Mactaquac Aquatic Ecosystem Study
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PROCEEDINGS OF THE
FISH PASSAGE EXPERT WORKSHOP:
GLOBAL VIEWS AND PRELIMINARY
CONSIDERATIONS FOR MACTAQUAC

Linnansaari, T., R.A. Curry, and G.
Yamazaki

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## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENTS</td>
<td>i</td>
</tr>
<tr>
<td>DISCLAIMER</td>
<td>ii</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>iii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. THE FISH PASSAGE EXPERT Workshop: OBJECTIVES</td>
<td>2</td>
</tr>
<tr>
<td>3. SUMMARIES OF EXPERT PRESENTATIONS</td>
<td>3</td>
</tr>
<tr>
<td>3.1 PRESENTATIONS BY NBP AND CRI</td>
<td>3</td>
</tr>
<tr>
<td>3.2 PRESENTATION 1: ALEX HARO</td>
<td>3</td>
</tr>
<tr>
<td>3.3 PRESENTATION 2: PAUL KEMP</td>
<td>6</td>
</tr>
<tr>
<td>3.4 PRESENTATION 3: SERGIO MAKRAKIS</td>
<td>7</td>
</tr>
<tr>
<td>3.5 PRESENTATION 4: LAURA WILDMAN</td>
<td>9</td>
</tr>
<tr>
<td>3.6 PRESENTATION 5: GREGORY ALLEN</td>
<td>10</td>
</tr>
<tr>
<td>3.7 PRESENTATION 6: ED MEYER</td>
<td>11</td>
</tr>
<tr>
<td>3.8 PRESENTATION 7: JOHN WILLIAMS</td>
<td>13</td>
</tr>
<tr>
<td>3.9 PRESENTATION 8: MR. CHRISTOS KATOPODIS</td>
<td>14</td>
</tr>
<tr>
<td>3.10 PRESENTATION 9: STEVEN COOKE</td>
<td>15</td>
</tr>
<tr>
<td>4. SUMMARY OF DISCUSSION SESSIONS</td>
<td>16</td>
</tr>
<tr>
<td>4.1 WHAT FISH SPECIES SHOULD / COULD BE PASSED?</td>
<td>16</td>
</tr>
<tr>
<td>4.2 WHAT COULD BE PASSED: UPSTREAM PASSAGE TECHNICAL SOLUTIONS</td>
<td>18</td>
</tr>
<tr>
<td>4.3 WHAT COULD BE PASSED: DOWNSTREAM PASSAGE TECHNICAL SOLUTIONS</td>
<td>20</td>
</tr>
<tr>
<td>4.4 EXPERT OPINION: A CONCEPTUAL PLAN FOR A NEW GENERATING STATION</td>
<td>21</td>
</tr>
<tr>
<td>5. CONCLUSIONS AND RECOMMENDATIONS</td>
<td>26</td>
</tr>
<tr>
<td>5.1 General conclusions and recommendations</td>
<td>26</td>
</tr>
<tr>
<td>5.2 Conclusions and recommendations specific to upstream passage</td>
<td>27</td>
</tr>
<tr>
<td>5.3 Conclusions and recommendations specific to downstream passage</td>
<td>27</td>
</tr>
<tr>
<td>5.4 Conclusions and recommendations specific to generic design of the facility</td>
<td>27</td>
</tr>
<tr>
<td>6. ACKNOWLEDGEMENTS</td>
<td>29</td>
</tr>
<tr>
<td>APPENDIX 1: List of Fish Passage Workshop invited expert participants and their contact information at the time of the meeting</td>
<td>30</td>
</tr>
<tr>
<td>APPENDIX 2: Presentation abstracts</td>
<td>31</td>
</tr>
</tbody>
</table>
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DISCLAIMER

Intended Use and Technical Limitations of the Fish Passage Workshop Report: The sole purpose of this report is to: 1) summarize the expressed professional opinions of the invited experts present at the workshop and including their subsequent related communications with the CRI; and 2) to inform, as an initial step in the process, the recommended engineering design options (NBP Project 2.1.3.1). The information contained herein does not necessarily represent the opinion of the CRI.
EXECUTIVE SUMMARY

A Fish Passage Experts Workshop was held on 3-4 November 2014, in Fredericton, NB, where nine of the world’s leading experts on fish passage shared best practices and lessons learned from various rivers and projects around the world. The objectives of the meeting were to learn about and discuss our current and best understanding of fish passage science globally, to discuss the experts’ fish passage experiences, and to listen to the lessons learned that may be applied to the Mactaquac Project. This report is a Final Deliverable of the NBP Project 2.1.2, Fish Passage Expert Workshop.

The Fish Passage Experts stated in general:

- They unanimously indicated that the removal of the dam and restoration a natural flowing river at this site is the most effective and desirable option for successful fish passage.
- Successful or functional fish passage in a multi-species setting is a very difficult challenge, but it is not necessarily impossible to achieve.
- A clear definition of “successful fish passage” is important to establish from the beginning.
- An adaptive management approach is required (active assessment and modification).
- The cumulative impacts of the multiple dams can’t be neglected.
- The behaviour of all fish species must be clearly understood (migrations and swimming abilities).
- Biological understanding must be incorporated early and often in engineering designs.
- It is important to understand and then address the impact of the reservoir on populations.

Regarding upstream fish passage:

- Attraction flows are the critical component of successful upstream passage.
- Multiple passage structures and entrance locations will be required.
- Structures will most probably include at least one fish-lift, a technical fish ladder, and an eel/lamprey ramp.
- A nature-like fishway may not be feasible at this site.

Regarding downstream fish passage:

- Downstream passage will require spillway, by-pass, and turbines solutions.
- Floating collection devices located upstream of the facility may not be suitable.
- Fish-friendly turbines provide the safest possible turbine passage.
- Surface- and bottom-oriented fish species require accommodation.

The overall design of a new facility that ensures functional fish passage will have incorporated:

- Orientation of the powerhouse and spillways to maximize attraction to entrances to passage facilities for fish moving up- and downstream.
- Hydrodynamic/computational fluid dynamics/physical models that have tested design options.
1. INTRODUCTION

Hydro-electric power generation or hydropower affects the ecology of rivers in various ways. Documented effects of hydropower on fish populations are numerous and include, e.g., habitat alterations, loss of spawning and nursery habitats, loss of diversity, changes in population structure, and disruptions to longitudinal connectivity. The latter effect is especially problematic for species that require up- and/or downstream migrations to complete their life cycle, i.e., barriers to these movements result in well-documented population effects. The connectivity issues can be mitigated to varying degrees of success by the provision of up- and/or downstream fish passage structures.

The Saint John River (SJR) is managed for hydropower by a provincial owner-operator, the New Brunswick Power Corporation (NBP). NBP operates a number of hydropower dams in the SJR system, and the largest are the Mactaquac Generating Station, Beechwood Generating Station, Tobique-Narrows Generating Station, and Grand Falls Generating Station (GS).

The first facility in the system (farthest downstream) is the Mactaquac Generating Station (MGS) located ~17 km upstream from the city of Fredericton and 115 km upstream of the Bay of Fundy on the mainstem of the SJR. The station began operating in 1968. The facility is ~1,100 m long with a head ~40 m (see diagram). It has the capacity to generate ~670 megawatts of energy using six Kaplan turbines. The MGS supplies ~12 % of the electric power production for New Brunswick.

The concrete portions of the station, ~300 m which include the spillways and the powerhouse, are expected to reach the end of their service lives in 2030 because of problems with concrete expansion. The problem is Alkali-Aggregate Reaction (AAR) and occurs when concrete paste reacts with silica in the sand and gravel mix of the concrete. The reaction causes the concrete to swell and crack over time. The earthen dam is a rock-filled structure sealed with clay; it is not affected by AAR and remains secure.

NBP has started a process to evaluate the future options for the MGS known as Mactaquac Project (www.mactaquac.ca/). These options are: 1) to repower the facility; 2) to retain the reservoir (commonly known as the headpond) but with no hydropower; or 3) to remove the dam and restore the river to a free-flowing state at the site.
NBP has engaged the Canadian Rivers Institute (CRI) to design a large, multidisciplinary aquatic ecosystem study to help the company make an informed, science-based decision for a preferred option. The CRI initiated *The Mactaquac Aquatic Ecosystem Study* (MAES) which is a planned, whole-river ecosystem study and manipulation.

In the first two options, a dam and headpond/reservoir would be retained and therefore, up- and downstream fish passage are major considerations in the programme of the MAES. The CRI is undertaking three approaches to address the specific issue of fish passage:

1) The state-of-the-art fish passage world-wide will be reviewed (published literature) along with direct input of expert advice from jurisdictions where fish passage solutions have been attempted in large rivers and/or in multi-species situations. [Project NBP 2.1.1]
2) The organizing of a Fish Passage Expert Workshop where world experts in the field of fish passage science have an opportunity to comment on the current status of fish passage in their jurisdictions and provide lessons learned that may be applied to the Mactaquac Project. [Project NBP 2.1.2]
3) The provision of recommendations for conceptual design options for fish passage for multiple fish species for a new facility at the MGS site. [Project NBP 2.1.3]

This report is a Final Deliverable of the *NBP Project 2.1.2, Fish Passage Expert Workshop* (FPEW) that was held in Fredericton, NB, November 3 and 4, 2014.

Stakeholder values and interests related to fish passage are recognized by NBP as an important part of their evaluation process. NBP has launched a separate process seeking input from the general public and various stakeholders (see www.mactaquac.ca/how-you-can-participate/). The *Fish Passage Expert Workshop* was not a venue to address these important aspects of stakeholder opinions, but rather focused on learning about fish passage science and experiences from other jurisdictions.

### 2. THE FISH PASSAGE EXPERT WORKSHOP: OBJECTIVES

The experts invited to the workshop hosted by the CRI were selected based on their established reputation in the fish passage science and management community. The group was convened with an objective to introduce global coverage of different expertise and experiences.

