A Performance Evaluation of Fishways at Sea Lamprey Barriers and Controlled Modifications to Improve Fishway Performance

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Final report of research conducted for the
Great Lakes Fishery Commission

December 31, 2003

Final Report for the Performance Evaluation of Fishways at Barriers

Short Executive Summary of Deliverables

The Cobourg Brook fishway began operations on March 24 when water temperatures reached 1° C, and the Big Carp River fishway began operations on April 28 when water temperatures reached 3°C. Staff at the Great Lakes Lab for Fisheries and Aquatic Sciences (DFO-GLLFAS) operated both fishways on a daily basis until the end of the fishing season to determine whether fishways successfully mitigate low-head sea lamprey barriers.

Given the success of the pilot passive integrated transponder (PIT) antenna and tag study in 2002 (O'Connor et al. 2003), functional antennae were in place in both streams shortly after opening the fishways. Mr. Vince Tranquilli from the Oregon Department of Fish and Wildlife assisted in the setup of three antennae on Cobourg Brook, the set up of which was replicated at the Big Carp River fishway. We PIT tagged 555 fishes (>100mm) of seven species in Cobourg Brook and 572 fishes of 6 species in Big Carp River in 2003. The antenna array was operational at Cobourg Brook for 74 days and at Big Carp River for 87 days. We then addressed the following objectives:

Estimate attraction efficiency for the fishways.

Attraction efficiency was separated into three components: those that approached the barrier, those that moved from the barrier to the fishway entrance, and those that moved into the traps within the fishway. At both streams attraction to the barrier was high ranging from 96 to 99% (Cobourg Brook and Big Carp River respectively). Attraction to the fishway entrance was slightly lower at 79 and 94% (Cobourg Brook and Big Carp River respectively) and attraction to the fishway traps was similar in both streams at 70 and 71%.

Estimate passage efficiency for the fishways.

Passage efficiency was determined by the number of PIT tagged fishes that remained in the traps to be passed over the barrier. While attraction efficiency to the traps was high at both locations, passage efficiency was much lower. Passage efficiency at Big Carp River was 27% and only 8% at Cobourg Brook.

Estimate the degree of passive sorting within the fishways.

For sea lampreys, the rate of passive sorting was estimated for the upper and lower traps within the fishways and for those sea lampreys released both below the fishway (within the attraction flow) and at the location used for release for Sea Lamprey Control Centre population estimates. As predicted, sea lampreys released in the upper trap remained in this location (log-linear analysis χ^2= 0.00, p=1.00, n=25) at Big Carp River; however, this was not supported at Cobourg Brook (log-linear analysis χ^2= 5.21, p=0.02, n=39). Sea lampreys released within the lower traps were not attracted to the upper trap as hypothesised (log-linear analysis, lower trap χ^2= 9.78, p=0.01, n=31 and χ^2= 23.78, p<0.001, n=35) for Big Carp River and Cobourg Brook respectively. For those lampreys released below the barrier (either location), our hypothesis of attraction to the upper trap was not met at either location.

Describe the barrier and fishway in terms of (i) water levels and velocity for each fishway section, (ii) a description of the horizontal and vertical distribution of velocity within each trap and at funnel orifices as a function of water level consistent with existing literature, (iii) the percentage of flow through the fishway vs. total stream flow.

Velocity measurements were made at each of the streams on at least three occasions. Measurements were made within the fishway and the area of attraction flow and additional measurements were made with the installation of level loggers at each fishway, both above and below the barrier. Observations were plotted on scale drawings consistent with fishway literature. The percentage of flow within the fishway in both cases was found to vary with stream flow. At the Big Carp fishway during extreme low flow, 100% of the stream passed through the fishway. Debris on intake screens frequently reduced fishway flow to as little as 0% at Cobourg Brook. Under typical flow conditions (assuming no debris) for these small streams expected fishway flow would range from approximately 15 to 30% of the stream flow.

Overall, attraction to the fishway entrance and into the traps was high at both fishways; however passage efficiency remains low in both streams. Improvements to the volume of the traps to increase holding capacity, maintaining flow within the fishway, and reducing impingement at the intake gate valve are required at the existing fishway locations. If our recommendations are incorporated into the existing fishway locations, attraction and passage efficiency should be re-examined to determine the relative measures of success of these modifications.

Final Report for the Performance Evaluation of Fishways at Barriers

Background:

The use of low-head barriers to block and trap sea lamprey spawning runs has been encouraged by the Great Lakes Fishery Commission (GLFC) since the mid-1970's. Sea lamprey barriers were designed according to fisheries management objectives at that time, with attention focused on sport-fish, particularly salmonids. Consequently, fish passage criteria used in early sea lamprey barrier designs allowed the passage of jumping fish. The resulting design, the low-head barrier, can be negotiated by these species, particularly rainbow trout, coho salmon, and kokanee (Johnson and McDonald 1984, Kelso and Noltie 1990).

By the mid- to late- 1980’s, fish management policies were changing. Unobstructed passage of non-jumping species was becoming a priority for fisheries managers (Biette et al. 1988). In the early 1990’s the sea lamprey management program began evaluation of several fishway designs for use with sea lamprey barriers to limit impacts on non-target species. Studies by Noakes et al. (1999), Kelso and O’Connor (1999) and Porto et al. (1999) confirmed the blockage of access by some fish species to upstream reaches, resulting in a reduction in the number and type of fish species present above the barrier.

Today, the construction of low-head barrier dams remains potentially at odds with trends in fisheries management as managers contemplate barrier mitigation measures. Such measures restore access to the upstream reaches for the entire fish community, but create a need to exclude sea lamprey from the upstream spawning habitat. New barrier projects are likely to meet growing opposition from fisheries managers unless acceptable fish passage can be provided to ensure the maintenance of biodiversity upstream. In Canada, Fisheries and Oceans Canada (DFO) may, at its discretion, require the inclusion of a fishway to mitigate where barrier construction is proposed, under Section 20 (1)(2) of the *Fisheries Act*.

The GLFC has proposed to increase the number of low-head barriers constructed as an alternative to the use of chemical lampricides (GLFC 1992). The addition of a fishway has been accepted as mitigation tool which allows for non-target fish passage above the barrier. However, we have only begun to assess the effectiveness of “trap and sort” fishways and the evidence suggests there is much room for improvement. The addition of a fishway has been accepted as a mitigation tool which allows for non-target fish passage above the barrier, but until recently there has been little performance based testing on these designs. Bunt et al. (1999) determined that a complete assessment of fishway performance should “address entrance attraction efficiency, difficulty or physical output associated with upstream passage and finally, passage efficiency”. In addition, three workshops sponsored by the GLFC, Fish Passage, Turner Falls MA, 2001, Interim Policy of Barrier Placement, Ann Arbor MI, 2001, and Hydraulic, Hydrological, and Biological Characteristics of Effective Sea Lamprey Barriers, Ann Arbor, MI, 2003 have all indicated the need for the completion of a fishway attraction study at low-head barrier dams.

This final report addresses the (i) quantification of attraction efficiency to the fishway at two streams, Cobourg Brook and Big Carp River, (ii) testing of the existing passage efficiency at the two fishways, (iii) determining the propensity of sea lampreys to passively sort from teleosts once inside the traps and (iv) the quantification of the hydraulic environment within each fishway and the relationship to fish passage. These issues were examined over a range of typical fishway hydraulic conditions throughout the operation of the fishways in 2003. Our evaluations provide essential support for the environmental assessment and permit application process for future barriers and fishways. Our results offer a quantitative determination of the capabilities of the current fishway design, their potential for improved fish passage, and we have provided recommendations for future fishway construction projects.

Study Location

Cobourg Brook

Cobourg Brook, located approximately 120 km east of Toronto, Ontario had a fixed-crest low-head barrier and fishway installed for the 1997 spring sea lamprey migration. This was the first fixed-crest barrier in Canada constructed with a vertical slot fishway designed to pass non-target fishes. The fishway was designed to increase in-stream fish movement and mitigate the effect of a low-head barrier throughout the year. During the spring sea lamprey migration the fishway is modified to become a trap and sort operation, where teleosts are passed upstream and sea lampreys are collected in the trap and removed from the system. Once the sea lamprey migration is completed, the fishway is opened to allow non-jumping species access to the upper reaches of the stream. The barrier and fishway are illustrated in Figure 1.

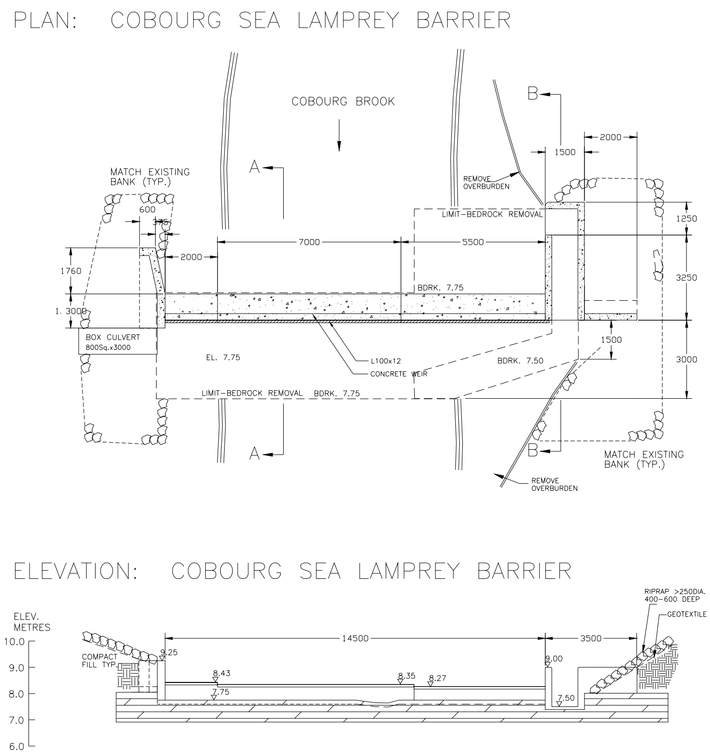


Figure 1: Plan and Elevation, Cobourg Brook sea lamprey barrier and fishway.

Big Carp River

Big Carp River, located approximately 5 km west of Sault Ste. Marie, had an experimental inflatable low-head barrier and fishway installed for the 1995 spring sea lamprey migration. This was the first Canadian barrier designed to block the stream only during the sea lamprey spawning migration. A modified vertical slot fishway was added to increase in-stream fish passage and mitigate the effect of stream blockage on non-target species. The upper end of the fishway is modified to include a sea lamprey trap. The barrier and fishway are illustrated in Figure 2.

