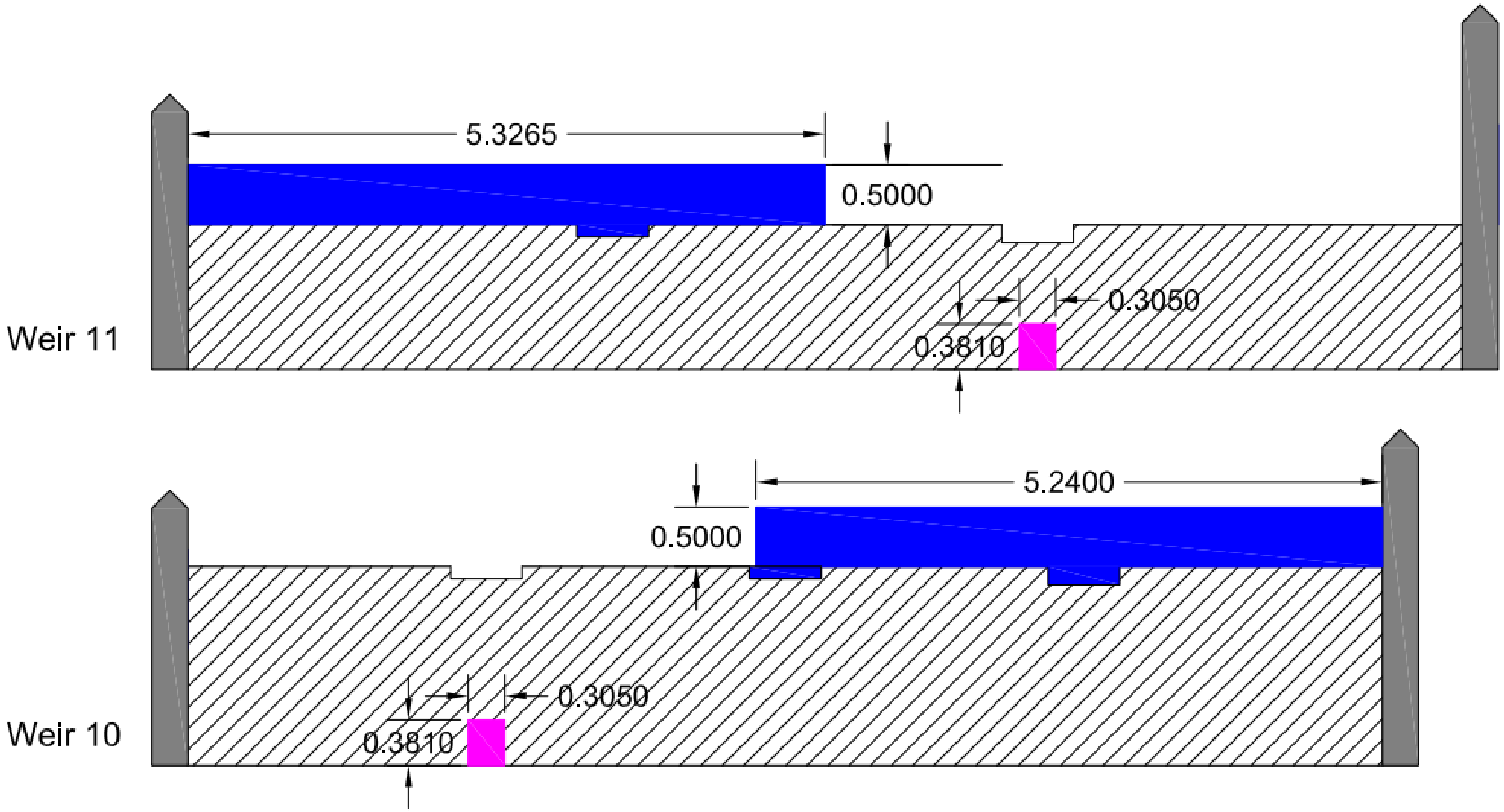