The invited experts were provided the background of the Mactaquac Project, its three options, and a list of the 55 fish species including the 14 diadromous species found in the SJR. In their invitation letter, the experts were given the following guidance:

*The purpose of the workshop is to learn about the cutting-edge fish passage technologies and from their successes and failures in the past in other jurisdictions so that the best practices can be adopted in the Mactaquac Project, should a new dam be build...The dam rebuilding scenario will consider a wide variety of options and will set forward a number of questions that will be discussed in the expert workshop. For example, if a new dam was to be constructed:*
1) What are the structures that each species would likely require for successful passage both up- and downstream;
2) Are there species for which it is unlikely that functional passage structures either up- and/or downstream can be found; and
3) Are there structures/techniques/designs that will work for a multitude of species present in the SJR and similarly, what species may require a specific passage structures? How might these designs or techniques work in a possible new generating station in the SJR and for the species present in this system?

Given this guidance, the experts were instructed to provide a 40 min presentation related to their expertise with up- and downstream passage structures, their functionality, turbine passage and design, spillway screening structures and design, provision of spill- or attraction flows, etc. The experts second task was to provide advice regarding “…what might work for fish if a new facility was built to replace the current Mactaquac Generating Station”.

3. SUMMARIES OF EXPERT PRESENTATIONS

The following summaries of the invited expert presentations are the interpretations and understanding of the CRI organizers. Importantly, the expert working group discussed the very significant difference between “fish passage” and “functional fish passage”, i.e., a facility may have a “fish passage” structure, but if it is not successfully passing fish up- and downstream, then it is not “functional fish passage”.

3.1 PRESENTATIONS BY NBP AND CRI

The morning session of the meeting was designed to provide an introduction to NBP’s Mactaquac Project (presented by the Mactaquac Project Manager, George Porter), CRI’s Mactaquac Aquatic Ecosystem Study (presented by Allen Curry), and the general hydropower operations and fish fauna of the Saint John River (presented by Tommi Linnansaari). To provide context and facilitate discussions, a site visit to the MGS was arranged. Experts had an opportunity to see the river, the headpond, and the current MGS site. The existing upstream fish passage system at the MGS was toured and explained by Fisheries and Oceans Canada personnel.

3.2 PRESENTATION 1: ALEX HARO

Remove or Rebuild? Considerations for the Mactaquac Aquatic Ecosystem Study from a River Continuity Perspective

The presentation by Dr. Haro outlined the benefits of dam removal as the ultimate solution for functional fish passage and then he concentrated on the possible fish passage issues and solutions in a possible dam rebuild scenario.
**Dam Removal:** Dr. Haro emphasized that the provision of fish passage is not equivalent with river restoration, and while technological solutions to passing fish may be possible for some species under some circumstances, such fixes rarely provide a fix for the complex, ecological matrix of problems created by dams. He argued that although the goal of functional fish passage is to allow a river to function ecologically, i.e., in the pre-dam state, such a goal may not be possible by simply providing fish passage. The existing data indicates that significant net benefits are incurred for both fish passage and ecosystem health following dam removals, although the examples of large dam removals are rare. Examples of large dam removal that have overcome most fish passage issues are the Veazie and Edwards dams on the Penobscot River and the Kennebec River, respectively. An additional benefit of dam removal is the significant regaining of spawning and nursery habitats.

Dam removal may also generate some unforeseen issues because the new environment may be different from the pre-dam state, e.g., modified channel morphology and flow regimes and if other dams still exist in the system. Naturally, dam removal means lost energy production and its economic benefits, although dam removal in one location may be compensated by increasing production at remaining dams (as in the Maine situation). A new, albeit controversial way of thinking is to “sacrifice” some rivers and/or tributaries for hydropower while safeguarding some rivers and/or tributaries as ecological reserves for diadromous fishes. Such practice would of course require difficult societal choices, e.g., which rivers to keep as reserves, which to sacrifice.

When considering the rebuilding options proposed for Mactaquac, it was pointed out that the first or downstream-most dam can have the largest impact in river systems where multiple dams occur. Fixing the passage problems at the first dam typically results in the greatest benefits for greatest number of species, and it also provides incentive to alleviate passage problems in the remaining dams upstream, i.e., a domino-effect.

Dr. Haro indicated that the common goal of functional fish passage up- and downstream of a dam can be accomplished in many different ways. Experience further suggests that when fish passage solutions are built as retrofits (post-dam construction), functional solutions for fish passage are difficult to obtain, i.e., facilities were built for power generation and not fish. Therefore, the potential re-build of a “new Mactaquac” should alleviate this issue because the species-specific fish requirements can be carefully considered based on a comprehensive scientific understanding prior to designing and building the facility.

Dr. Haro introduced the first common theme of the workshop, i.e., fish attraction to a passage structure is one of the most critical aspects of functional fish passage. Multiple variables need to be considered at entrances including turbulence and fish behavior. In general, many species simply “follow the flow”, but flow dynamics can be hard to understand in what is a turbulent environment. Often the failure of passage structures, whether up- or downstream, are a product of the fish not locating the entrance of a passage structure which can lead to significant migration delays or complete migration failures. Examples of problems include too little water being directed to the passage structure for attraction, or trying to force fish into a small opening from an open area causing avoidance.
The presentation outlined two generic upstream passage options. The first option is a volitional passage (i.e., fish actively move into the structure) using a technical fish ladder (most common) or nature-like fishways (less common). Assuming 0.25 m head-drop per pool for a 32 m high dam, the ladder would require 128 pools. Then assuming a 5 m length for each pool, the resulting fishway would be 640 m in length. This is extremely long for a technical fishway which may render the volitional fishway solution non-practical for Mactaquac.

The new Mactaquac facility may require consideration of non-volitional fish passage, e.g., a fish lift – the second upstream option. Fish lifts can provide passage for the greatest number of species, e.g., its potential usefulness for a diverse community of fish as occurs in the SJR. Dr. Haro pointed out that a fish lift will need a very large capacity due to high numbers of migrating Alewife and Blueback Herring (two fish species commonly referred to as Gaspereau) and thus most probably, the provision of more than one fish lift.

The non-volitional solution suites the widest range of fish species, but some non-volitional solutions, like fish lifts, do not work for all species. Juvenile American Eel passage upstream was specifically mentioned as an example of poor performance of fish lifts in general (at least those designs currently used). The presentation also pointed out that, although fish lifts may accomplish the task of passing various fish species and life stages upstream, fish lifts still cause an unnaturally stressful period in the lift due to crowding and high densities, including other species that may be predators or prey. Fish lifts also have issues associated with migration delays. Dr. Haro concluded by pointing out that post-passage problems are also important to consider, i.e., entry from a lotic habitat into a lentic environment (the reservoir) with potentially different temperature/dissolved oxygen regimes may prove problematic, e.g., behavioural or orientation problems and fallback.

**Downstream Passage:** Dr. Haro described the principal problems for downstream passage as the lack of appropriate attraction flow to by-pass structures, i.e., the powerhouse, and impingement problems at trash racks. Downstream passage generally takes one of two forms. Fish are either excluded from hazardous routes physically using screens and behavioural guidance devices, or passage through the hazardous route of the turbines (considered in more detail in Section 3.6) is engineered to be less hazardous. Generally, bar racks and screens are designed to exclude debris and not fish from entering the turbines. Dr. Haro noted that bar rack designs are over 100 years old and suggested the need for additional research and design of new technical solutions for physical exclusion devices at turbine intakes. Various behavioral guidance solutions exist, e.g., light and sound, but the functionality of these solutions remain untested for many species, i.e., they are not a generic solution in a multi-species situation. Massive, floating fish filtering devices are used with success in some low debris situations. While technically possible, Dr. Haro did not think such solutions would be practical for Mactaquac due to the site’s debris load. Guidance of fish to a spill passage route can be effective in some cases where suitable plunge pools exist, but research only exists for small-bodied, salmonid smolts and thus there are many unknown issues for large-bodied species and their life stages, e.g., salmon adult (kelts).

As concluding remarks, Dr. Haro proposed that hydropower producers consider building smaller projects, or at least projects that do not require as much water for power generation and thus provide adequate water directed to enhance fish passage performance (e.g., guidance of fish to a
structure). General guidelines he suggested included increasing the generally applied nominal 3-5% of flow for fish passage to at least 5-10%. He also encouraged potential new projects to boldly try new and promising technologies like fish-friendly turbines rather than blindly relying on traditional technologies. The latter may be in the “comfort zone” of engineers and hydropower managers, but traditional engineering solutions have a poor history of functional fish passage. He reiterated that a single technical solution had an infinitesimal probability of success at Mactaquac, i.e., multiple passage solutions will be required. From the management perspective, he emphasized that any new project must establish a well-defined target for success, i.e., what is functional fish passage and this is not necessarily 100% successful passage of all individuals. Both the target species to be passed now and in the future and the passage performance targets should be identified and established by appropriate regulatory agencies before any decisions regarding the planning, designing, and building of a fish passage structure. Such plans are best constructed using an adaptive management approach and thus reviewed regularly. Finally, Dr. Haro emphasized that the state of science for fish passage technologies and applications is not clear-cut; many aspects still remain unknown.

3.3 PRESENTATION 2: PAUL KEMP

Fish passage: challenges, failures, and potential solutions

Dr. Kemp started his presentation by giving a historical overview of fish passage issues in Europe and the UK dating back to the 7th century. His intent was to emphasize the fact that we have understood for a very long time that dams and impoundments have an impact on fish populations. There is a long history of mitigation strategies and solutions. Yet despite this knowledge and countless efforts to overcome the problem, Dr. Kemp stated that fish passage science is still struggling with passage solutions that rarely work, i.e., they exist but are rarely functional. To substantiate his statement, Dr. Kemp showed numerous examples of recent meta-analyses where the success of various fish passage structures have been intensively reviewed. The documented passage rates and attraction efficiencies show a large range of success and failures with no patterns or guaranteed results. Dr. Kemp also pointed out that attraction and passage efficiencies are often negatively correlated resulting in poor overall success of for fish passage. Functional fish passage is rare.