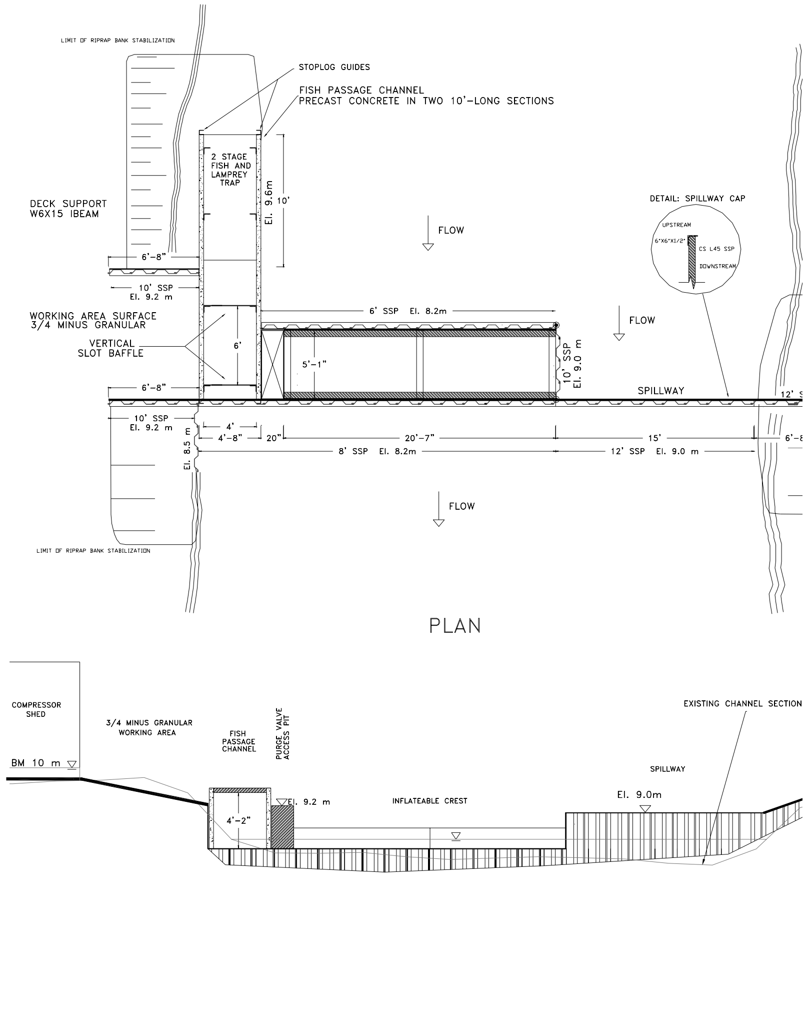


Figure 2: Plan and Elevation, Big Carp River barrier and fishway.

Methods

Details of the 2003 Fishway Operation

Physical Measures:

The Cobourg Brook fishway was checked on a daily basis from March 24 to the close of operations on June 27 and the Big Carp fishway was operated from April 28 through July 31, 2003. Five staff gauges were installed (four inside the fishway and one outside) at Cobourg Brook and six (five inside and one outside) were installed at Big Carp River. Level loggers which measure water level every 6 hours were installed at both fishway locations, one above and one below the barrier. During the daily operation of the fishways the staff gauge readings were recorded to provide a record of flow condition and frequency of flow at each location. OnSet temperature loggers were installed at each fishway to continuously monitor temperature and a daily reading was made with a hand-held thermometer for comparison. Water clarity was classified as clear, partially clear or turbid during each trip and at the Cobourg Brook location a turbidity meter was used to quantify the visual classification.

Fishway Operation:

Each fishway contains two separate traps which we emptied in the morning on a daily basis. All captured fish were identified and a subset of each species were measured (± 1 mm) and weighed (± 1 g) to provide an estimate of the abundance and biomass of the species using the fishway during its operation. All fish approximately 100 mm and larger captured in the fishway were checked for a pelvic fin clip or an abdominal scar which would indicate the presence of a passive integrated transponder (PIT) tag, and in Big Carp the pectoral fins were examined for fin punch marks from the 2002 fishway operation. All new fishes were marked with a fin clip at the time of capture, and all teleosts were released above the barrier. The fin clip allowed us a method of determining the rate of fall back, those fish recaptured in the fishway after being released above the barrier. Fish that were recaptured within the fishway were given a second mark and again released above the barrier. This work also represents the first ever measurement of fall back at a Sea Lamprey Control Centre (SLCC) barrier.

Results:

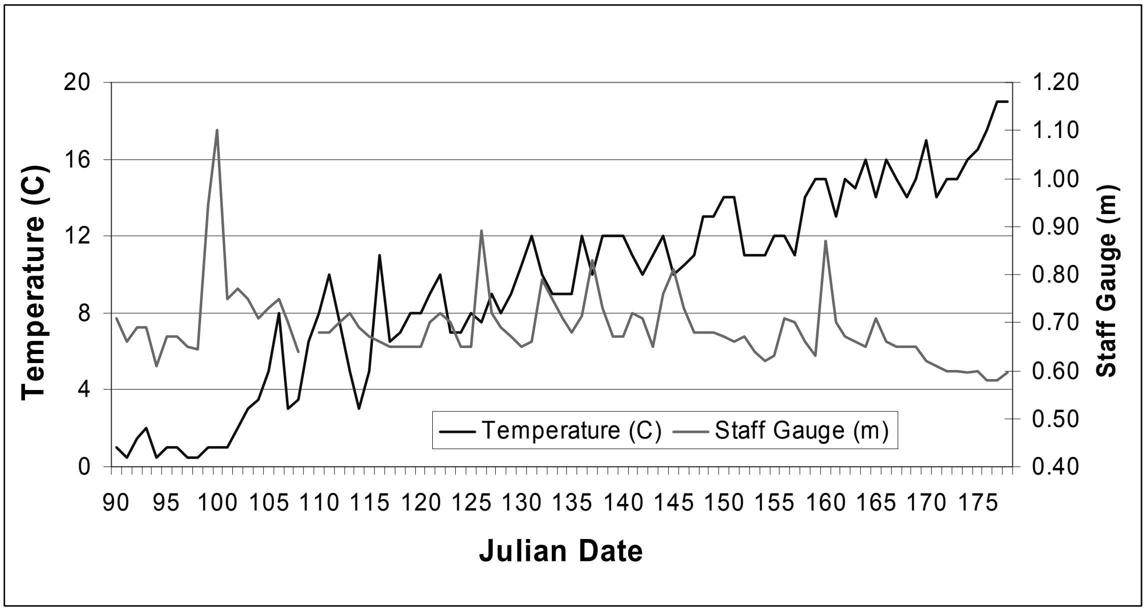
Flow, Temperature, and Catch:

Cobourg Brook

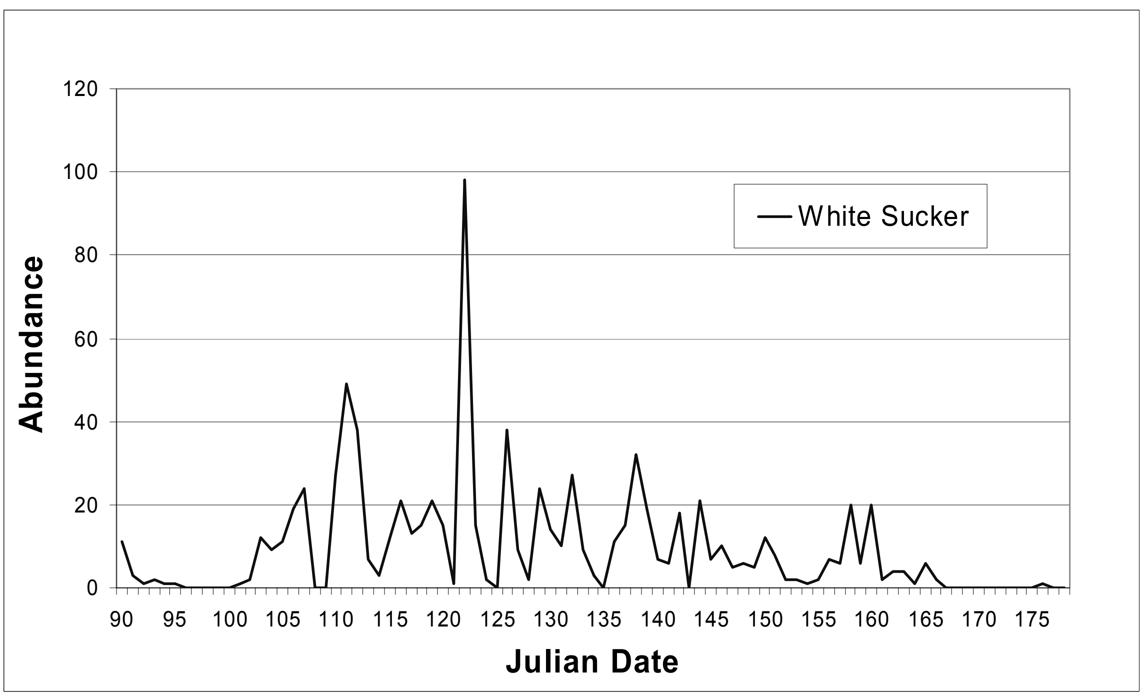
Water level was measured daily using the five staff gauges located within and around the fishway. Measurements were used to prepare a stage vs. velocity relationship for the fishway compartments. Flow data were compared with data obtained from the Water Survey of Canada and compared with the daily measurements (see Hydraulics section for summary).

Daily teleost catches fell to an average of 23 per day from an average of 36 per day once the white sucker migration had passed through the fishway. Flow through the fishway remained relatively consistent throughout the fishway operations in 2003 (Figures 3 a – d).

3 a.


Temperature (C)
Staff Gauge (m)
Julian Date
20
16
12
8
4
0
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175

3 b.


White Sucker
Abundance
Julian Date
120
100
80
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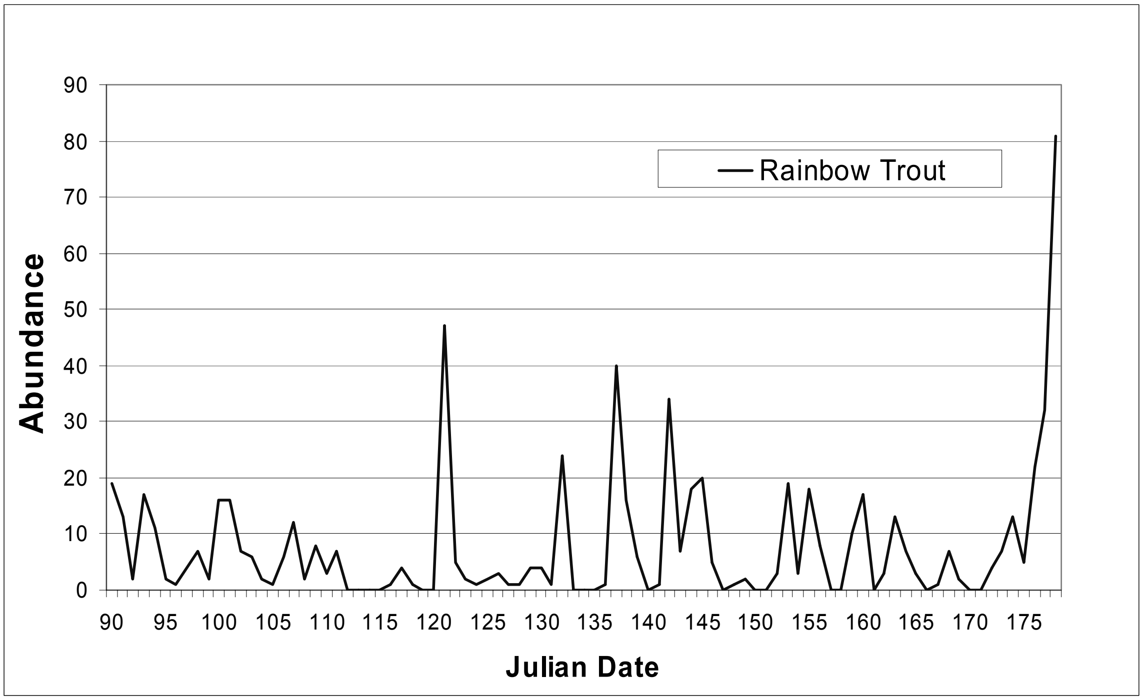
40
20
0
90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175

3c.