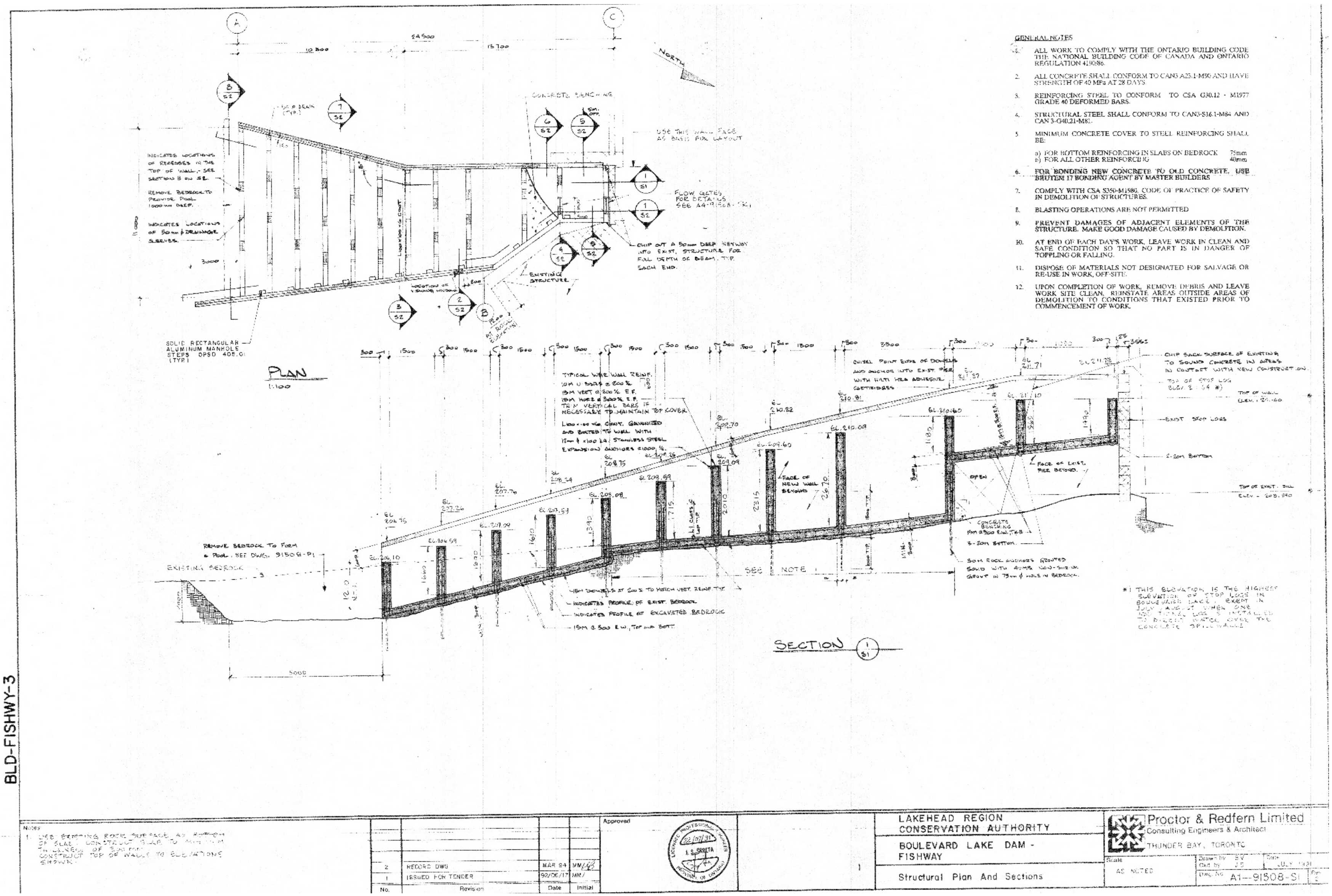