Dr. Kemp reminded the audience about the concept of ecological traps. Fishways can act as predator hotspots and large reservoirs can act as “ecological barriers”, i.e., once in a reservoir, a migrating fish may become disoriented, lost, or more vulnerable to predation. This is important because even the most effective fish passage solutions may not fully compensate for the impact of an impoundment (reservoir) on ecological connectivity.

Dr. Kemp shifted his focus to discuss future needs for fish passage science. He offered five points for consideration:

1) Recognizing the problem: fish passage is not a universal panacea.

Dr. Kemp stated that it is important to admit that functional fish passage is difficult and that even with the advancements in fish passage science and engineering there are no guarantees. He used an example from the Columbia River from the Pacific Northwest, USA, to illustrate the
point. While two decades of work on fish passage has resulted in relative success in passing salmonid fishes at some hydropower facilities, there still are many dams in the Columbia system that do not have functional solutions. Furthermore, even in this relatively well-studied river system there are many fish species, essentially the non-salmonids, for which fish passage solutions function very poorly. Therefore, it may not be appropriate to say that the fish passage problems in the Columbia River “have been fixed”.

2) Developing realistic fish passage design criteria for multiple species:
   Dr. Kemp discussed the fact that our current understanding of fish passage science comes from economically important species in the temperate regions. There is a clear need to focus the science on developing solutions for other species that take into consideration the realities of various swimming modes, body morphologies, and life-history types. Such tests are best undertaken under realistic conditions which are preferably large, controlled swimming performance facilities.

3) Embracing the importance of fish behavior in passage efficiency:
   Dr. Kemp’s next crucial reminder was that it is of the utmost importance to first understand the species-specific fish behavior and the links to physical or environmental conditions, e.g., flow and temperature. Passage structures must be built to accommodate these specific behaviors, i.e., building a structure and assuming fish will learn to use it has not worked. He used an example for European Eel to demonstrate how behavioural studies combined with detailed hydrodynamic modeling has resulted in significant improvements in eel passage in Swedish rivers.

4) Improving understanding of population-scale responses including cumulative impacts:
   It is important to consider “the big picture”. Decisions and solutions for a specific hydropower project must be linked to the larger, population-scale effects on fish and the ecosystem. This is especially important in river systems with multiple hydropower facilities and thus very real, cumulative impacts on populations.

5) Considering alternative mitigation options and develop techniques to effectively prioritize actions:
   To conclude, Dr. Kemp discussed prioritization of goals and objectives in situations where multiple impediments for fish migration exist. Assuming a limited resources scenario, effective decision-making systems are required to find the solutions to maximize the economic investments, i.e., invest in effective solutions. Dr. Kemp reiterated that building fish passage is not a guarantee of the protection of a functional ecosystem system and alternative mitigation options should be considered, e.g., complete removal of the migration impediment.

3.4 PRESENTATION 3: SERGIO MAKRAKIS

Fish migration and passage in Neotropical regulated rivers: the case of the upper Paraná River, Brazil.

Dr. Makrakis examined fish passage issues from a different perspective by emphasizing large numbers and sizes of hydropower projects and the associated fish passage problems and solutions, i.e., a broader ecosystem and cumulative effects approach. The presentation outlined the intensive and extensive hydropower facilities across Brazil, including the largest hydropower project in the
world in terms of electric power generation - the Itaipu Dam with 14,000 MW and at a height of 196 m. Hydropower constitutes a critical energy source for Brazil and thus, fishways are mandated by law to "permit free ascent of fishes".

The hydropower-regulated, upper Paraná River offers parallels to a project like Mactaquac. In the Paraná, solutions are required for a large variety of fish species, solutions are needed for high head situations that necessitate large fish passage structures, and fish migrations occur through a river system with multiple dams. The Upper Paraná is the most regulated river in South America with over 130 dams that are >10 m in height. Such a density of hydropower projects combined with high fish diversity puts extra pressure on securing fish passage. Dr. Makrakis presented data emphasizing the importance of understanding the migration patterns of various species. As in the SJR, the migration needs of all species were unknown in the Paraná River system, but through a 10-year series of mark-recapture studies, Dr. Makrakis was able to demonstrate that to complete their life-cycles: a) a number of fish species undertook migrations into the tributaries to the reservoirs between different hydropower dams (non-diadromous species); and b) the up- and/or downstream migration through dams via passage structures was not required for all species. The message for the Mactaquac Project was the need for comprehensive studies to understand the fish movements within the impounded parts of the regulated river system, i.e., such studies provide important insights for species requiring either obligate or facultative fish passage solutions.

To highlight the challenges encountered in fish passage science in Brazil, Dr. Makrakis presented two examples of very large-scale fish passage solutions installed in the Paraná River: the fish ladder of Porto Primavera Dam (a weir and orifice type) and the fish passage system of Canal da Piracema at the Itaipu Dam. Dr. Makrakis explained that the location of the Itaipu Dam formed a natural barrier to fish migration. Since the construction of the dam and its fish passage structures, 33 fish species have extended their range into areas that were not naturally possible. Initially, a volitional fish ladder model was constructed, but based on the successful migration of only seven migratory species in the model, it was decided that the Canal da Piracema would be required. The Canal is a hybrid passage system consisting of a nature-like fishway and a technical reach with various engineered solutions. The nature-like fishway utilizes a natural river (the Bela Vista River) as a base for the fish passage structure with entry to the Canal ~5 km downstream of the Itaipu Dam. The Canal is 10.3 km long of which 6.8 km is formed by the natural river bed of the Bela Vista River and the remaining 3.5 km is a combination of engineered channels. The Canal is 6-12 m wide and climbs a total of 120 m along its 10.3 km length forming one of the largest fish passage systems in the world. Dr. Makrakis showed evidence that, while intensive species-specific biological studies combined with modeling efforts can lead to significant improvements in fish passage efficiency in engineered fish passage structures, bottlenecks created at relatively short sections can significantly reduce the total efficiency of the whole structure, e.g., a 200 m technical section had poor passage efficiency. The conceptual idea of a combined nature-like and engineered reaches for Mactaquac was introduced using the Keswick River as a natural bypass channel and an engineered connection to the headpond (see later discussion for the conclusion).

Dr. Makrakis discussed another example of a large fish passage structure at the Porto Primavera Dam. The weir and orifice type technical fish ladder surpasses a 20 m head using 49 pools with a total passage length of 520 m. Various fish species use the ladder. Attraction efficiency varied...
greatly between four species studied from 7-55 %. Passage efficiency was also variable and ironically, with 100% passage efficiency achieved for the species that had the lowest attraction to the ladder (as reported by Dr. Kemp).

Dr. Makrakis concluded his presentation by showing another example of an experiment that highlighted the importance of studies examining the effect of body morphology on passage success. Such data is critical for achieving functional fish passage in large, technical fish ladders and often such data is not readily available.

3.5 PRESENTATION 4: LAURA WILDMAN

Nature-like Fishways Around the World: What Are We Learning

Ms. Wildman provided a thorough synthesis of the variety of nature-like fishways constructed around the world and focused on some of the larger-scale natural bypass channels currently existing or under design. She first pointed out that a comprehensive on-line handbook on nature-like fishways has been recently compiled which illustrates 121 projects worldwide and includes a comprehensive overview of the subject (https://sites.google.com/site/naturelikefishwayspublication/).

The first part of the presentation concentrated on outlining the different categories of nature-like fishways based on their form, slope, construction materials, and physical location (in- or off channel). Ms. Wildman then discussed bypass channel fishways because such a solution would be the most applicable to Mactaquac versus other types of nature-like fishways such as rock-ramps (most effective as a low head solution). While most nature-like bypass channel examples are at small dams, Ms. Wildman presented pertinent attraction and passage efficiency data for a number of larger projects in Europe and the USA. The examples reviewed were natural bypass channels designed to guide fish over 5–10 m vertical barriers. Generally, the natural by-pass channels provided a variety of hydraulic conditions suitable for a wide range of species.

Some channels were also used as a preferred habitat and may be reducing their overall passage efficiency. An additional problem was related to the location of the entrance to natural bypasses, the attraction efficiency. If the entrance is located at a distance, e.g., hundreds of meters downstream from the facility, then fish have difficulty finding the entrance and are instead attracted to the greater flow at the actual facility (dam with turbines and spillways). Functional, natural by-pass channels typically require a relatively long channel in situations with higher hydraulic head differentials. Another observation at some natural bypass channels constructed without liners has been water seepage from the channel. This can impact adjacent physical structures, e.g., under-cutting or weakening structures as well as requiring management of surface water quantities in the channel. Such problems can be addressed with careful planning and analysis of the underlying geology of the area. Again, it was emphasized that there is still is a need for accurate biological information related to fish swimming capabilities for each of the target species that will use the channel.
Ms. Wildman examined the specific case of Mactaquac and surmised that a natural by-pass channel would have to be a very long channel. One option was to connect the Keswick River to the northern end of the Mactaquac reservoir (the Mactaquac Arm) via a 1 km channel engineered across land. While this is technically possible, challenges would be: 1) attraction efficiency of fish to the Keswick River (not in the main channel); and 2) downstream passage through the impoundment including finding the Mactaquac Arm, to find the new channel.

Overall, the summarized benefits of nature-like fishways included their habitat value, varied cross-sectional velocities allowing passage by wide range of species and life history stages, and aesthetics. The challenges are: they are not being appropriate for all sites; they are difficult to modify after construction; stability issues due to potential seepage issues; and varying efficiency stemming in part from design inexperience. Ms. Wildman concluded by reviewing additional, real-life examples of nature-like fish-passage highlighting that they are often suitable for a large variety of species, but require quantitative assessments of their efficiency. Adaptive management and monitoring were again highlighted as an important part of the process, i.e., to identify and correct problematic sections. As a concluding remark, Ms. Wildman stated that no fishway can be directly compared to the ecological benefits of dam removal because dams create a host of other problems irrespective of the fish passage issue.