3d.

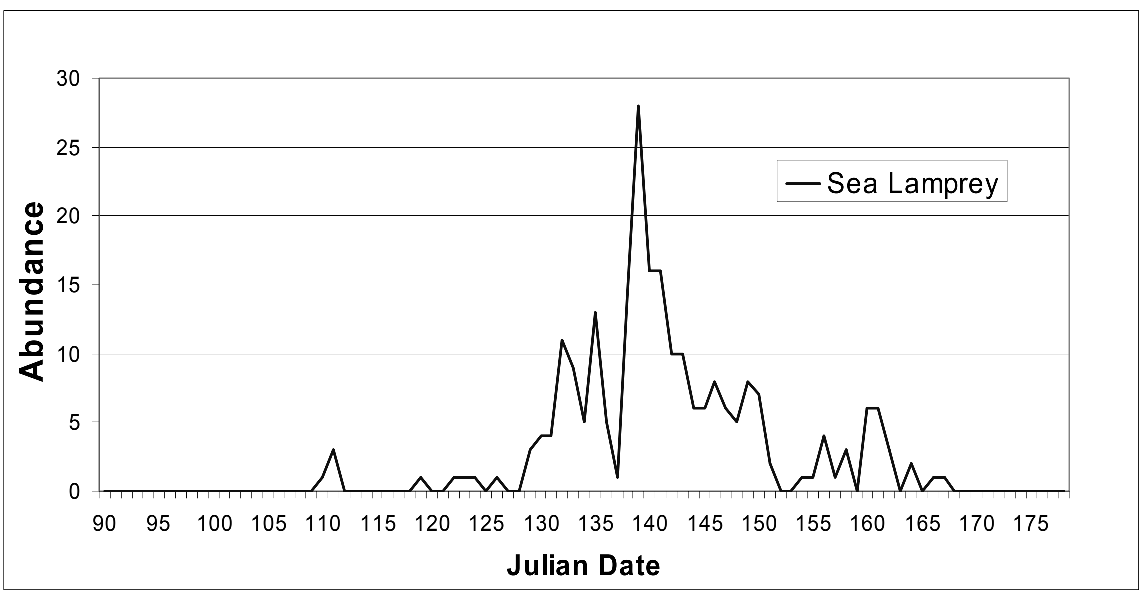


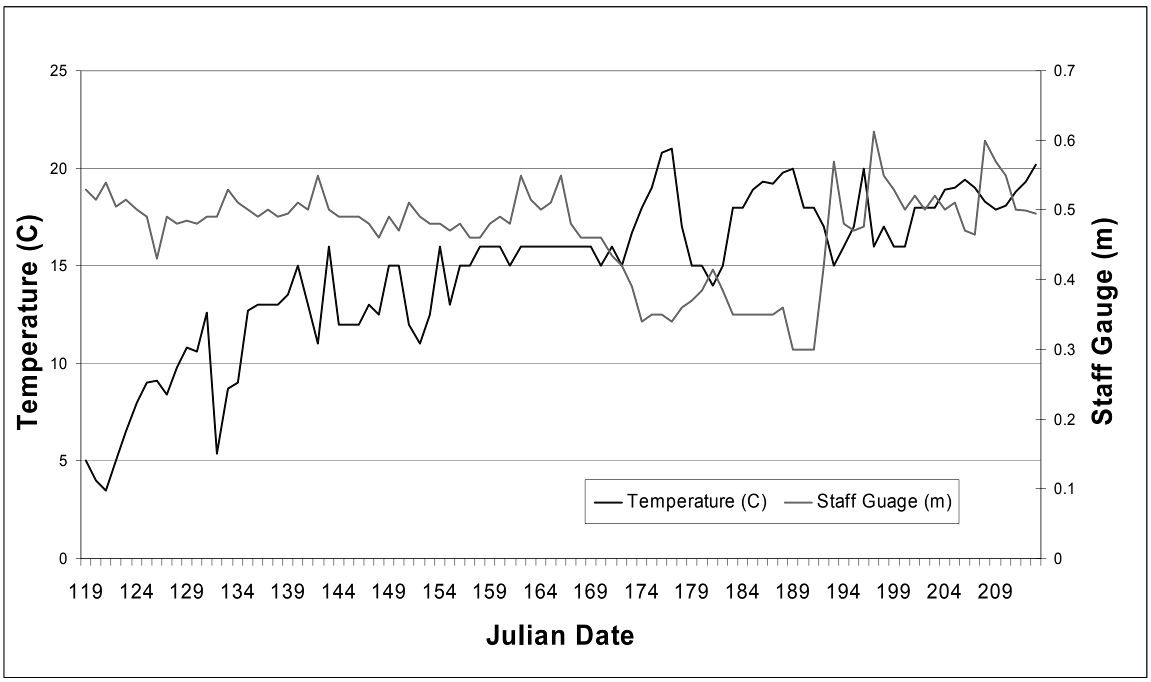
Figure 3 a: Cobourg Brook temperature (°C) and staff gauge (m) measurements taken during the 2003 field season. Panels 3 b through 3 d detail the daily abundance for white sucker, rainbow trout, and sea lampreys during the 2003 fishway operations.

Big Carp

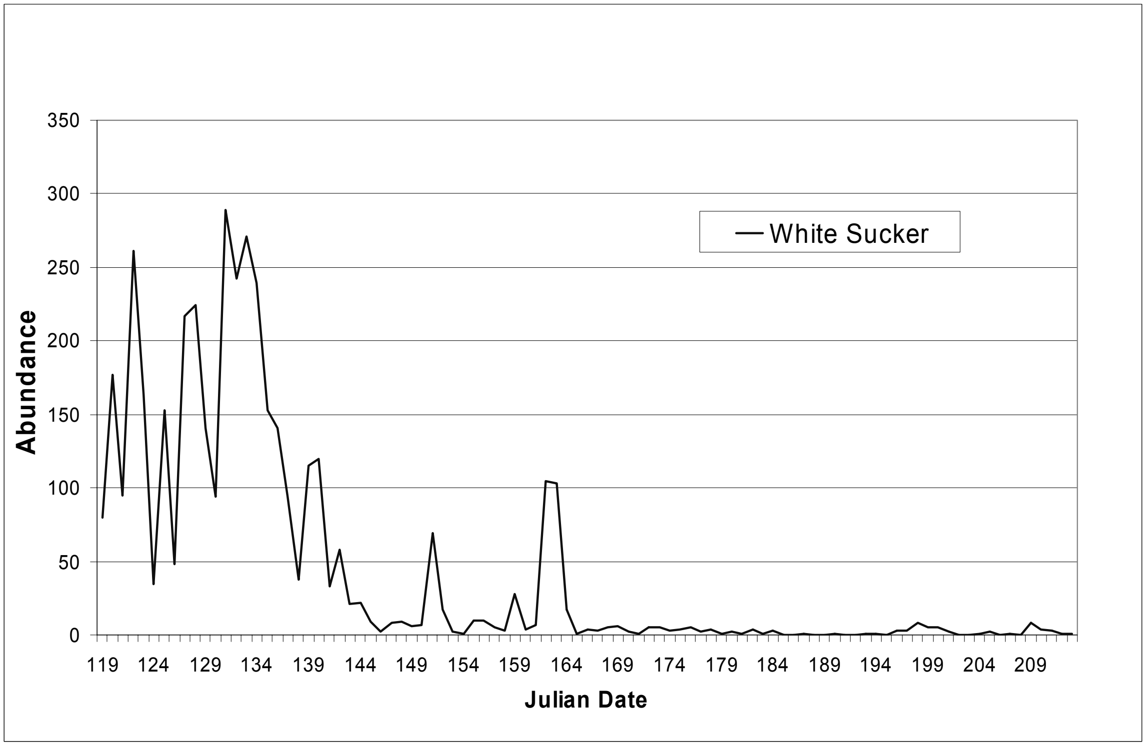
Water level was measured daily using the six staff gauges located within and around the fishway. Measurements were used to prepare a stage vs. velocity relationship for the fishway compartments. Flow data were compared with data obtained from the Water Survey of Canada and compared with the daily measurements (see Hydraulics section for summary).

Daily teleost catches fell to an average of 34 per day from an average of 156 per day once the white sucker migration had passed through the fishway. After the white sucker migration, increases in fishway catch were noted on days of increased flow. Individual species catch increases were noted at times of increased flow and as water temperature warmed during the season (Figure 4 a – e).

4 a.

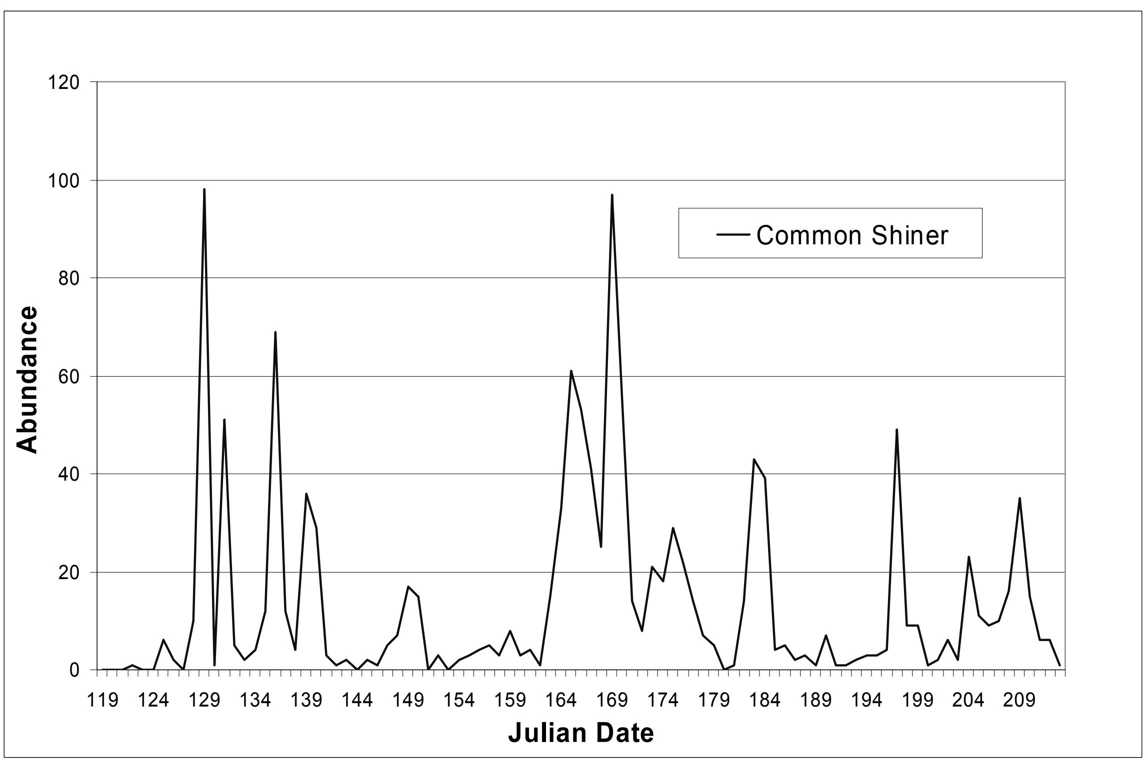


4 b.



