Resilient Waters

Pump Stations and Fish Passage on the Lower Fraser

Literature Review and case studies from around the world

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The function of pump stations

A typical diked river valley will have many tributaries and side channels that connect to the main river through the dike. The passage of water through or over the dike is controlled by floodgates and pumps. During times of flood or high tides, floodgates and tide gates close to protect the area behind the dike. During these times, pumping is required for continued drainage to the mainstem (Thompson *et al*. 1999). In some instances, pumps are the sole method for drainage over the dike.

Information on the function and design of floodgates and tide gates is found in the companion document "Technical Options for Tide Gates, Flood Gates and Fish Passage on the Lower Fraser" (Hubert and Straker 2022).

The impact of pumps on fish

Most older pumps in the lower Fraser have a major negative impact on fish and other aquatic organisms, because fish passage was not a consideration in their design. There are a few mechanisms through which fish are harmed by conventional pumps. Firstly, they can be injured or killed by the blades of the impeller or the guiding vanes (van Esch *et al.,* 2014; Bierschenk *et al.*, 2018; Thompson *et al.*, 1999). Secondly, there are rapid drops in pressure which may cause the swim bladder to expand and burst or cause internal bleeding, resulting in immediate or delayed death (van Esch *et al.*, 2014; Thompson *et al.*, 1999). Thirdly, if a fish survives and is expelled into the downstream waterbody it may become disoriented, making it more susceptible to predation (Thomson *et al.*, 1999).

Pumps are most often operated during the spring snowmelt, when Fraser River water levels are high and flood gates are closed. Fish are thus trapped behind dikes unless they move through the pumps. The period when gates are closed and pumps are operational may last up to six months in certain watersheds, severely impacting fish passage and limiting access to important rearing habitat (Thompson *et al*., 1999).

Improving pump stations for fish

It is possible to reduce or eliminate the harms to fish caused by pump stations, while maintaining cost-effective pumping capacity. Attachment 1 of this document describes the main qualities of fish-friendly pumps, including options that can fit a variety of budget and space constraints.

Fish-friendly pump station upgrades have been undertaken successfully in British Columbia and other jurisdictions. Attachment 2 of this document provides examples.

Designs and Manufacturers of fish-friendly pumps

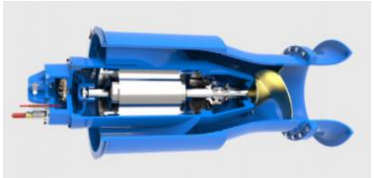
There are three general types of pumps used for flood control purposes: axial flow (propeller pumps), radial flow (centrifugal pumps), and Archimedes screw pumps. For axial- and radial-flow pump types, there are now fish-friendly features available. Archimedes screw pumps are generally fish friendly.

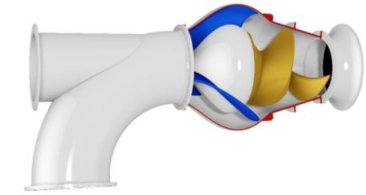
Axial-Flow Pumps

Axial-flow pumps are the most common pump type in the lower Fraser, due to their relatively simple design and high efficiency (Thomson *et al.*, 1999). An axial-flow pump uses an impeller, or rotor, to generate a lift force in the water, much like a helicopter generates a lift force in the air. They may operate at speeds over 1,000 revolutions per minute (rpm) though many operate between 500 rpm to 800 rpm (Thompson *et al.*, 1999). This type of pump can be made fish-friendly using new impeller designs, including updated design of the guide vanes (grooves) on the impeller. The impeller must also exceed a certain size to pass fish without injury (White et al., 2012; Vaipuhi, 2017).

Table 1. Manufacturers and models of fish-friendly axial-flow type pumps.