3.6 PRESENTATION 5: GREGORY ALLEN

Downstream Passage Technologies: Research and Applications

The presentation by Gregory Allen examined the advancements in downstream passage technologies focusing on exclusion and guidance structures and then, recent advances in fish-friendly turbines.

Mr. Allen first reviewed the typical downstream routes used as fish passage, e.g., spillways, turbines, and bypasses, and the important general considerations for optimizing fish survival. Mr. Allen provided some specific case studies related to narrow-spaced bar racks, angled bar racks, and louvers (a guidance device where the racks are angled 90° degrees to the flow). Laboratory studies on American Eel, sturgeons, and salmonids indicate that the angle and the spacing of the bar slats can greatly improve passage success. An optimum louver design now exists: 15° angle to flow with >50 mm slat spacing. Surface bypass efficiency can be improved by designing surface weirs where the engineered acceleration of water is uniform versus rapid changes of velocity fields that fish seem to avoid. This concept has been applied with success at Hadley Falls and Turner Falls (northeastern USA). Similarly, uniform acceleration has also been applied at hydroelectric dams of the Columbia River using removable spillway weirs.

The second part of the presentation focused on new turbine technologies. Mr. Allen reviewed the mechanisms of fish mortality in turbines, i.e., pressure and mechanical injuries with a specific focus on blade strike injuries as related to fish length and turbine design/operation. In traditional turbines, 5-30% of fish passing through a turbine are killed by blade strikes. Mr. Allen showed examples of research undertaken in their laboratory indicating that a decrease in fish survival occurs when the fish length to the blade’s leading edge thickness (L/t) ratio is >1 combined with
strike speeds >5 m/s. Species-specific differences occur with eel and sturgeons showing greater survival than salmonids at a given L/t ratio. Improved turbine designs also include a reduction of gaps which represent the space where physical abrasion often occurs. Minimum Gap Runner turbines have been designed and improve survival of salmonids at least, e.g., 97% survival for juvenile salmonids at two Columbia River dams.

Mr. Allen presented survival data for the new fish-friendly, Alden turbines that haven’t yet been tested outside the laboratory. The turbine has three helical blades to reduce the probability of a blade strike. The turbine has a shroud attached to the blades eliminating abrasion between moving and non-moving parts within the turbine. In their experiments, 12 and 24 m head situations with down-scaled turbines (1:3 models) improved survival rates for a variety of species. With the results up-scaled to 1:1 size (4 m diameter, spinning at 110 rpm), predictions show turbine survival of 98–100% for young salmonids, Smallmouth Bass, and Alewife, and 99–100% survival of young American Eel and sturgeons (<200 mm in length). Mr. Allen stated that Alden turbines are typically 1.5 times larger than comparable Kaplan units, which makes retrofits difficult. For a new project, the turbines should have the same water use efficiency as Kaplan turbines. With the Minimum Gap Runner turbines, the water use efficiency may in fact increase by 3% as compared to Kaplan units. The operational range across flows is, however, higher for the Kaplan units.

Mr. Allen provided a number of recommendations for new hydropower projects. It is important to start the planning by developing project design criteria in terms of the total passage survival target, determining the maximum size of fish allowed to enter turbine units, and the minimum acceptable turbine survival for those species. The bar spacing for exclusion or guidance of the fish away from turbines is important. Both surface and submerged bypass structures and careful consideration of survival are important when selecting spillway discharge structures. Also, minimizing refuge areas near bypasses that may attract predators can be important in planning.

### 3.7 PRESENTATION 6: ED MEYER

**Introduction to Upstream Fish Passage Systems**

Mr. Meyer brought a wealth of experience related to upstream passage solutions based on successes and failures in the large hydropower operations of the Pacific Northwest, USA, and in the Columbia River in particular. The presentation concentrated on provision of volitional fish passage, i.e., technical fish ladders that have been utilized with success for adult salmonid fish. Mr. Meyer noted in his presentation that while the fish ladders cannot replace dam removal, they can move some species over a large range of flows.

Mr. Meyer defined fishways as “a water passage around or through an obstruction, so designed as to dissipate the energy in the water in such a manner as to enable fish to ascend without undue stress and without significant delay.” The presentation discussed the important factors for functional fishway design. First, design criteria need to be conservative to ensure the greatest possible range of passage conditions. The typical target in the Pacific Northwest is passing 95% of the fish that approach a fish ladder with a survival through the fishway >98%. Such success has been achieved in many of the large dams in the Columbia system. He noted that one of the benefits of volitional
fish passage is survival which is greater than trap-and-haul or fish lift options. Second, the fish passage season, i.e., the timing of the run, must be well-studied and understood in relation to environmental parameters to ensure fish ladders are operational during appropriate times. It is equally important that all of the run including the first and last 5% are successfully passed because these individuals can represent important genetic components of the population, e.g., early run fish may need the time to access the farthest upstream spawning locations and the last of the run may arrive just prior to spawning which necessitates an immediate passage without delay. The numbers of fish in the runs and thus the capacity of the fish ladder is another important factor to consider. Third, basic ecological information describing the spatial-temporal distribution of fish and their species-specific capabilities and habits are the irreplaceable data for successful fish passage. Such knowledge informs suitable locations for passage structures and the specific engineering designs for successful passage. Mr. Meyer emphasized that it is critical for engineers and biologists to work in a close collaborative environment to ensure successful fish passage.

Mr. Meyer outlined the hydrological design criteria for fish passage structures that are used in the Pacific Northwest. They have low flow designs, i.e., the mean daily average stream flow is exceeded 95% of the time, high flow design flows, i.e., the mean daily average stream flow is exceeded 5% of the time, and flood flows, i.e., providing enough freeboard in the dam system to minimize risk to the passage structure for the 50 year flood. These hydrological design criteria are important because they provide enough attraction flow for the fish during various river discharges and protect passage, e.g., fish ladders must never be inoperable due to high river flows for a period >7 days during the migration period.

Mr. Meyer provided an insightful “dissection” of a typical fish ladder. Fishway entrances are the most critical component in the design of an upstream passage system. Location is everything, i.e., the entrance has to be readily discovered/detected by the fish. Generally, the best practice is to locate the entrance as far upstream as possible; these are the areas where fish congregate and are naturally attracted. A good entrance creates a noticeable attraction jet (often best with a rectangular or square shape). Large dams typically require multiple entrances. These are often located on each bank or each side of the powerhouse and/or the spillway, but the exact location will be dictated by the site’s hydraulic condition and the competing flows from turbines and spillways. Low and high flow conditions need to be considered. A separate or second ladder may be useful, e.g., a dysfunctional ladder during migration could have serious population level impacts. Such designs have been successfully utilized to pass adult salmonids at the Bonneville Dam, Columbia River.

Upon entering the fishway, the entrance pool guides fish to the beginning of the actual ladder and preferably without delay or confusion. An auxiliary water supply (AWS) is often introduced to augment attraction flows as fish ladders have typical flows only of 1–3 m³/s. The amount of AWS depends on the powerhouse or spillway flows, but generally 5-10% of high flows from the powerhouse are required to obtain an efficient attraction, e.g., ~140 m³/s is used in the entrance for attraction flows at the Bonneville Dam. Mr. Meyer also noted that power can be generated from the AWS in secondary and often smaller turbine units, i.e., the AWS is not necessarily a loss of hydropower production. The interplay of the AWS and flows from the main body of the fish ladder
mustn’t confuse the hydraulics and therefore emphasizes the role of good engineering design to avoid confusing hydraulics.

The purpose of the ladder body is to provide suitable flow and cover conditions for fish to hold, rest, and ultimately pass upstream. Mr. Meyer described the vertical slot and weir and orifice ladders (both successful for adult salmonids). The vertical slot fishways are well suited for situations where the forebay or tailwater levels fluctuate, the length-width-slot size engineering and adjustments must match the species-specific swimming abilities. Weir and orifice ladders provide passage through the submerged orifices or over the weir. For example, in the Columbia adult salmonids use the orifice route, except in cases of extreme crowding (>30,000 fish) and American Shad use the weir passage. Sea Lamprey passage can also be improved in these ladders by rounding the orifices (lamprey use their suction disk and creep along the hard surface). Full and half-Ice Harbor style weir and orifice ladders were discussed noting that relatively stable water levels are required. At high flows, large quantities of water would be directed to the ladder, whereas flow over the weir was eliminated in low flow conditions. On exit structures, the problem is how to get the fish out without delay, but not flood out or starve the ladder.

Mr. Meyer also presented examples of counting stations and trapping facilities within ladder structures that can be used for the needs of fisheries research.

3.8 PRESENTATION 7: JOHN WILLIAMS

Downstream fish passage at dams: the Columbia River experience

Dr. Williams’s presentation focused on the lessons learned from the Columbia River system regarding downstream passage for juvenile salmonids. Dr. Williams began with his conclusions which were based on decades of research. Four conditions must be met to achieve successful downstream passage: 1) a team of biologists and engineers must work “hand-in-hand”; 2) well-defined goal is needed, for example to get the fish downstream through a non-turbine passage or to maximize total survival, among others; 3) accurate understanding of behaviour as it relates to hydraulics for the target fish species; and 4) adaptive management - efficiency needs to be continuously evaluated to ensure success.

Dr. Williams used a historical approach with examples from the Columbia River system to show how the downstream passage systems have evolved. In the 1930’s, surface collectors filtered the fish to safe passage ways - these efforts proved unsuccessful. The next two decades concentrated on how juvenile salmonids survive turbine and spill passage. The generic estimates for spill survival were in the range of ~98% and turbine survival was 85-90%. This result was not acceptable because juvenile salmonids were negotiating a sequence of dams and the cumulative mortality through a typical eight dams was ~80%. Research through 1960’s to 1980’s focused on making turbines safer and building better guidance structures. That work indicated that the best fish survival is achieved when running the turbines at their peak efficiency.