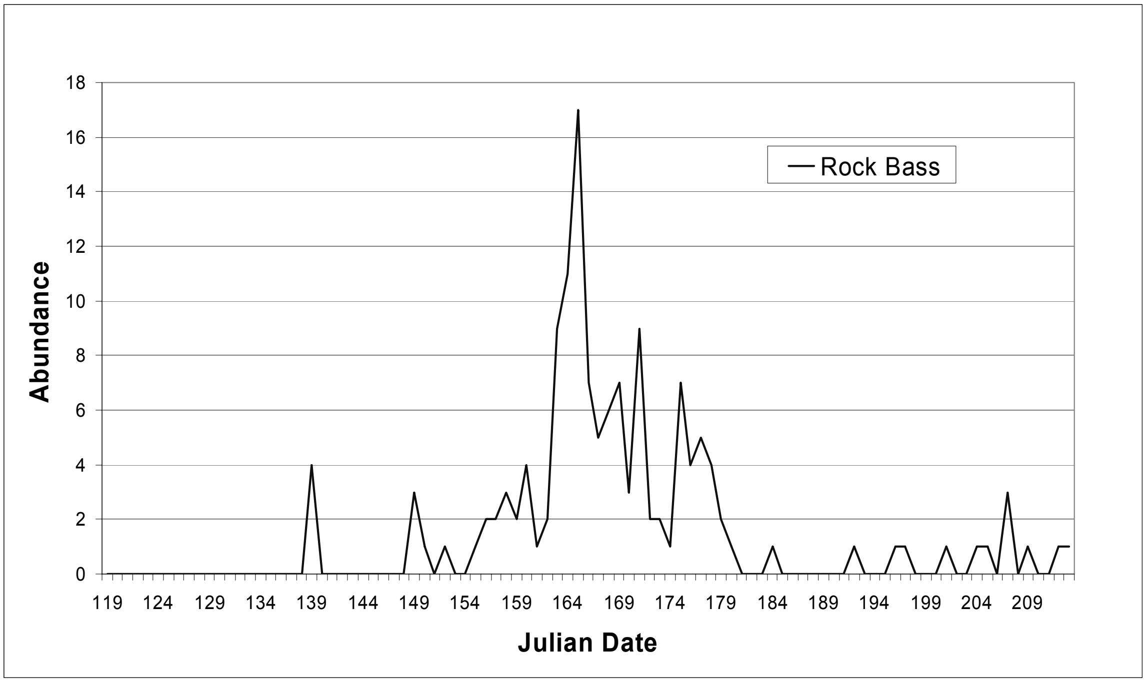
350
300
250
200
150
100
50
0
Abundance
White Sucker
119 124 129 134 139 144 149 154 159 164 169 174 179 184 189 194 199 204 209
Julian Date

4 c.



120
100
80
60
40
20
0
Abundance
Common Shiner
119 124 129 134 139 144 149 154 159 164 169 174 179 184 189 194 199 204 209
Julian Date

4 d.



4 e.

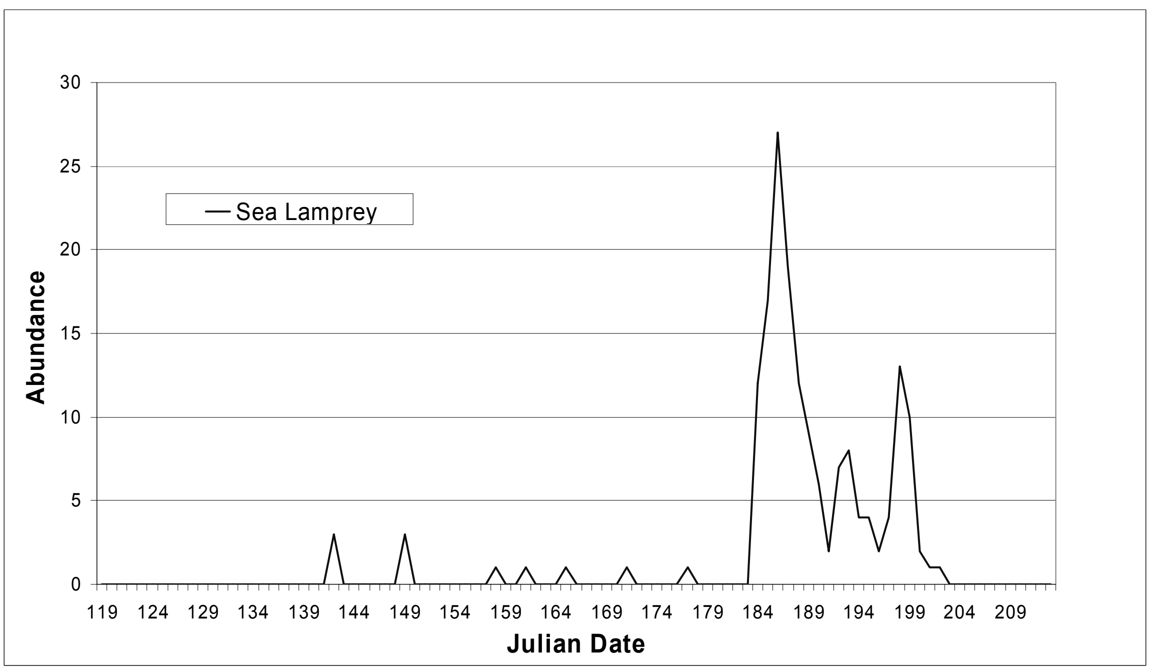


Figure 4 a: Big Carp River temperature (°C) and staff gauge (m) measurements taken during the 2003 fishway operation. Panels 4 b through 4 e detail the daily abundance data for white sucker, common shiner, rock bass, and sea lamprey during the 2003 season.

Fishway Results:

Cobourg Brook

The first teleosts were recorded on March 25. The white sucker (*Catastomus commersoni*) spawning run began shortly after the initiation of trap operation, with an interruption of approximately 1 week when the water temperature dropped to less than 1°C. The peak capture of 105 fish occurred on May 2, 2003. During the spawning run, many of the adult suckers were recorded as marked with growths or tumours on the body, and three were recorded as having sea lamprey scars. Only two white suckers were found dead in the Cobourg fishway in 2003 and over all mortality was low (39 teleosts). A total of 16 species (1895 individuals, 1856 live, 39 mortalities), not including sea lampreys were collected in the fishway during its operation (Table 1). Total estimated biomass passed through the fishway was 871 kg (teleosts) for 2003. Fall back was only observed in 2 species, and fall back rates were consistently low (Table 1).

Table 1: Summary of species abundance, mortality, estimated biomass, and percent fall back (marked fish) for those teleosts passed by the Cobourg Brook fishway, 2003 field season.

Species	Total Catch	Mortality	Biomass (kg)	% Fall Back
White sucker	838	2	812.93	3.7
Rainbow trout	695	9	50.44	0.4
Longnose dace	137	10	1.20	
Creek chub	54	3	2.85	
Mottled sculpin	45	13	0.465	
Pumpkinseed	36	1	0.720	
Brown trout	17	1	0.83	
Rock bass	13	0	1.63	
Blacknose dace	7	0	0.070	
Common shiner	6	0	0.036	
Johnny darter	4	0	0.016	
Brown bullhead	2	0	0.056	
Golden shiner	2	0		
American brook lamprey	1	0	<0.01	
Brook trout	1	0	0.049	
Northern redbelly dace	1	0	<0.01	
Total Teleosts	**1895**	**39**	**871**	**1.9 (avg.)**
Sea lamprey	235	3	62.54	
Total Catch	**2094**	**42**	**934**	

Big Carp River

The first teleosts were recorded on April 29, 2003. The white sucker (*Catastomus commersoni*) spawning migration began shortly after the initiation of trap operation, with the majority of the run passing through the trap within the first three weeks. The peak capture of 352 fish occurred on May 11 and the largest single mortality was on May 12, with 15 white suckers. A total of 23 species (6422 individuals, 6305 live, 117 mortalities), not including sea lampreys, were collected in the fishway during its operation (Table 2). Total estimated biomass passed through the fishway was 3502 kg for 2003. Fall back was only observed in 4 species, and over all fall back rates were consistently low (Table 2).

Table 2: Summary of species abundance, mortality, estimated biomass and percent fall back (marked fish) for those teleosts passed by the Big Carp River fishway, summer 2003.

Species	Total Catch	Mortality	Biomass (kg)	% Fall Back
White sucker	4059	67	3445.5	1.8
Common shiner	1292	20	13.1	0.2
Creek chub	367	0	7.7	
Rainbow trout	163	2	16.7	
Rock bass	141	3	11.1	0.7
Silver redhorse sucker	109	6	0.91	
Log perch	92	8	1.0	
Chinook salmon	78	2	1.2	
Brook trout	34	0	0.7	
Pumpkinseed	23	0	0.4	
Brown bullhead	21	0	2.7	
Bluntnose minnow	11	0	0.07	
Golden shiner	7	1	0.06	
Pearl dace	4	1	0.03	
Longnose sucker	3	0	1.1	33.3
Sculpin	3	0	0.03	
American brook lamprey	2	0	<0.01	
Lake chub	2	1	0.04	
Central mud minnow	1	0	<0.01	
Fathead minnow	1	0	0.02	
Smallmouth bass	1	0	0.03	
Trout perch	1	0	0.01	
Johnny darter	1	0	<0.01	
Unknown (decomposed)	6	6	**n/a**	
Total Fish	**6422**	**117**	**3548**	**1.2 (avg.)**
Sea Lamprey	171	2	45	
TOTALS	**6593**	**119**	**3503**	

Impingement:

Cobourg Brook

The original configuration of the baffle and intake gate valve did not allow for an examination of impingement. The <40 cm distance from the gate valve to the intake screen formed a small upper cage; however, the original design did not allow for cleaning and screen removal, whereby potentially impinged fishes could be removed and counted. On April 8, 2003, the intake gate and screen assembly were reversed and an internal screen added to keep fishes moving up through the fishway from becoming entangled in the gate valve. This reversal was originally made to facilitate screen cleaning and improve flow through the fishway (see Hydraulic Section); however, it also prevented fishes from accessing the upper trap section and becoming impinged.

Big Carp River

An examination of impingement rates at the Big Carp barrier was not part of the original proposal; however, during the course of the field work in 2002, we found impingement occurring in the upper section of the barrier. In 2003, we continued to follow impingement and the efforts to correct the problem during the fishway operations.

The intake section for the Big Carp fishway contains the gate valve for flow regulation; however, there is less than < 40 cm from the opening of the gate valve to the upper cage mesh, forming a small upper cage. This section was checked on a daily basis to clean debris from the screens and maintain flow regulation for the fishway. In 2003, prior to the opening of the fishway, a fence of 1 cm mesh was constructed and attached from the back of the fishway to the stream bank behind the fishway in an effort to prevent fishes from accessing the gate valve area. While the fence initially appeared to block the access to the intake screen, fishes were still able to get around the fence and become trapped in this upper trap section. During the daily checks any fishes found within this section were removed and their condition noted at the time of release. Several adult white suckers were captured in this section at the beginning of the spawning migration. Due to the small size of this area and the high water velocity, the fish were unable to orient themselves to the doorway in order to escape.

During the field season 16 teleost species, 5 terrestrial/invertebrate species, and one category for unknown fishes (too badly decomposed for identification) were collected in this section (Table 3). A total of 1350 individuals were collected in this upper compartment. Mortality was 27% for teleosts and 33% for other species. At the start of the fishway operation, it was assumed that those fish trapped in this section were in the process of migrating upstream. At this time, fish were released above the barrier, well away from the influence of the intake valve. As the fishing season progressed, flow over the barrier ceased. The Big Carp River barrier is unusual in its operation in that approximately halfway through the fishway operation, low stream flow above the barrier result in the dewatering of the barrier and all available stream flow passing through the fishway. At this point, fish captured in the upper compartment were assumed to be migrating downstream and were released below the fishway. Increases in impingement occurred as the flow over the barrier ceased on May 30, 2003 and remained intermittent until June 9 (Figure 5). On June 20 flow over the barrier again ceased until July 11, again trapping downstream migrating fishes above the barrier.