Pump Manufacturer	***Pump Model***	***Manufacturer Location***	***Manufacturer website***
Bedford Pumps Limited	Fish friendly variants of submersible axial and bowl pumps	United Kingdom	https://www.bedfordpumps.co.uk/fish-friendly-pumps
Pentair	Pentair Fairbanks Nijhuis fish-friendly pump	The Netherlands and USA	https://fairbanksnijhuis.pentair.com/en/products/fish-friendly-pumps-vpf-hpf-series
Rodelta	Fish-friendly version of Axial Concrete Volute Pump	The Netherlands	https://www.rodelta.com/fish-friendly-pumps/
Bosman Water Management	Vision MC	The Netherlands with USA distribution	https://bosmanwater.nl/en/products/pumping-installations/vision-mc-fish-friendly-pump/

Bedford	

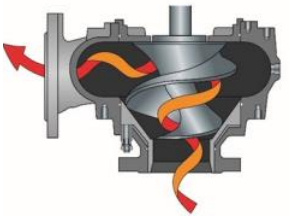
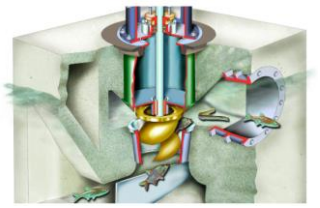
Pentair (Fairbanks-Nijhuis), Fish Flow Innovations	
Rodelta	
Bosman Water Management	

Radial-Flow

A radial-flow pump uses a rotating impeller to generate a centrifugal force which draws water into the pump's center and accelerates it outwards into an outlet. Radial-flow pumps operate within similar rpm ranges as axial-flow pumps (300 rpm to 900 rpm); however, they are far less frequently used for pumping stations (Thompson e*t al.,* 1999). These types of pumps typically do not require guide vanes, which removes a significant danger for fish. Casings for the impeller can be made from metal (see Hidrostal type, Table 2), or concrete (see Bosman type, Table 2) The most common design that has been studied for fish impact is the Hidrostal centrifugal pump (McNabb et al., 2003; Bedford, 2020). All fish-friendly radial-flow pumps use a novel impeller design, often with a helical conical shape.

Table 2. Manufacturers and designs of fish-friendly radial-flow type pumps.

Pump Manufacturer	***Manufacturer Location***	***Manufacturer website***
Hidrostal	International	https://www.hidrostal.com/
Bosman Water Management	The Netherlands with USA distribution	https://bosmanwater.nl/en/products/pumping-installations/vision-fish-friendly-pump/
Rodelta	The Netherlands	https://www.rodelta.com/fish-friendly-pumps/

Hidrostal	
Bosman Water Management	
Rodelta	

Archimedes Screw pumps

Archimedes screw pumps are typically fish friendly. They are a type of positive displacement pump that uses a large screw to pull water up an incline and deposit it at a higher location. The screw operates at low speeds and is independent of any pressure or velocity gradients, allowing for consistent pumping. Archimedes screw pumps rotate much slower than axial- or radial-flow pumps by at least an order of magnitude, usually operating at speeds of 10 rpm to 60 rpm (McNabb *et al*., 2003; Thompson *et al*., 1999; CTQ Consultants Ltd. 2016), though they may be operated at speeds as low as 1 rpm (Thompson *et al*., 1999). Several upgraded pump stations have switched from traditional axial flow pumps to Archimedes screw pumps for their fish-friendly nature (Hickey and Whyte 1992).

Table 3. Manufacturers and models of Archimedes screw pumps.

Pump Manufacturer	***Pump Model***	***Manufacturer Location***	***Manufacturer website***
Landustrie	Archimedean screw pump	The Netherlands	https://landustrie.nl/en/products/water-management/archimedean-screw-pumps/

Fish Flow Innovations	Fish Friendly screw pump	The Netherlands	https://fishflowinnovations.nl/en/innovations/screwpump

Landustrie	
Fish Flow Innovations	

Case Studies

There are many examples of fish-friendly pump installations in British Columbia and other jurisdictions. A common feature of fish-friendly pumps is a slow rotation speed, which is correlated with larger-sized pumps.

Axial-flow fish-friendly pumps manufactured by Bedford Pumps, and Archimedes screw pumps are two popular choices for fish-friendly pumps in Canada. However, these options can be more expensive than a traditional axial-flow pump equipped with a fish-friendly diversion, which is a successful option described in the Duncan-Bateson pump station case study.