A variety of turbine intake screen options have been tried at different facilities. Travelling screens with attached fyke nets for capturing fish have had low durability. Long turbine intake bar screens
have been tried. Physical guides for surface-oriented fish moving them into the ice and debris sluiceways had limited success owing to the low flows in the structures, especially when multiple spatial locations were utilized. Overall, the success rate for travelling screens was 20–75% and 50% for the ice and debris sluiceways. In general, surface collectors are not effective in high debris situations.

Spilling is the most natural strategy that achieves successful downstream passage. It can be an expensive option because of lost power production, particularly in low flow conditions (when head potential is critical). The use of surface spill via removable spillway weirs has been effective for juvenile salmonids, i.e., with higher survival and shorter delays for the fish. Dr. Williams showed recently collated data of for juvenile salmonids utilizing various passage routes and the associated survival in the Columbia system. The data indicated that despite elaborate passage structures, the majority of fish use the spillways, 52-84 %, with survival rates of 93-97 % (two hydropower stations in the Columbia system).

Dr. Williams concluded with examples of behavioural research that has been fundamental in designing functional passage structures. For example, flume studies show that Pacific salmonid juveniles reject a rate of change in hydraulic conditions that exceed 1 cm/s over a 1 cm distance when moving either up- or downstream. Dr. Williams recommended such fundamental research on species of concern was required to achieve functional fish passage. Dr. Williams emphasized the importance of avoiding delays in the downstream migration of juvenile salmonids. Salmonids smolts have a specific and restricted biological and environmental window for preparation for life at sea (smoltification) and delays during migration may cause a mismatch in timing to meet these conditions. Lastly, one major downstream issue for juvenile salmonids is the orientation of the dam and power house. Where these structures are perpendicular to the flow, the hydraulic conditions appear to reduce successful downstream migration. The exception is the Bonneville Dam with its specific hydraulics. Structures that are parallel to flow may be a better design for successful downstream passage of fish.

3.9 PRESENTATION 8: MR. CHRISTOS KATOPODIS

MAES – Fish passage considerations at Mactaquac Dam and the Saint John River

Mr. Katopodis provided a wide overview of various fish passage projects in Canada, USA, and internationally highlighting the many biological and technical aspects of functional fish passage. He started his presentation by advocating for basin-wide approaches where multiple dams exist, i.e., the focus may be specific solutions in one site, but population-scale consequences can’t be forgotten.

The presentation reviewed the main factors contributing to successful fish passage: motivation to migrate, attraction and passage efficiency variables, and the broader, resource management objectives. The role of these factors was reviewed for some real life examples. One successful solution has been to provide migrating fish with number of options (to address their varied effectiveness) because this can maximize overall passage success.
Mr. Katopodis provided multiple examples of detailed engineering studies and demonstrated that concentrating on minute details can significantly impact successful passage. Often, this requires studying engineered structures in a laboratory environment (model of the hydraulic conditions). Ultimately, all functional fish passage solutions depend on solid scientific data and rarely match the preliminary, conceptual designs.

Mr. Katopodis reiterated the importance of cumulative effects within the whole system. Successful fish passage is meaningless if suitable habitat doesn’t exist in the environments fish will access. In Finland in a multi-dam river, passing salmonids through the first dams resulted in very little net gain because access to suitable habitat was not achieved until multiple dams had been passed.

His concluding remarks called for thought-out, field and laboratory ecohydraulic studies to best understand the best passage options for a new facility for Mactaquac. Whatever the solution, the functionality of the designed structures will have uncertainty. Therefore, monitoring and an adaptive management approach will be needed to adjust the design features for best long-term success.

### 3.10 PRESENTATION 9: STEVEN COOKE

*Fishway Science Relevant to Fish Assemblages in North America*

The presentation by Dr. Cooke provided an overview of the critical factors that need to be considered when examining the efficiency of fish passage structures and particularly interpreting the reported efficiency estimates. The latter part of the presentation reviewed the status quo of community-level fish passage work in North America.

Dr. Cooke reiterated that both the attraction and passage efficiency of fish passage structures vary greatly, essentially 0 to 100% regardless of the passage structure type. Dr. Cooke discussed the problems with passage efficiency estimates and went on to state that these could be overcome with more careful planning. There is a need to: 1) minimize the capture and handling stress of the individual fish used in the studies; 2) consider where the tagged individual fish are being released; 3) use optimal tagging techniques applied by well-trained professionals; 4) use proper control groups; and 5) consider the motivation of fish to migrate. A more thorough example was provided on the last point highlighting that the tagged fish in one study consisted of some individuals that had no intention (i.e., motivation) to move into or navigate through a fish ladder, in this case because a suitable spawning area existed below the fish passage structure.

The second part of the presentation addressed the challenges for multi-species passage. The studies on fish passage are biased towards salmonid fishes, particularly in North America and only a few examples examining a whole fish community exist. One example, a vertical slot fishway in Quebec, emphasized the importance of detailed monitoring studies for identifying the bottlenecks for passage success for different species.
4. SUMMARY OF DISCUSSION SESSIONS

The afternoon sessions called on the experts to address the specific engineering scenarios for a new facility as presented by NBP (as they were currently understood and proposed). The experts were asked "what species of fish should and/or could be on a list for which a successful fish passage can be arranged." Second, experts were asked to discuss the technical solutions. The third discussion considered "a clean slate" approach: what would the experts design for a generating station at the site that maximized the probability of functional fish passage?

4.1 WHAT FISH SPECIES SHOULD / COULD BE PASSED?

As a preamble, the group was reminded that the current MGS is actively managing only three fish species, the Atlantic Salmon, Alewife, and Blueback Herring, upstream passage is trap-and-truck, and downstream passage has no active management operations. First, there was discussion regarding the limited number of species being actively managed when there are many more species in the system. Next, the discussion moved to what should and what could be passed at a new hydropower facility.

The experts agreed that the list of species that should be considered for fish passage was a question for the local stakeholders. Such a decision must be based on a well-drafted management plan built by regulators and with input from local stakeholders. The experts indicated that the management plan must be drafted as early as possible. It necessarily requires early design flexibility for passage structures because the final decisions are long-term and not easily changed, i.e., re-engineered after the facility is built is either impossible or uneconomical.

One key discussion point was the impact of the reservoir for both up- and downstream migrants. The reservoir impacts are currently largely unknown for the species in the river, i.e., their capabilities of navigating through the reservoir either up- or downstream. For example, if disorientation (lost individuals) or significant migration delays are caused by the reservoir, e.g., caused by its large size or shape or thermal/dissolved oxygen barriers, then a management plan must consider this as part of the fish passage challenge. The experts agreed that such information requires tracking studies for species and life history stages that currently pass or will pass through the reservoir.

Another critical aspect of successful fish passage is incorporating the cumulative effects of multiple dams and reservoirs in a management plan. If species are destined to headwaters and require passage at upstream facilities, then the overall, system-wide passage is non-functional and functional fish passage at a new Mactaquac would be a waste of effort and money. A better option in this scenario may be to intercept the migrating fish and trap-and-truck them past the remaining facilities (noting that this too requires an understanding of the species-specific life history needs). The experts were told that CRI is working on a list of species and their pre-dam migration patterns to help inform these decisions.
Passage of American Shad and American Eel were discussed. Shad were originally managed in the trap-and-truck plan at MGS, but this species incurred mass mortalities during the process and the activity was abandoned. The experts suggested that was probably not the right decision. Shad is managed with good success using trap-and-truck operations in other jurisdictions.

For American Eel, the experts indicated that suitable, engineered technologies exist for arranging upstream migration of eel elvers. The CRI is currently assessing their access to the dam. Most of the discussion focused on the uncertainty related to the reservoir migration and downstream passage (at the facility). No consensus on eel management was achieved among the experts. Some workshop participants were optimistic and believed that eels would find their way out of the large reservoir relatively fast and that relatively simple solutions for eel downstream passage could be found, e.g., an exclusion system (taking them away from turbines) and a bypass weir in the dam where eels could be guided. The remaining experts who had worked directly with eel species were more reserved. They proposed the need for experimental work, e.g., tracking studies, particularly related to reservoir migration that would add confidence to any management decisions, e.g., silver or migratory eels could be translocated from lower in the SJR to test their capability to migrate downstream. Technical solutions for downstream passage would be complicated at this relative large dam. Adaptive management was again discussed as a necessary approach. Finally, the management of American Eel will be ultimately dictated by the desired outcomes for the species. American Eel in the SJR are a part of one panmictic population reproducing in the Sargasso Sea and thus the management outcomes will have to be set in terms the river specific freshwater habitat, socioeconomics, and traditional use. We currently don’t know if access to upstream reaches has affected the viability of a population-specific genetic component of the population in the SJR.

The general conclusions regarding the species that should pass up- and downstream at a new facility were:

1) Existing knowledge of species and their distribution in the river system requires further assessment, we need a complete list including pre-Mactaquac distributions. Technical passage solutions for each species, both up- and downstream, should then be created to develop a species risk-assessment for passage options, i.e., outlining their probable passage timing, among-species interactions during passage (including abundances), overall efficiencies (expected), and the passage targets (i.e., species X requires an abundance of Y to pass the facility).

2) Because of the SJR diversity of fish at the MGS site, the species list should also include body/swimming types (classes).

3) A new facility should be designed to pass the greatest number of diadromous species with a capacity to sort and separate species. The ability to separate the fish is critical for technical passage, but equally important in the adaptive management approach. For example, if later studies indicate that a technique for passing fish is failing, e.g., negative impact of delayed passage or the reservoir is an ecological trap, then management activities can be adjusted accordingly, i.e., the adaptive management process provides an efficient and timely correction of the ecological problem that could be immediately impacting the population status versus delays in a bureaucracy of revisiting the issue, re-engagement of stakeholders, etc.
4.2 WHAT COULD BE PASSED: UPSTREAM PASSAGE TECHNICAL SOLUTIONS

Discussion regarding what could be passed at a new facility focused on technical solutions. The experts discussed two fundamentally different, but not mutually exclusive, generic options for upstream passage: 1) fish-lift structures; and 2) volitional passage using fish ladders, both engineered and nature-like solutions.