The fence that was installed around the gate valve at the beginning of the 2003 fishway operation was not as effective as first hoped, though mortality was less in 2003 than in 2002. On June 25, 1 cm mesh screen that encircled the gate valve was added to the fishway. Impingement dropped to zero, with the exception of two impinged individuals on June 27 most likely trapped prior to the screen addition, for the remainder of the fishway operation.

Table 3: Summary of impinged catch in the Big Carp River fishway 2003, including species, total abundance, live catch, and total mortality.

Species	Total	Live	Dead
White sucker	487	326	161
Chinook parr	288	209	79
Common shiner	214	170	44
Rainbow trout	174	160	14
Creek chub	31	26	5
Silver redhorse sucker	19	3	16
Brook trout	17	17	0
Unidentified	14	0	14
Rock bass	11	7	4
Log perch	8	8	0
Sculpin	5	4	1
Bluntnose minnow	1	0	1
Central mudminnow	1	0	1
Golden Shiner	1	0	1
Johnny darter	1	0	1
Blue gill	1	1	0
Smallmouth bass	1	1	0
All fish	1274	932	342
Crayfish	57	43	14
Tadpole	12	3	9
Giant water bug	4	4	0
Frog	2	0	2
Toad	1	1	0
Terrestrial/aquatic total	76	51	25
TOTAL	**1350**	**983**	**367**

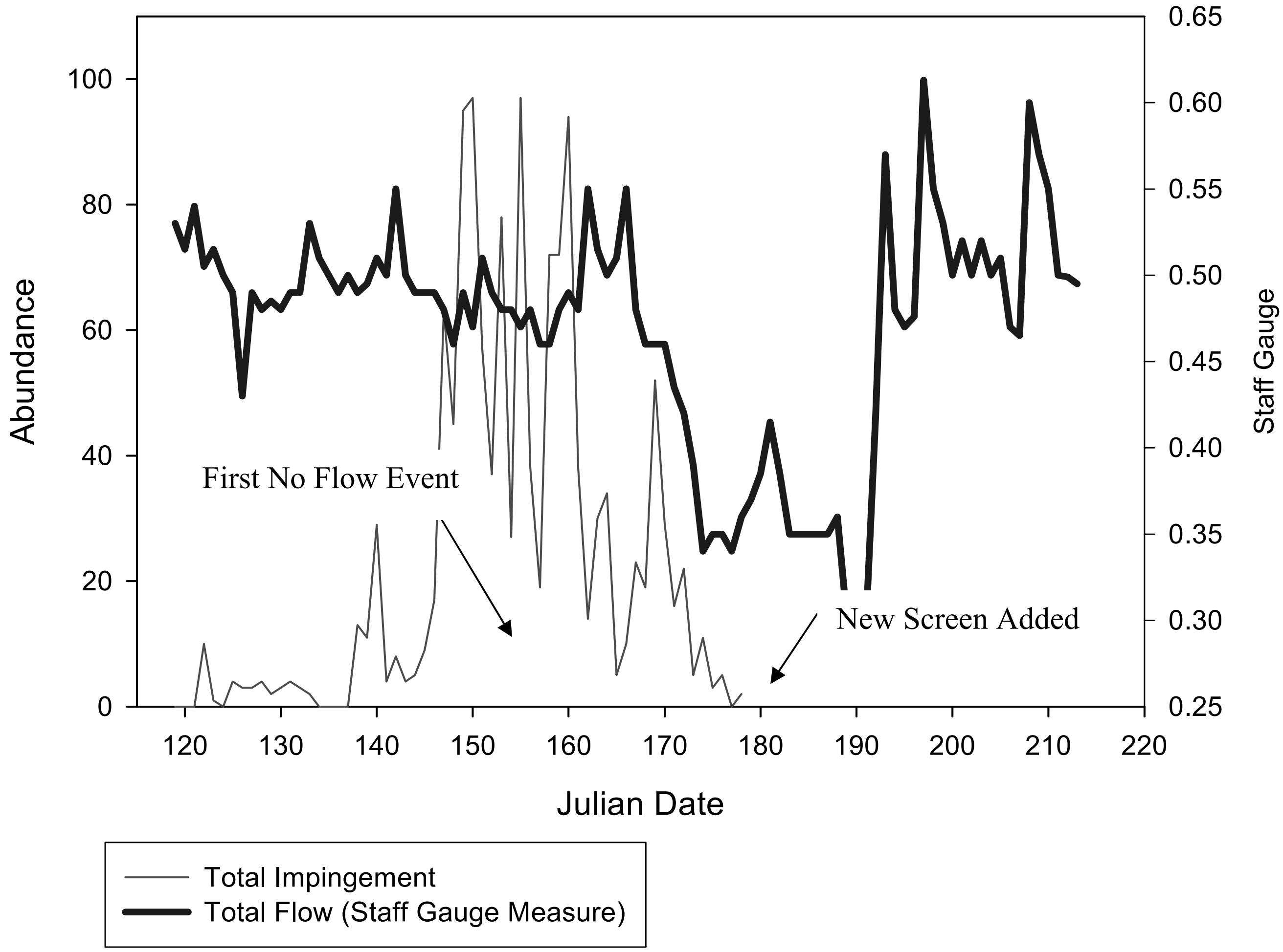


Figure 5: Impingement and flow as detailed by staff gauge readings for the 2003 field season. The first "no flow" event lasted two days, with intermittent flow over the barrier until June 25 (Julian day 175) when the additional screen was added to the upper intake valve section. Flow over the barrier remained intermittent until the barrier was lowered on August 1, 2003.

Tag Retention:

To increase the read-range of the tags, we used PIT tags 23 mm x 2.8 mm, which are too large for hypodermic needle insertion. Our PIT tags were surgically implanted into the ventral side of all fishes collected and the wound was sealed with VetBond surgical glue. Given the size of the fishes tagged (>100 mm) suturing is not considered necessary: however, for all fishes, we felt it was better to use as a minimum the surgical glue to prevent tag loss.

PIT tag retention rates have been described in the literature as ranging from 84.8% (Roussel et al. 2000) to 99.8% (Gries and Letcher 2002) for juvenile salmonids with surgical implantation of PIT tags. For those sea lampreys recaptured in the fishway, PIT tag retention rates were 100% in Cobourg Brook and 99% (1 lost tag) in Big Carp River. Wound healing was evident for all animals recovered. For the fishes recovered in the fishways, tag retention rates were 100% for both streams. We did not find any immediate mortality due to the tagging process. In Big Carp River in 2002 we tagged 92 white sucker and 12 rock bass in 2002 in 2 tagging periods (May and July). We recovered 17 white sucker (18%) and 1 rock bass (8%) from this period. Wound healing was complete for all fishes and we did not locate any other marked fish from this period without a PIT tag. Tag shedding post spawning for bull trout has been observed in Oregon (V. Tranquilli, personal communication). Tag shedding rates for white sucker are unknown as 2003 was the first year of tagging prior to spawning for this species. At Cobourg Brook proportionally the same number of males and females were detected on the lower antenna as they migrated downstream, indicating that both males and females may retain tags post spawning.

PIT Work:

Cobourg Brook

Mr. Vince Tranquilli (Oregon Department of Fish and Wildlife) assisted in the setup of three antennae at Cobourg Brook (April 12 to 14, 2003) (Figure 6) The antenna array consisted of a lower antenna (approximately 15m x 1m) placed approximately 10 m below the barrier and two smaller antennae of approximately 1m diameter at the fishway entrance and at the entrance to the upper trap. The antenna array was operational for April 14 to June 26, 2003 (74 days). Tagging of teleosts began on April 15. Seine netting supplemented with dip-netting, was used to collect fishes below the antenna array for PIT tagging. The majority of the tagging effort took place from April 15 to 20, and additional electrofishing efforts were made throughout the stream below the barrier during the trap operations to supplement both species and numbers tagged. A total 555 fishes of 7 different species were PIT tagged in 2003 (Table 4). Tagging numbers for the largest migratory species (white sucker) was based on a minimum of 10% of the 2002 fishway catch (1156), with other fishes >100mm tagged as they were captured.

Big Carp River

Three antennae were setup at Big Carp River on May 2, 2003 using the same configuration as those in Cobourg Brook (Figure 6). The lower antenna was approximately 13m x 1 m and the fishway antennae were approximately the same size as those constructed for the Cobourg Brook fishway. Vandalism on May 3 rendered the lower antenna inoperative until May 5 when the antenna module was replaced. The antenna array was operational from May 5 through July 30, 2003 (87 days). Tagging of teleosts began on May 1 using trap nets set downstream of the barrier, with the majority of the fish tagged on May 2, and continued through mid-June for additional fishes. A total of 572 fish of 6 different species were PIT tagged in 2003 (Table 4). Tagging numbers for the largest groups of migratory fishes (white sucker, rock bass) was based on a minimum of 10% of the 2002 fishway catch (2855 and 344 respectively), with other fishes >100 mm tagged as they were captured.

Figure 6: Schematic of antennae placement for Cobourg Brook and Big Carp River 2003. The lower antenna is approximately 10 m below the barrier, the entrance antenna is located within the fishway entrance, and the upper antenna is located within the upper trap and the funnel entrance.

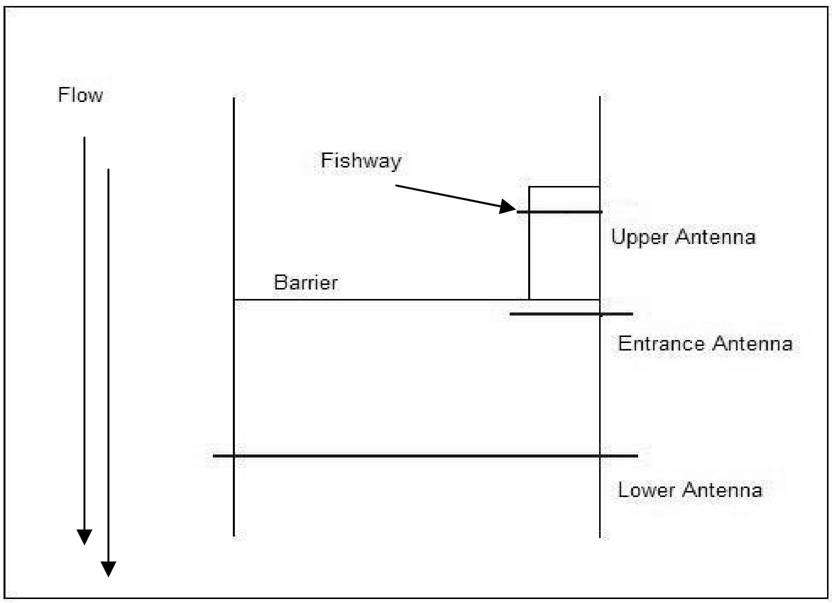


Table 4: Summary of fishes PIT tagged during the 2003 field season for Cobourg Brook and Big Carp River.