Figure B-6. Weir 10 and 11 details (looking upstream).



BLD-FISHWY-3

Figure B-7. Structural details from original construction drawings (Drawing No. A1-91508-S1).

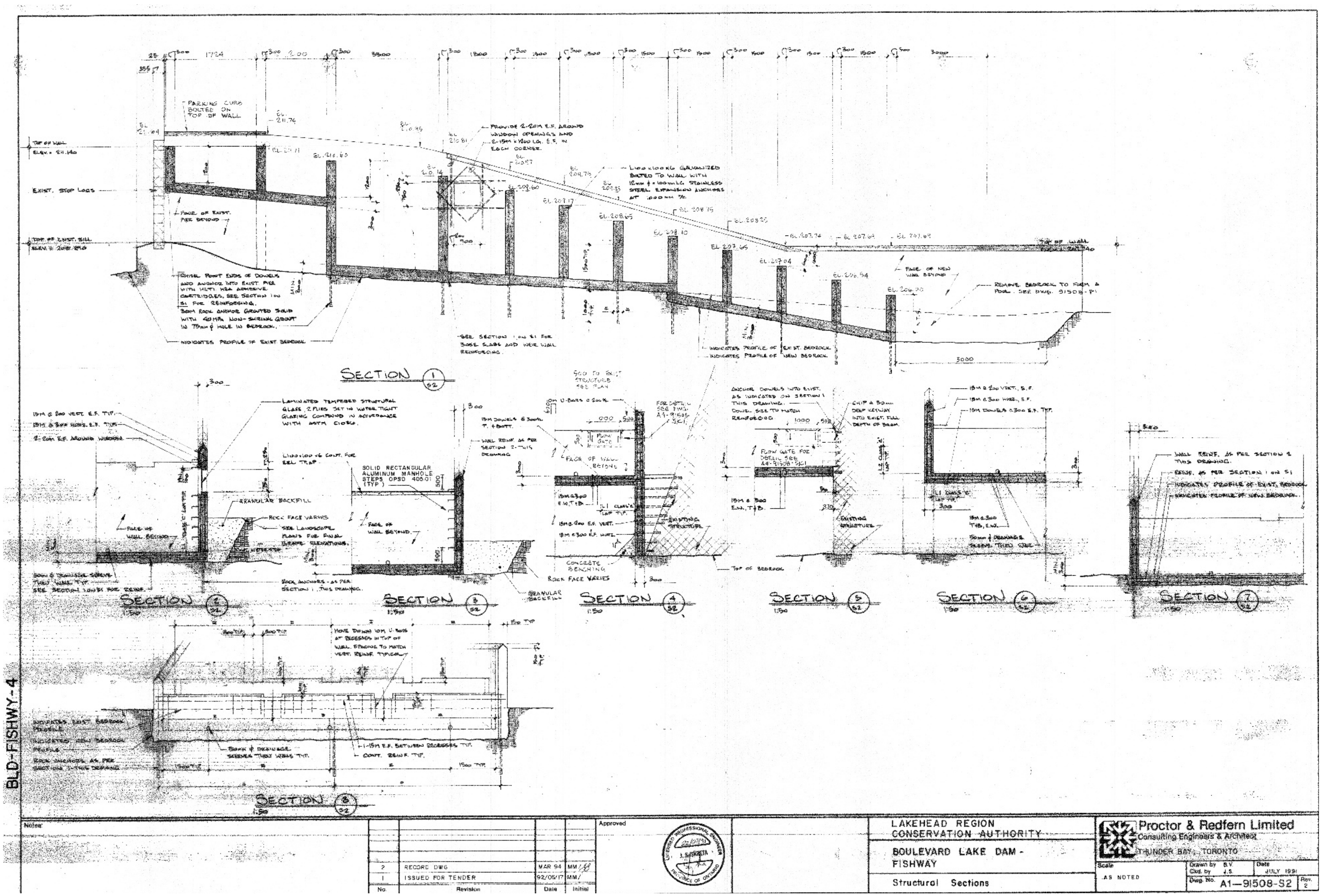


Figure B-8. Structural details from original construction drawings (Drawing No. A1-91508-S2).