The expert consensus was that a well-designed fish lift will have the greatest probability of accommodating the largest variety of fish species to be passed at the Mactaquac site (with species exceptions of course). A fish-lift also provides the ability sort fish, including potential invasive species. However, their experience indicates that there are challenges with attraction flows into fish-lifts, and for reasons that are not always well-understood. Fish-lift efficiency can be depressed by large numbers of individual during migrations, e.g., Alewife. Concurrently, the other species using a lift during such migration runs can be negatively impacted and thus multiple fish-lifts may be required. Fish-lifts also incur a continued cost for operations, maintenance, and operators.

Understanding the deficiencies in fish-lift design can most probably be overcome for a new Mactaquac facility. For example, attraction could be improved by novel entrance designs. Bottom-oriented species such as the sturgeons can be accommodated with a deeper entrance and shad with a surface entrance. The entry could be an inclined substrate ramp for all bottom-oriented species. The fish-lift “hopper” could be designed for different species and their temporal abundance patterns, e.g., a small and a large hopper, separation cells that sort small and large bodies via slotted screens. Finally, the timing of fish-lift operations including attraction activities must take into account species-specific habits, e.g., operations for day- and nighttime migrants.

Some of the potential deficiencies of fish lifts can be addressed by technical fish ladders. A major strength of functional fish ladders is that they allow volitional passage of fish rather than limiting passage to operator decisions, e.g., a single salmon can pass a technical fish ladder at will but an on-site decision is required to lift one individual fish. Regardless, engineering of a functional fish ladder for any species will be very difficult owing to the high head of the potential new facility. Some technical fish ladders have been highly effective for passing adult Pacific salmonids upstream, e.g., the Columbia River system, and that experience suggests a functional ladder for adult Atlantic Salmon travelling upstream is highly probable for a new facility at Mactaquac. However, accommodating other species such as shad and gaspereau would require a very long and large pooled ladder to accommodate the quantity of fish in those migration runs. The experts suggested that the best engineering design for a technical ladder was not necessarily an existing full Ice-Harbour ladder or others, but rather a new “Mactaquac” design could be engineered to accommodate the species diversity in the SJR and thus increase the success of achieving management targets. Whatever the technical solution, it was proposed that the ladder be constructed using modular units, i.e., a “LEGO” approach, that are easily replaced and thus the functionality of the structure can be adaptively managed, e.g., altering hydraulics if required or replacing non-functional units during migration periods. Overall, the experts were uncertain that a functional fish ladder for species other than Atlantic Salmon was possible.
The eventual management objectives for a potential new facility at Mactaquac will dictate the passage solutions and the experts indicated that that 2-3 different upstream passage structures and/or operations may be required. The experts repeatedly reminded us that it is of utmost importance to plan for flexibility to insure a successful project. Hybrid passage systems that provide passage flexibility exist elsewhere, e.g., the Mekong River system. Examples of flexibility include a passage structure with a combined attraction area leading to a fish ladder and a fish lift where the ladder is in constant operation and the fish-lift operated as needed. If eel and lamprey passage is a management target, then separate eel and/or lamprey climbing ramps will be required.

It is evident from the expert experiences that attraction to fish passage structures is often the most important feature determining the success of a passage structure. The fish passage experts debated the suitable attraction and entrance design at length resulting in consensus on some topics and some aspects with variable opinions among solutions.

It was generally agreed that upstream fish passage is most successful if attraction flow is situated adjacent to the powerhouse as opposed to the spillway structure. More specifically, at least one entrance to the fish passage facilities should be situated as close to the powerhouse as possible. The exact location should depend in part on the systems hydraulics, using either a physical model or computational fluid dynamics (CFD) model, or both. It was agreed that a passage structure on the opposite bank where the current power house is located (north bank) would have poor attraction capabilities if the powerhouse moves to the south bank.

The opinions were divided regarding the best location to situate the entrance to any fish passage structures, as well as the need for a single, large entrance or multiple, smaller entrances. A single, large opening extending to the bottom of the river for the benefit of bottom-oriented species was suggested given the diversity of SJR fishes, but other experts proposed multiple entrances in key locations, e.g., on both sides of spillways and both sides of the powerhouse. In general, experts thought it unlikely that all species would be attracted to a single entrance or area which necessitates a number of flow-defined areas with different features for attracting the greatest diversity species across the greatest range of flow conditions. Providing multiple options from the beginning of facility operations is the best action to ensure effective, functional passage solutions for a new facility.

Different opinions were voiced regarding the locations of entrances either above the turbine draft tubes or on the side of the powerhouse or spillways. The above draft tube has been used with success for some species, e.g., adult Pacific salmonids, but some experts’ experiences suggested these were non-functioning for many other species. The Vernon Dam, Connecticut River, was an example of an above draft tubes entrance and which is generally not used. If the entrances to the fish passage structures are situated on the sides of the powerhouse or spillway, then a structural guidance system may be useful to guide fish to the entrance and away from the turbines. One example of a conceptual design discussed (Figure 1) had an elevated apron to deflect turbulent flow discharging from the draft tube turbine boil) effectively creating a waterfall and a barrier for fish trying to erroneously enter the turbine units. This was one example preliminarily discussed,
but it was again emphasized among experts that hydraulic modeling of flow patterns is critical to best design locations for fish passage entrances.

The technical solutions discussed for downstream passage were specific by-pass structures, spillway passage, and turbine passage. The consensus opinion for a potential new Mactaquac facility was that all three options would be required to ensure successful passage for the diversity of species and their migration needs. By-pass structures can be engineered to meet certain species needs. Fish-friendly turbines (see Section 3.6) were strongly supported as the most promising option to maximize downstream passage survival via turbines. Fish survival via the spillway was predicted to be good for salmon smolts and kelts (post-winter adults returning to the sea) because
spilling of water will occur during the main migratory periods. Some experts reminded us that passage delays caused by the hydropower facility, specifically its hydraulic environment, maybe a bigger issue than the actual onsite route. In addition, we were reminded that migration through the large reservoir may be the bigger issue in terms of the population-scale effects, i.e., total mortality for the system. Again, more studies of the species and life history stages using the reservoir are required to address these downstream migration and passage issues.

The experts were asked for advice for setting target levels for survival in each facility given the current technologies. First, the number of dams a species transverses generates a cumulative mortality. An important element in this discussion during the management planning is deriving comparative information from nearby, free-flowing rivers, i.e., what are the natural mortality rates by life history stage. The target for juvenile salmonid survival at each facility in the Columbia River system (fish can traverse 8 or more dams) is 95% through the reservoir and dam, and including any delayed mortality (post-passage at the facility). There are no fixed survival targets for east coast rivers of the USA, but generally, 90% survival at individual facilities has been considered acceptable. Survival targets are 95-96% per site for Atlantic Salmon in the Penobscot and Kennebec rivers, Maine. The EU regulations call for an overall catchment survival target of 40% for European Eel.

There was some discussion of hydro-combine designs where spillways for downstream passage are located directly above the turbine units. Some facilities, e.g., Wells Dam, Columbia River, have had good downstream passage survival for juvenile salmonids, i.e., survival >98%. The benefit of the hydro-combine design is that the greatest downstream attraction flow is provided by the water directed to the turbines, but which are situated deeper in the water column such that surface-oriented species such as salmon smolts are directed into the spillway/by-pass facility at the surface of the water column.

The design minimizes power generation loss and minimizes the footprint of the facility. A hydro-combine design may also be successful for other surface-oriented species such as alewife, but this has not been tested. Still, despite the success of the Wells Dam hydro-combine, such success has not been reproduced in other facilities where hydro-combines have been installed, e.g., Cowlitz Falls Dam.

The discussion of downstream passage for bottom-oriented species focused on the American Eel. Eels are believed to be structure-oriented during downstream migrations, e.g., eels may follow a guidance structure such as an angled, ¾” bar rack on the bottom and possibly a full-depth vertical slot spill opening. This discussion re-emphasized our lack of understanding of these species, their behaviour, and therefore best solution options for their secured passage downstream. More studies specific to the SJR are required.

4.4 EXPERT OPINION: A CONCEPTUAL PLAN FOR A NEW GENERATING STATION

The final theme in our discussions was a conceptual, overall design of a potential new hydropower facility at the Mactaquac site. The task was: “In terms of optimal fish passage, how would the powerhouse and spillway of a potential new facility be configured”. We assumed the current
understanding of constraints: accommodate similar power generation and hydraulic head as the current facility with the new powerhouse located on the south (opposite) shore.

Different options were presented and discussed. Some of the conceptual drawings are included herein, but the experts warned that these are very preliminary ideas for further discussion and not intended as final recommendations. Again, both the biology and engineering teams would have to work through design options after management objectives are set and ecology of the species of concern is expanded. They agreed that a final design of the powerhouse and spillways structures with locations of up- and downstream entrances for fish passage must eventually rely on appropriate hydrodynamic modeling of the design options.

The first design discussed configured the powerhouse and the spillway structures situated at 45° forming a downstream facing “V” (Figure 2). The entrance to the downstream bypass structure (D) would be situated at the joint of the powerhouse and spillway structures, whereas the entrance to upstream passage structure (U) would be situated in the farthest upstream corner of the tailrace where the powerhouse would provide attraction flow (Figure 2).

Figure 2. Conceptual Design 1 highlighting a hypothetical configuration for the powerhouse and spillway structures superimposed on the proposed location for a potential new hydropower facility. U and D are the proposed entrance locations of upstream and downstream passage structures, respectively.
The second design option, Design 2, angled the powerhouse and spillway to form an upstream facing “V” with the powerhouse on the river bank (Figure 3). This orientation may provide better attraction flows for upstream migrants during the lowest flows when only a few turbines units would operate. This design requires the turbine units closest to the shore to operate during low flow conditions. Conceptually, this design would provide attraction for both up- and downstream migrants during low flow conditions.