Cobourg Brook		Big Carp River	
Species	Number Tagged	Species	Number Tagged
White sucker	373	White sucker	407
Rainbow trout	57	Rock bass	53
Brown trout	7	Brown bullhead	2
Creek chub	2	Burbot	1
Brown bullhead	1	Common shiner	1
Rock bass	1	Sea Lamprey	108
Sea lamprey	114		
Total	555	Total	572

Attraction Efficiency:

Cobourg Brook

Of the 555 fishes tagged, 404 (73%) were detected on at least one of the antennae during the fishway operations in 2003, and of those, 321 were teleosts. Attraction efficiency was separated into three components: those that approached the barrier, those that moved from the barrier to the fishway entrance and those that moved into the traps within the fishway. At Cobourg Brook, 307 (96%) teleosts crossed the lower antenna approaching the barrier, 253 (79%) approached the fishway entrance, and 225 (70%) moved into the cages within the fishway (Table 5). Movements were recorded day and night for most species, and repeated visits to the fishway entrance and into the cages were recorded for most individuals during the operation of the antennae. Overall, 1644 individual tag numbers were recorded during the 74 days of antenna operations in 2003.

Big Carp River

Of the 572 fished tagged in 2003, 457 (79%) were detected on at least one of the antennae during the fishway operations and of those 380 were teleosts. Attraction efficiency was separated into the same three components as in Cobourg Brook. At Big Carp River, 375 (99%) teleosts crossed the lower antenna, 355 (94%) approached the fishway entrance and 267 (71%) moved into the cages within the fishway (Table 5). Movements were recorded day and night for most species. Movements were recorded with several visits to the fishway entrance; however, the majority of the movements for fishes recorded followed the sequence of: to the barrier, to the entrance, and into the traps. Overall, 1368 individual tag numbers were recorded during the 87 days of antenna operations in 2003.

Table 5: Summary of attraction efficiency results for Cobourg Brook and Big Carp River, 2003. Attraction efficiency was separated into three components: attraction to the barrier, attraction to the fishway entrance, and attraction into the fishway traps.

Stream	Attraction to Barrier	Attraction to Fishway Entrance	Attraction to Fishway Traps
Cobourg Brook	96 % (n = 307)	79 % (n = 253)	70 % (n = 225)
Big Carp River	99 % (n = 375)	94 % (n = 355)	71 % (n = 267)

Passage Efficiency:

Cobourg Brook

Passage efficiency was determined as the number of PIT tagged individuals that were passed over the dam through the fishway. Of the 225 PIT tagged fishes that entered the traps during the 2003 fishway operation, only 25 (8%) remained in the fishway at the time of opening (Table 6). The maximum number of PIT tags detected on the antennae over one day was 157; however, only 60 fishes (4 PIT tagged) were recovered in the trap in the morning. An average of 23 PIT tags per day were detected on the antennae, while an average of 23 fishes per day (average 2.2 PIT tagged) were collected in the traps. During the white sucker run (estimated from April 16 to May 10) and average of 36 tags per day were recorded, while an average of 24 fishes per day (average 0.44 PIT tagged per day) were passed over the barrier.

Big Carp River

Passage efficiency for Big Carp River was calculated as 27% for 2003 as 126 fishes tagged in 2003 were passed through the fishway. In addition to the fishes tagged in 2003, 17 fishes tagged in 2002 also approached the fishway in 2003 and 7 were passed over the barrier. Passage and attraction efficiency did not change with the addition of those tagged in 2002 (Table 6). The maximum number of PIT tags detected in the trap over one day was 263 and 258 (15 PIT tagged) fish were recovered in the trap in the morning. A mean of 15 PIT tags per day were detected on the antennae, with an average of 67 fish per day (average 2.9 PIT tagged) recovered in the trap during the fishway operations. During the white sucker run (estimated from fishway opening until May 25, 2003) an average of 35 tags per day (average 4.7 PIT tagged) were detected, with an average of 156 fish per day passed over the barrier.

Table 6: Summary of PIT tagged fish attraction and passage by species for Cobourg Brook and Big Carp River, 2003. * Sea lampreys were counted only for the time of first released to antenna detection and recovery within the trap, counts were not included for passive movement between traps study.

Cobourg Brook			Big Carp River		
Species	Number Attracted	Number Passed	Species	Number Attracted	Number Passed
White sucker	297	20	White sucker	350	121
Rainbow trout	18	1	Rock bass	27	3
Brown trout	4	4	Brown bullhead	2	2
Creek chub	2	0	Burbot	1	0
Brown bullhead	0	0	Common shiner	0	0
Rock bass	0	0	Sea Lamprey*	77	67
Sea lamprey*	83	62			
Total	404	87	Total	457	193

Comparison of In-Stream Movements:

In addition to differences in passage rates between Cobourg Brook and Big Carp River, we also found differences in the behaviour of teleosts in the two streams. We looked at the number of times (24 hour periods over which the data was recorded) that an individual fish was recorded as attracted to the barrier/fishway and the total number of days over which those time periods were recorded. Teleosts in Cobourg Brook approached the barrier/fishway significantly more times x = 18.1 (Mann-Whitney U test, $p<0.001$) than those in Big Carp River, x = 12.8. Teleosts also spent significantly (Mann-Whitney U test, $p<0.001$) more days approaching the barrier in Cobourg Brook (x = 14.4) than in Big Carp River (x = 6.8). The maximum number of days a teleost spent approaching the barrier in Cobourg Brook was 66 and in Big Carp River 87.

Sea Lampreys

Cobourg Brook

A total of 103 sea lampreys were captured in the Cobourg Brook fishway in 2003. All were weighed (± 1 g), measured (± 1 mm), and fitted with a PIT tag. We attempted to capture sea lampreys as they entered Cobourg Brook (near the mouth) in order to determine the timing of the run from the mouth to the barrier (<1 km). A hoop net was set near the stream mouth from May 10 through June 10 (not continuously); however, only 1 new sea lamprey and three already tagged sea lampreys were collected. The hoop net collected a variety of other fishes during its use, indicating that it was fishing properly. To simulate the movement of sea lampreys new to Cobourg Brook approaching the barrier and additional 11 sea lampreys were released over time near the stream mouth. Large numbers of sea lampreys were not available due to previous commitments to the sterile male release program and testing for heterosporis in Lake Ontario in 2003.

Big Carp River

A total of 2 sea lampreys were captured in the Big Carp fishway in 2003. We supplemented the natural run of sea lampreys with an addition of 106 collected from the Little Carp (2), the Thessalon River (9) and the St. Marys River (95). All additional sea lampreys were initially released near the mouth of the river to simulate a natural run to the fishway.

Passive Sorting and Movement Between Traps:

Once sea lampreys were collected in the fishways, they were released in a variety of locations to test passive sorting and movement between the traps.

Cobourg Brook

We released a total of 242 sea lampreys over a 55 day period, 39 in the upper trap, 35 in the lower trap, 47 below the lower antenna (within the range of attraction flow), and 121 at a park near the mouth of the river (Sea Lamprey Control Centre population estimate release location). The release locations were used to examine the degree of attraction and passive sorting between the traps (Table 7). We looked at each release site as an individual test of movement into the upper trap for those individuals released at each specific location. For those released in the upper, two choices were available, to stay within the trap or to leave. We hypothesized that the attraction flow and the small funnel entrance size would keep sea lampreys within the upper trap. Using log-linear analysis, our hypothesis was rejected (χ^2= 5.21, p=0.02) with 5 of the 39 sea lampreys (13%) of the leaving the trap. In the lower trap released lampreys had three choices: move to the upper trap, stay in the release location, or leave the fishway. We hypothesized the lampreys would follow the attraction flow into the upper trap. While the majority of the lampreys moved into the upper trap (n=19, 54%), compared with those that remained in the lower trap (n=0, 0%) or left the fishway (n=16, 46%), movement from the middle trap was significantly different from our hypothesis (χ^2= 23.78, p<0.001). We hypothesized that those sea lampreys released below the fishway (within the attraction flow) would also return to the upper trap. Movement into the upper trap was significantly less (χ^2= 54.88, p<0.001) than was expected, with only 16 (34%) of the sea lampreys returned to the upper trap after release. For those sea lampreys released at the park we hypothesized that they would move upstream to the fishway, following the attraction flow of the river. Movement into the upper trap was significantly less (χ^2= 203.48, p<0.001) than was expected with only 23 (19%) of the sea lampreys released at the park returning to the trap.

Big Carp River

We released a total of 262 lampreys over 56 days, 25 in the upper trap, 31 in the middle trap, 35 below the lower antenna (within the range of the attraction flow), and 171 at a boat launch near the river mouth (Sea Lamprey Control Centre population estimate release location) (Table 7), following the same hypotheses at each release location as in Cobourg Brook. For the individuals released in the upper trap, our hypothesis of attraction flow and small funnel size retaining sea lampreys was supported (χ^2= 0.00, p=1.00) with all of the sea lampreys released remaining in the upper trap. In the lower trap released sea lampreys had three choices: move to the upper trap, stay in the release location, or leave the fishway. We hypothesized that the lampreys would follow the attraction flow into the upper trap. While the majority of the lampreys moved into the upper trap (n=23, 74%), compared with those that remained in the lower trap (n=0) or left the fishway (n=8, 26%), movement from the lower trap was significantly different from our hypothesis (χ^2= 9.78, p=0.01). While the majority of the sea lampreys released below the barrier (within the attraction flow range) returned to the upper trap (n= 22, 63%), this was significantly less (χ^2= 18.03, p<0.001) than was expected. Seventy-two (42%) of the sea lampreys released at the boat launch were attracted to the upper trap; however, this was significantly less (χ^2= 173.68, p<0.001) than was expected.

Table 7: Summary of sea lamprey movements for those sea lampreys released within the fishway during the 2003 field season.

Release Site	Number	Did Not Move	Moved to Up	Left Fishway
Cobourg Brook				
Upper Trap	39	34	n/a	5
Lower Trap	35	0	19	16
Below Barrier	47	n/a	16	31
At Park	121	n/a	23	98

Release Site	Number	Did Not Move	Moved to Up	Left Fishway
Big Carp River				
Upper Trap	25	25	n/a	0
Lower Trap	31	n/a	23	8
Below Barrier	35	n/a	22	13
At Boat Launch	171	n/a	72	99

Our hypothesis that all sea lampreys would passively move to the upper trap from the site of release was only supported for those released in the upper trap in the Big Carp River fishway. While the majority of the sea lampreys released in the lower trap and below the barrier at Big Carp River did return to the upper trap, our hypothesis of 100% attraction was not met. At Cobourg Brook, none of the released locations met our hypothesis of 100% attraction to the upper trap, including for those released in the upper trap location.

Video Work:

Cobourg Brook

Underwater video cameras were placed at the upper funnel and fishway entrances to record teleost and sea lamprey movement within the fishway (Figure 7). Cameras were operated for 48 nights (9:30 pm – 5:30 am). Water clarity ranged from clear to turbid during the study; however, both lampreys and teleosts were clearly visible on the recordings. At the upper trap funnel, sea lampreys and small teleosts generally moved quickly through the funnel and into the trap; however, both teleosts and sea lampreys often left the upper trap throughout the 8 hours. At the fishway entrance both teleosts and sea lampreys are observed moving into and out from the trap, particularly during low flow events in the fishway.

Big Carp River

Underwater video cameras were placed in the fishway in the same locations as in Cobourg Brook (Figure 7). Cameras were operated for 22 nights (9:30 pm to 5:30 am) and 5 days (generally 9:30 am to 4:30 pm). Water quality ranged from clear to partially clear throughout the study. Two sea lampreys were observed leaving the upper trap and 9 were observed leaving the fishway entrance. Other teleosts were also observed leaving the both the upper trap and the fishway entrance. The camera at the fishway entrance observed both sea lampreys and teleosts approaching the fishway entrance and swimming around the entrance without entering the fishway.

The underwater cameras were effective in monitoring teleost and lamprey movements into and out from the upper traps in the fishways under a variety of lighting and water clarity conditions. The underwater video at the fishway entrances showed teleosts and sea lampreys entering and exiting the fishway as well as those that searched around the fishway entrance without moving into the traps. In Cobourg Brook movements into and out from the traps occurred throughout the night indicating that fishes were able to locate the entrance and move into the fishway under low flow conditions.

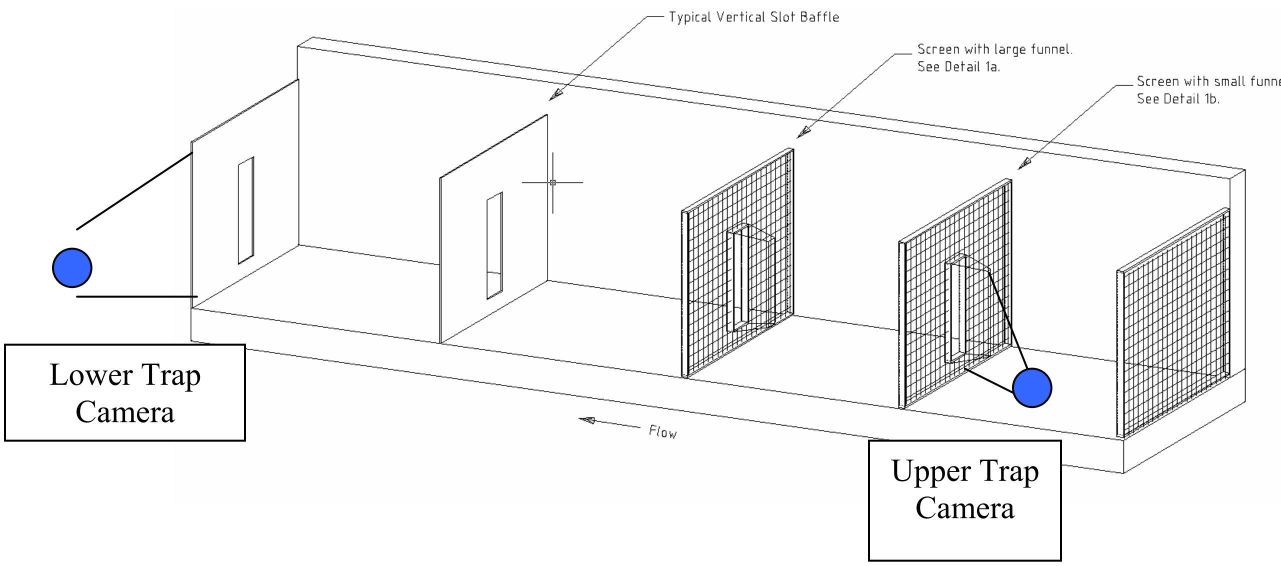


Figure 7: Cutaway view of the modified vertical slot fishway showing camera positions used in the 2003 field season at both Cobourg Brook and Big Carp River fishways.

Fishway Hydraulics:

Cobourg Brook

Fishway hydraulics were measured on three occasions using the Marsh-McBirney Flomate electromagnetic flow meter, during the fishway operations, under normal flow conditions. Flow varied little on Cobourg Brook during the fishway operations in 2003, and subsequently during our fall survey, water levels had not increased. The flow meter was set to report average velocity for a period of measurement of 30 seconds. At least three measurements were taken at each grid node, and when consistent results were obtained a velocity was recorded. Average velocity within the water column was calculated from the average of corresponding upper and lower measurements.

Velocity measurements used in the flow calculation were collected along a transect in the trap compartment, where flow conditions were most uniform. Mean fishway flow during the 2003 fishway operations was 0.225 m^3/s when the intake screen was cleaned of debris. When cleaned, the volume of the upper and lower traps was $1m^3$. In Cobourg Brook, in-stream debris repeatedly clogged the upper intake screen within approximately 1 hour of cleaning. At this time, fishway flow was reduced to almost 0 m^3/s (Figure 8) and the volume of the upper and lower traps was reduced to less than 0.5 m^3. Full flow was only maintained in the fishway for approximately 5% of the day.

8 a.

8 b.

Figure 8 a: Photograph of the intake screen at the Cobourg Brook fishway detailing leaf-litter build-up on the outside and 8 b: photograph of the interior of the fishway showing limited water in-flow when the intake screen is blocked.

Between the baffles a two-tier grid was set up to measure velocity, with nodes on the upper grid directly above the nodes on the lower grid. Water depth was measured with a graduated column at each node on the grid. Between baffles, velocity measurements were taken in the lower grid at 0.2 times the depth of water column and in the upper grid at 0.8 times the depth of water column. At baffles, the instrument was positioned 0.4 times the depth of flow above the baffle sill, and at 0.4 times the depth of flow in the vena contracta – the minimum width of the jet typically occurring 3 to 5 cm downstream of the baffle. For all measurements, the flow meter was oriented parallel to the fishway walls, facing upstream to provide a one-dimensional flow profile. The velocity measurements taken under low flow allowed visualization of re-circulating (rest-areas) within the fishway compartments as well as visualization of the filament of maximum velocity through each fishway compartment (Figure 9).

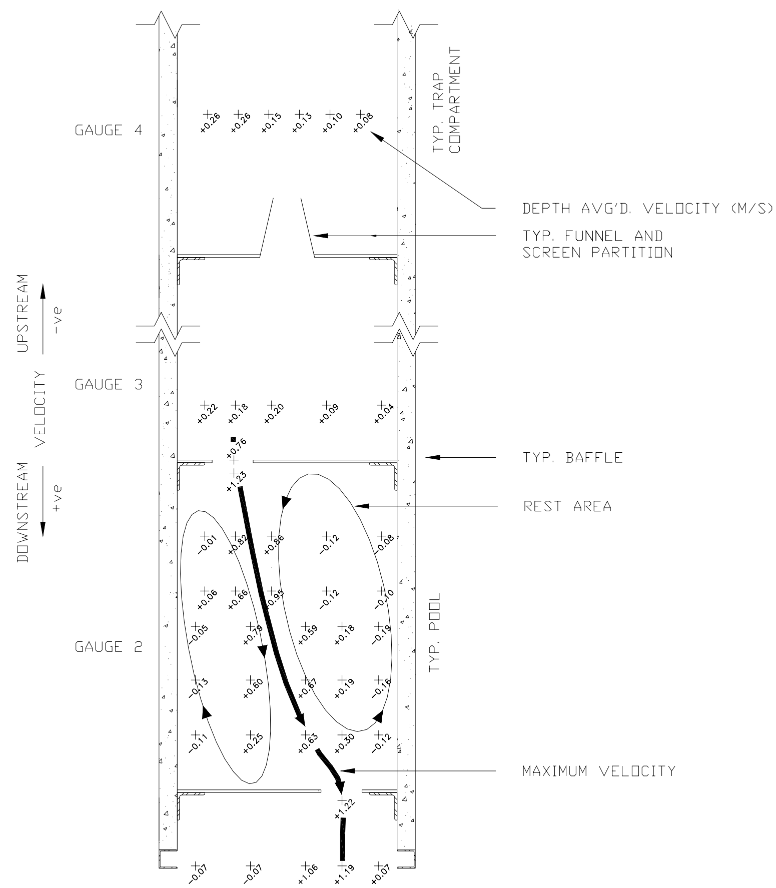


Figure 9: Summary of typical flow patterns for both Cobourg Brook and Big Carp fishways 2003.

In addition to the measurements taken within the fishway, velocity was measured at a distance of 0.5m, 1.0 m, and 2.0 m at 0.4 times the measured depth downstream of the fishway to visualize the jet of attraction flow both when the intake screen was blocked and when fully cleaned. Downstream of the spillway, backward flow was measured at this depth and is consistent with the presence of a submerged hydraulic jump, where the nappe plunges to the channel bottom, rising to the surface a short distance downstream of the barrier creating a "roller", or backward surface flow. To the right of the spillway, the fishway attraction area is a quiet pool, approximately two meters in diameter. When the fishway intake was blocked with debris, some of the backward flow from the spillway was apparent in this pool, but to a lesser degree and no attraction flow from the fishway was present (Figure 10). Velocities are measured in meters per second, and are circled. Flow direction may be inferred from the "tail" on the flow measurement. When debris was removed from the intake screen, the jet of water from the fishway was readily apparent over a meter away from the fishway (Figure 10).