Figure 3. Conceptual Design 2 highlighting a hypothetical configuration for the powerhouse and spillway structures superimposed on the proposed location for a potential new hydropower facility. U and D are the proposed entrance locations of upstream and downstream passage structures, respectively.
Design 3 modified the powerhouse/spillway placement to incorporate “fish friendly turbines” (Figure 4). A full-depth, angled bar-rack to guide migrating fish to the entrance of the by-pass structures was discussed.

*Figure 4. Conceptual Design 3 highlighting a hypothetical configuration for the powerhouse and spillway structures superimposed on the proposed location for a potential new hydropower facility. The red dashed line indicates an angled bar-rack that would be installed to exclude migrant fish from entering the powerhouse. U and D are the proposed entrance locations of upstream and downstream passage structures, respectively.*
The fourth option, Design 4, rotated the powerhouse perpendicular to the existing earthen dam and river flow (Figure 5). Entrances to the passage structures would be located at the shoreline and the downstream migrating fish could be guided by an angled bar-rack to the bypass structure. Orienting the structures in this fashion could provide attraction flow close to shore for upstream migrants and minimize attraction to turbines during downstream migrations.

Although different designs were discussed, the experts were unambiguous and unanimous that the orientation of the powerhouse and spillway will impact fish passage up- and downstream and therefore these structures should not be finalized without computational hydrodynamic modeling of all the various options and which is linked to the species in the management plan. Once a candidate design is in place, it was highly recommended that a physical model also be constructed to test and better understand the resulting flow fields both up- and downstream of the structures. The probability of success for a fish passage system for a new facility at Mactaquac will be significantly improved by understanding these hydrodynamic characteristics.

*Figure 5. Conceptual Design 4, highlighting a hypothetical configuration for the powerhouse and spillway structures superimposed on the proposed location for a potential new hydropower facility. U and D are the proposed entrance locations of upstream and downstream passage structures, respectively.*
5. CONCLUSIONS AND RECOMMENDATIONS

The Fish Passage Experts Workshop presented a series of conclusions and recommendations for achieving function, i.e., successful fish passage for a new hydropower facility in NB Power’s Mactaquac Project.

5.1 GENERAL CONCLUSIONS AND RECOMMENDATIONS

- The fish passage experts were unanimous in their opinion that Option 3, the removal of the Mactaquac Dam and restoration a natural flowing river at this site is the most effective and desirable option for successful fish passage.
- While major advances in volitional fish passage and other technical fish passage structures has been achieved in the last few decades, arranging functional fish passage in a multi-species setting still remains a very difficult challenge with no guarantees for success. Functional fish passage in a multi-species setting will be difficult, but not necessarily impossible to achieve.
- Fish passage efficiency to date has experienced high uncertainties of success. Even with technical solutions with successful passage for certain species, the proportion of fish actually attracted and eventually passed are uncertain, and additionally, how the associated passage delay affects the true success of migrations is uncertain.
- A clear definition of “successful fish passage” is important to establish from the beginning. Success must be a function of one or more species-specific targets measured as proportion of fish that survive the phase from entering through exiting the facility. This target provides the tangible end-point in the necessary adaptive management approach required for assessing and achieving functional fish passage. When determining passage targets, it is important not to neglect the cumulative impacts of the multiple dams that are present in the SJR.
- Early engagement of provincial and federal agencies is important to ensure the creation of an appropriate and broadly accepted management plan and its passage targets.
- The behaviour of affected fish species must be clearly understood, e.g., their migration patterns, swimming abilities, etc. The critical needs are: 1) the species and their migration behaviours at the site (e.g., do all species present require a passage solution?); 2) swimming abilities and general preferences, e.g., bottom- vs. surface-oriented; 3) the downstream approach by species to the dam; 4) the upstream approach by species to the dam; and 5) the migration behavior in the reservoir which can be a potential ecological bottleneck for migration. These biological findings must be incorporated in engineering designs and thus requires close collaboration between biologists and project engineers.
- It is important to understand the impact of the reservoir (head pond) on the migration success of the species expected to pass from the facility (moving upstream) and find their way to the facility (moving downstream).
- Whatever option(s) is selected for fish passage, there are no guarantees of success and thus it is critical to sustain design “flexibility” in the management plan which is therefore an adaptive management plan.
5.2 CONCLUSIONS AND RECOMMENDATIONS SPECIFIC TO UPSTREAM PASSAGE

• Attraction flows are the critical component of successful upstream passage, i.e., successfully finding the entrance of passage structures. Suitable attraction can be related to the orientation of the powerhouse and spillways, but auxiliary flow is most probably required to ensure flows for attraction are “competitive” with flows from turbines and spillways. Power may be produced from the auxiliary flow by employing a small turbine.

• A new hydropower facility in this multi-species river will most probably require multiple passage structures and entrance locations. Most probably, these will include a specifically designed, non-volitional structure, e.g., at least one fish-lift to pass most species, a technical fish ladder for salmonid passage, and an eel/lamprey ramp.

• Construction of a nature-like fishway may not be feasible given the high hydraulic head and long channel requirements in the available, useable space at the Mactaquac site.

• A modular design is recommended for a technical fish ladder (if selected) where potentially problematic sections can be replaced to ensure migration is not significantly interrupted in-year and as part of the overall adaptive management process.

5.3 CONCLUSIONS AND RECOMMENDATIONS SPECIFIC TO DOWNSTREAM PASSAGE

• Downstream passage is generally achieved via passage over spillways, specifically designed by-pass structures, or turbines.

• All three downstream routes should be fully developed to ensure the greatest probability of downstream passage success. The technical requirements for these structures must be derived from full consideration of target species biology and especially behaviour in the area.

• Floating collection devices located upstream of the facility may not be suitable for a new facility at Mactaquac due to the high debris load during spring when salmonids are migrating.

• “Fish-friendly turbines” are proposed as a state-of-the-art option for providing the safest possible turbine passage. Using these turbine units for at least some of the power generation was strongly recommended.

• Novel engineering designs are likely to be required for a potential new facility, e.g., hydro-combine options and new bar-rack designs to prevent fish entering undesired areas.

• Downstream passage will be required to accommodate both surface- and bottom-oriented fish species. Suitable solutions may include spillway and by-pass structures with full-depth entries or separate openings at the surface and bottom of the water column and the ability to be effective at the varied flow conditions required among the species.

5.4 CONCLUSIONS AND RECOMMENDATIONS SPECIFIC TO GENERIC DESIGN OF THE FACILITY

• The location of the up- and downstream passage structure entrances is the most important feature in designing functional fish passage.

• Careful consideration of the orientation of the powerhouse and spillways is required to ensure successful fish passage.
Hydrodynamic and computational fluid dynamics (CFD) modeling will be required to design the optimal orientation of the powerhouse and spillway structures required to provide the attraction flows for up- and downstream migrants. CFD modeling may prove difficult in the downstream area due to the turbulent nature of flows, thus construction of a physical model of a selected option is recommended to visualize the resulting hydraulics and ensure flows meet the needs for attraction to designed fish passage facilities.
6. ACKNOWLEDGEMENTS

The funding for this workshop was provided by NB Power and eventually a NSERC Collaborative Research and Development Grant. The workshop organizers would like to thank the international and national fish passage experts who contributed to the presentations and discussions. Dr. Michelle Gray and Mrs. Amanda Babin are specifically acknowledged for webcasting the workshop for a combined 75 attendees, arranging the audio-visual recording of the meeting, and the additional logistical help prior to and during the meeting. Ross Jones, Brian Jessop, John Whitelaw, Stephanie Ratelle, and Rod Bradford from Fisheries and Oceans Canada provided historic fish capture data for various species and in various SJR locations as background material for the meeting. We greatly appreciated Robert Beaumaster’s arranging the tour of the fish capture facility at the MGS, and Phillip Gilks and his MGS NB Power personnel who conducted the tour of the current facilities.
## APPENDIX 1: LIST OF FISH PASSAGE WORKSHOP INVITED EXPERT PARTICIPANTS AND THEIR CONTACT INFORMATION AT THE TIME OF THE MEETING.

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Alex Haro</td>
<td>US Geological Survey, Conte Anadromous Fish Research Center (USA)</td>
<td><a href="mailto:Alex_Haro@usgs.gov">Alex_Haro@usgs.gov</a></td>
</tr>
<tr>
<td>Mr. Christos Katopodis</td>
<td>Fisheries and Oceans Canada (retired; Canada)</td>
<td><a href="mailto:katopodisecohydraulics@shaw.ca">katopodisecohydraulics@shaw.ca</a></td>
</tr>
<tr>
<td>Dr. John Williams</td>
<td>NOAA Northwest Fisheries Science Centre (retired; USA)</td>
<td><a href="mailto:jgw3@uw.edu">jgw3@uw.edu</a></td>
</tr>
<tr>
<td>Dr. Steven Cooke</td>
<td>Carleton University (Canada)</td>
<td><a href="mailto:steven_cooke@carleton.ca">steven_cooke@carleton.ca</a></td>
</tr>
<tr>
<td>Dr. Sergio Makrakis</td>
<td>Western Paraná University (Brazil)</td>
<td><a href="mailto:smakrakis@folha.com.br">smakrakis@folha.com.br</a></td>
</tr>
<tr>
<td>Mr. Gregory Allen</td>
<td>Alden Research Laboratory (USA)</td>
<td><a href="mailto:gallen@aldenlab.com">gallen@aldenlab.com</a></td>
</tr>
<tr>
<td>Mrs. Laura Wildman</td>
<td>Princeton Hydro (USA)</td>
<td><a href="mailto:lwildman@princetonhydro.com">lwildman@princetonhydro.com</a></td>
</tr>
<tr>
<td>Dr. Paul Kemp</td>
<td>University of Southampton (UK)</td>
<td><a href="mailto:P.Kemp@soton.ac.uk">P.Kemp@soton.ac.uk</a></td>
</tr>
<tr>
<td>Mr. Ed Meyer</td>
<td>NOAA, National Marine Fisheries Service, West Coast Region (USA)</td>
<td><a href="mailto:ed.meyer@noaa.gov">ed.meyer@noaa.gov</a></td>
</tr>
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APPENDIX 2: PRESENTATION ABSTRACTS

Removal or Rebuild? Considerations for the Mactaquac Aquatic Ecosystem Study from a river continuity perspective.

**Presenter:**
Alex Haro, Ph.D., Research Ecologist  
S. O. Conte Anadromous Fish Research Laboratory  
U. S. Geological Survey  
1 Migratory Way  
Turners Falls, MA USA  01376

**Abstract:** Conventional thinking regarding river continuity and restoration projects considers dam removal as a "best option". Several recent experiences with small- and medium-sized dams have confirmed this approach, yet issues of scale, indirect effects, and economics have made removals a more difficult option for larger dams, especially hydroelectric dams. This presentation will review the viability of removal of the Mactaquac Dam as an option for large dams, from the perspective of fish passage and ecological continuity. Alternative options for rebuilding Mactaquac Dam will also be presented, both from the aspect of hydro project features that “work” and that have “failed” with respect to effective fish passage. Other indirect effects of retaining the dam, exclusive of fish passage design features, will also be reviewed.

Fish passage: challenges, failures, and potential solutions

**Presenter:**
Paul Kemp, International Centre for Ecohydraulics Research, University of Southampton, UK.  
(p.kemp@soton.ac.uk; www.icer.soton.ac.uk)

**Abstract:** The need to provide routes of alternative passage for moving fish impeded by river infrastructure is well recognized. In Europe, understanding of the potential for impoundments to block the spawning migrations of fish and as a result cause population declines date back to before the reign of the English Monarch, Richard the Lionheart, in the 12th Century. Despite continuous development of fish passage solutions, such as fishways for upstream migrating fish, and bypass facilities designed to aid downstream movements, robust evaluation of their efficiency is rare when viewed from the global perspective. Where effectiveness has been monitored, results frequently fall below expectation and in some cases the fish passes are themselves a cause for concern as a potential impact on fish populations. This has led to current fish passage solutions being described as "half-way" technologies and partially explains why many populations have continued to decline, and in some case become extinct, despite mitigation. The development of fish passes that effectively attract multiple species (taking a community perspective) to their entrances, allow successful entry and passage while minimizing energetically costly delay and potential for predation remains a major and fundamental challenge. This presentation will outline some of the current problems and future challenges associated with fish passage development and provide recommendations for further progress in this field. These can be summarized as: 1) recognizing the problem; fish passage may not provide a universal panacea; 2) developing realistic fish passage design criteria for multiple species; 3) embracing the influence of fish behaviour in passage efficiency; 4) improving understanding of population response and cumulative impacts; and 5) considering alternative mitigation options and developing techniques to effectively priorities actions.
Approach of fish migration and fish passages in Neotropical regulated rivers: the case of Upper Paraná River, Brazil

Presenter: Sergio Makrakis, Universidade Estadual do Oeste do Paraná, Toledo-Paraná State, Brazil E-mail: makrakis@terra.com.br

Abstract: The energy demand is increasing especially in developing countries, and the hydropower is still renewable matrix to meet it safely. However, it may cause high negative impacts mainly for long-distance migratory species. The understanding of the migratory behavior and the use of fish passages is quite complex for the Neotropical ichthyofauna. Although in dealing with potamodromous species, the few available studies may contribute to generate insights for the species discussed in this Workshop.

The Paraná River is the second longest and the most regulated river system in South America, with numerous dams built to support this growing demand for hydropower. The large dams along the Paraná River have caused severe impacts on long-distance migratory species, through the interception of migration routes and reductions of spawning and nursery grounds. Migratory fishes may travel long distances during the reproductive season (Piracema) in search of suitable spawning habitats, and they may have to move through one or more fish pass during migration.

Migratory movements are more diverse; could be long, short, or at times absent; upriver, downriver, or lateral; and the diversity of movements can vary within and among species. The intense lateral migrations exhibited by a diversity of species, especially to and from large tributaries (above reservoirs) and reservoir tributaries, illustrate the importance of these habitats for fish species life cycle. Also, preferences exhibited by spawners for a particular tributary may be related to discharge and site characteristics as migrators search for desired conditions for reproduction and initial development. Considering that the Paraná River is highly impounded, special attention should be given to the few remaining low-impact habitats as they continue to be targets of hydropower development that will likely intensify impacts on migratory fish stocks. Many hydropowers have installed fish passages in order to restore the longitudinal connection, however very few are evaluated on attractiveness and efficiency of upstream and downstream movements. Considering the high diversity of species in the Neotropical region, and the fact that many of them are long-distance migrators, the fish passage must meet the biological and behavioral characteristics of multispecies.

Multispecies fish passage aimed at the whole migratory community may, in many cases, be a huge challenger. The principles of effective multispecies fish passage need to characterize the spatial and temporal components of such behaviors, swimming capacity and behavior of the range of Neotropical species, and assessing the attractiveness and passage efficiency. Thus, examples of assessment and monitoring of passages for Neotropical fish based on field will provide knowledge whether the passages could actually promote permeability.

Nature-Like Fishways Around The World: What We Are Learning

Presenter: Laura Wildman, P.E., Fisheries Engineer Princeton Hydro LLC., 931 Main Street, Suite 2, South Glastonbury, CT 06073; lwildman@princetonhydro.com; w. 860-652-8911, c. 860-989-7966

Abstract: As nature-like fishways gain popularity around the world, more examples of completed nature-like fishways exist to learn from. This presentation will give examples of the variety of nature-like fishways already constructed, and focus on some of the larger scale bypass channels.
currently existing or under design. Site constraints and design considerations for large scale bypass channels will be discussed including: the creation of preferential flow paths; the potential increased risk of dam failure; the location of the bypass channel entrance(s) and exit(s); and the need to consider swimming endurance of target fish species. A selection of the recent studies evaluating fish passage efficiency at nature-like fishways will be discussed, pointing to the need for well-planned designs that integrate both the targeted fish species' behaviors and their interactions with/within the fishway. The pros and cons of nature-like fishways will be compared to the larger scale ecological benefits of dam removal.

**Introduction to Upstream Fish Passage Systems**

*Presenter:*

**Edward Meyer**, Senior Fish Passage Engineer,  
National Marine Fisheries Service, Portland, Oregon

*Abstract:* There is a long history of designing upstream passage to allow migrating fish to move around obstacles in a river or stream. Depending on the species, some designs have been successful but many have met with failure. Designing an effective upstream fish passage system can be a challenging endeavor. However, with basic understanding of the target species biology and physiology as well as the project's hydraulics and hydrology, a truly effective fish passage system can be developed. With this information, biologists and engineers can develop the criteria and guidelines that are necessary to design the various components that make up an effective fish passage system. During this presentation, I will briefly discuss some of the required information as well as the various components of a fishway (including traps and lift systems) and how they come together to create a functional system. I will also discuss some features (such as count stations and PIT tag systems) that allow for monitoring of fish using the fish ladder.

**Discussion of Downstream Passage Systems at Columbia River Dams**

*Presenter:*

**John Williams** – Affiliate Professor,  
School of Aquatic & Fishery Sciences,  
University of Washington, Seattle

*Abstract:* Research to develop downstream passage systems has been driven by defined passage goals. The goals have changed over decades and thus $US100 millions in research, installation of prototypes, operational equipment, and operational changes have been required to meet changing goals. Downstream passage in the Columbia River has mostly been directed at juvenile salmonids; only in the last decade has it included kelts. Successful downstream passage installations or operations of turbines and spill at dams must mesh with downstream fish behavior; including where fish are in water column, within the flow field, and how they react to changing water velocities. The use of means to modify behavior, such as lights, has generally had little effect on fish guidance. Successful guidance has relied on screening structures, flow manipulation, spill, surface weirs, or some combination of all techniques. Spill has led to unintended effects of gas supersaturation. Effectiveness of methods is not known for most other species in the river system. Existing fish guidance efforts are presumed poor for bottom oriented fish. I will discuss and provide pictures of what has worked, what has not, why, and some lessons learned.
MAES – Fish passage considerations at Mactaquac Dam and the Saint John River

Presenter:
Christ Katopodis, Katopodis Ecohydraulics Ltd.
KatopodisEcohydraulics@live.ca

Abstract: The hydroelectric dams of the Saint John River Basin present fish passage challenges, which are compounded by lack of some species-specific habitat information. Upstream and downstream movements for several species are crucial to the recovery of fish populations, especially the wild stocks. The Mactaquac is the most downstream of the hydroelectric dams and backs water levels to near the Beechwood Dam, affecting fish habitat in-between. Habitat changes and fish passage challenges at Beechwood and Tobique Narrows also affect migratory populations, especially Atlantic salmon. Addressing fish passage issues at the Mactaquac Dam only, may not be sufficient, especially since some of the best remaining fish habitat may be in upstream tributaries, particularly the Tobique River. Conventional and nature-like options for upstream and downstream fish passage systems are outlined from a conceptual perspective. Species specific considerations are emphasized as they are key to the effectiveness of possible passage facilities. Passage systems both for up and down river fish movements would be most limited in their effectiveness, if minor changes are made to Mactaquac or the other existing dams. Removing the Mactaquac, without addressing fish passage effectiveness at the other hydroelectric dams in the Saint John River, may very well prove unsuccessful for the recovery of wild stocks. Large modifications to Mactaquac, incorporating best feasible fish passage options, may provide in-between solutions of various levels of effectiveness. The most effective fish passage systems are possible with dam designs which integrate best available information and recognize knowledge limitations, particularly on species movements and behaviour. Appropriate flow regimes to attract fish to upstream passage systems and guide them to downstream facilities are critical and entail trade-offs between fish passage effectiveness and power generation. Science-based processes as well as overall management objectives for the Saint John River, including the state of fish populations and power generation expectations, will be instrumental in arriving at feasible solutions. Further work and study will be needed on a short list of feasible solutions. Whatever solutions are devised will need to enable adaptable management through design features that are amenable to change and a well-designed long term scientific monitoring program.