Intake Blocked

Intake Unobstructed

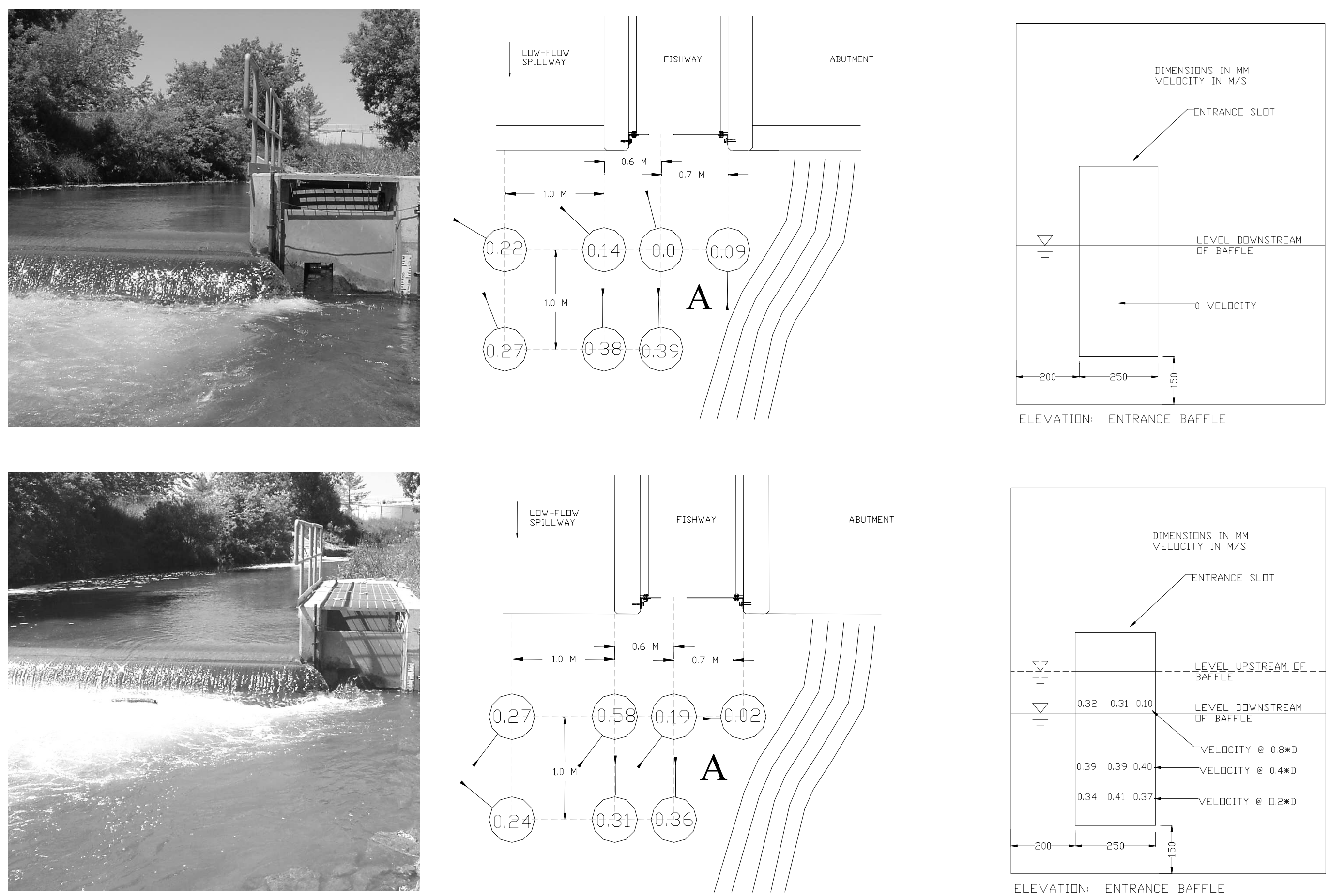


Figure 10: Cobourg Brook Fishway Hydraulics

Big Carp River

Velocities in the fishway were measured on three occasions, including flow conditions under which the trap was normally operated and on November 25, 2003, when conditions were consistent with spring flow velocities. The Marsh-McBirney Flomate meter was used for all measurements as at Cobourg Brook. The instrument was set to report average velocity for a period of measurement of 30 seconds. At least three measurements were taken at each grid node, and when consistent results were obtained a velocity was recorded. Average velocity within the water column was calculated from the average of corresponding upper and lower measurements. Mean flow during normal operating conditions was 0.243 m^3/s, similar to flow conditions measured in Cobourg Brook and those measured in 2002 (0.2 m^3/s).

Flow through the fishway was calculated from the velocity measurements at 0.09 m^3/s; 50% of the 0.18 m^3/s reported in Water Survey of Canada's provisional data for the same date. Later in the season, as much as 100% of the stream flow was passed through the fishway, fully dewatering the barrier spillway. Velocity measurements used in the flow calculation were collected along a transect in the trap compartment, where flow conditions were most uniform. Only one transect was collected in the trap compartment because the screens upstream serve to diffuse the jet from the fishway intake.

Between the baffles a two-tier grid was set up to measure velocity, with nodes on the upper grid directly above the nodes on the lower grid. Water depth was measured with a graduated column at each node on the grid. Between baffles, velocity measurements were taken in the lower grid at 0.2 times the depth of water column and in the upper grid at 0.8 times the depth of water column. At baffles, the instrument was positioned 0.4 times the depth of flow above the baffle sill, and at 0.4 times the depth of flow in the vena contracta – the minimum width of the jet typically occurring 3 to 5 cm downstream of the baffle. For all measurements, the flow meter was oriented parallel to the fishway walls, facing upstream to provide a one-dimensional flow profile. The velocity measurements taken under low flow allowed visualization of re-circulating (rest-areas) within the fishway compartments as well as visualization of the filament of maximum velocity through each fishway compartment (Figure 9). In addition to the measurements taken within the fishway, average velocity was also recorded at 0.5m, 1.0m, and 2.0m downstream of the fishway entrance to determine the velocity of the vena contracta, attraction flow, as it projected from the fishway entrance under both average and high flow conditions (Figure 11).

Typical Flow

High Flow

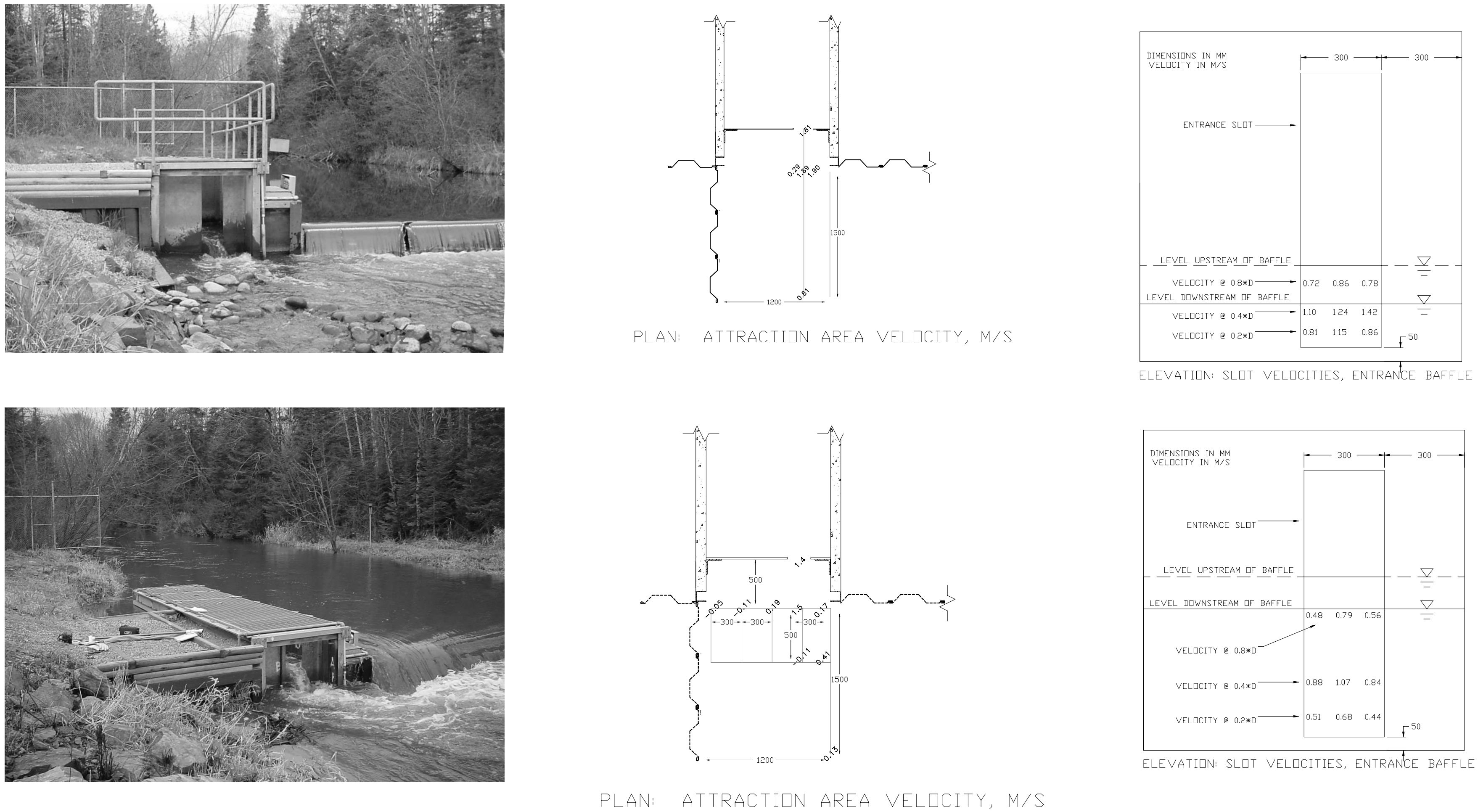


Figure 11: Big Carp River Fishway Hydraulics

Summary:

Overall our work found that while fishes are attracted to the fishway and into the traps, passage success remains low at both fishway locations. Small trap volumes in the fishway provide little capacity for storage of large numbers of fishes, particularly when large bodied species such as white sucker or rainbow trout occupy the space. Limited flow in the fishway at Cobourg Brook compounds the problem by reducing the available trap capacity to approximately 0.5 m^3, compared to 1 m^3 when full flow when the intake screen is clean. Minimum recommended compartment volume for a vertical slot fishway (where holding capacity is not required) is 2.5 m^3 (United Nations 2002). The intake screens used at the fishways need to be improved to shed in-stream debris and maintain attraction flow within the fishway.

Impingement will continue to be an issue, unless the gate valve is screened to prevent downstream migration fish from becoming caught in the upper compartment. We demonstrated the success of such screen at Big Carp River in 2003. The Big Carp River retains the problem of downstream passage during the summer months. Once stream levels are reduced by low summer flows, flow over the barrier ceases trapping any fishes migrating downstream above the barrier. At this point fishes must wait for a rain event to raise the stream level and restore flow over the barrier or attempt to follow the in-stream flow through the fishway where they may become impinged in the gate valve. As downstream migration is an area of concern at large dams, the GLFC will need to ensure that this issue is resolved at this location and at future barrier sites.

For sea lampreys, both the PIT array and the video analysis indicate that they will readily move into the upper trap at both fishway locations; however, both locations also show sea lampreys leaving the trap. We believe trap retention can be improved through the combination of maintaining flow, increasing the trap volume, and improving funnel design.

Recommendations:

1. **Increase trap size within the fishway:**
   The current trap size of approximately 1 m^3 appears to be inadequate at these two small streams for retaining the number of migrating teleosts. Trap size in comparable vertical slot fishways is 2.5 m^3 in circumstances where storage is not occurring. By increasing the trap volume, more fishes may remain in the fishway until it is emptied, thereby increasing fish passage and reducing the effect of the in-stream barrier.

2. **Ensuring intake screens are self-cleaning to maintain attraction flow and reducing or eliminating impingement:**
   Adequate flow must be maintained at existing fishways and at any newly constructed facilities. Self-cleaning screens that shed in-stream debris will prevent

the reduction of attraction flow within the fishway and help to maintain trap volume throughout the fishway operation.

Intake gate valves must be covered with a screen to prevent impingement from occurring at fishway locations. Mortality can be high for those fishes trapped in the gate valve compartment and any reduction in fish mortality will benefit the fish community.

In addition to maintaining flow through the fishway, downstream flow must also be considered in order to provide for downstream migration. In the case of the Big Carp River, during low water, all stream flow is diverted through the fishway, trapping fishes above the barrier and preventing any downstream migration. As downstream movement of fishes is also a concern for fisheries managers, the GLFC will also need to examine this issue as it relates to low-head barrier construction.

3. **Increasing the frequency of trap operations during peak migration periods:**
   During the white sucker spawning migration, large numbers of large bodied fish attempt to utilize the fishway. By increasing trap operating frequency during this time, a greater number of individuals would be passed over the barrier quicker thereby reducing the "waiting time" fish are experiencing below the barrier.

   A second option to reduce the pressure of the spring migration of white suckers (likely to occur in most Great Lakes streams) would be delaying the "trap and sort" operation at the fishway for approximately 2 weeks from the current opening date. We did not capture any sea lampreys during the first three weeks of operation at either fishway and this would allow the majority of the white sucker migration to pass through the fishway unobstructed. This would reduce operation and labour costs for the fishway, but does include the risk of a sea lamprey escapement above the barrier during this time.

4. **Funnel improvements for sea lamprey retention:**
   To retain sea lampreys in the upper trap and improve passive sorting within the fishway, we recommend that the upper trap funnel be converted to a design that will reduce escapement. Funnels similar to those used in the St. Marys River trap (R. McDonald design) have been shown to block sea lampreys from leaving and would provide an effective, low-cost solution. We do not recommend this funnel be used at the lower trap entrance unless the trap volume is increased and flow can be maintained within the fishway, to prevent injury or mortality of larger fishes that may become trapped within this section.

There is great potential to move large numbers of fishes around the low-head barrier using the recommended modifications to the current fishways. If these recommendations are incorporated into the existing fishway locations, attraction and passage efficiency should be re-examined to determine the relative measures of success of these modifications.

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