Pumps manufactured by Bedford Pumps need to be imported from Europe, as do some Archimedes screw pump models. This may significantly raise costs, although in some cases parts of the manufacturing process can be conducted locally.

Monitoring programs are important to understand the success of a new system and where improvements can be made. Many pump upgrades described in the case studies lacked monitoring plans, which makes their success difficult to define. Any fish-friendly pump upgrades in the lower Fraser should be implemented together with a monitoring and adaptive management program.

British Columbia case studies

Duncan-Bateson Pump Station

Location: District of Kent, B.C.
Cost: $1.4 million
Year: 2009
Pump: Flygt - Aquaculture Pump

Project Overview: The upgrades at the Duncan-Bateson pump station occurred in response to the need to replace an aging pump with limited capacity. The existing pump station consisted of a single axial-flow pump with a capacity of 0.3 cms (cubic meters per second). The existing pump was not fish friendly. However, creating a fish-friendly solution was a priority for the district given the presence of coho and chum juveniles upstream of the pump station.

[1]Duncan-Bateson Pump Station

[1] Photo by Meghan Rooney 2021

The station was upgraded to a configuration with three pumps: two traditional axial-flow pumps, and one radial-flow centrifugal pump designed for transporting fish in the aquaculture industry. The inlet to the fish pump was integrated into a fish screen that prevented fish from entering the main pumps. The fish pump was set to turn on two minutes before the main pumps and stop two minutes after to ensure fish were able to make it through to the other side. The project utilized old pipes from the previous pumps to cut down costs.

Results: The two new pumps increased capacity from 0.3 cms to 1.5 cms and increased fish survival rate by 90% (resulting in total fish survival of over 90%), thereby addressing both objectives of the upgrade. Debris must be removed from the screen to ensure water passage to the main pumps. The use of an aquaculture pump instead of an Archimedes screw is estimated to have cut project costs in half.

Key takeaways:

- Costs were significantly reduced by adding a fish pump alongside traditional pumps, and reusing existing materials;
- Adding a screen increases maintenance costs; and,
- The monitoring plan confirmed that the upgrade was effective at mitigating harm to juvenile salmon.

Reference: Association of Consulting Engineering Companies Canada, 2011.

Hatzic Lake Pump Station

Location: City of Mission, B.C.
Cost: $4 million
Year: 2014
Pump: Submersible axial fish-friendly pump from Bedford Pumps

Project Overview: The upgrades to the Hatzic Lake Pump Station were conducted in response to inadequate and aging pumps that were suspected of causing high fish mortality. The pumps serve the entire Hatzic Lake watershed which extends north through the Hatzic Prairie and drains the surrounding hills.

The station was with three submersible axial fish-friendly pumps manufactured by Bedford Pumps. These are the first of this type of pump installed in the lower Fraser. The pumps operate identically to traditional axial pumps but operate at the lower end of the rpm spectrum for axial pumps and have a novel impeller design.

Figure 1 Hatzic Lake Pump Station

Results: The pump stations now provide a combined capacity of 8.1 cms. According to independent testing conducted in the Netherlands, the pumps have a survival rate of ~98% for fish under 15 cm in length and ~95% for individuals over 15 cm. Fish-friendliness has been

shown to vary between pump sizes and types and no on-site tests have been performed to confirm ratings (Vaipuhi 2017). This project was considered successful and led to five more fish-friendly Bedford Pump installations in Canada, including the Pitt Polder station.

Key takeaways:

- This was the first Bedford Pumps installation in Canada, followed by five more at various sites;
- The installation was a success, and the goals were achieved.

Reference: Bedford Pumps Ltd., 2014.

Pitt-Polder Pump Station

Location: Pitt Meadows, B.C.
Cost: $6.9 million
Year: 2020
Pump: Submersible axial fish-friendly pump from Bedford Pumps

Project Overview: The upgrades to the Pitt-Polder pumping station were conducted in response to two aging pumps that needed to be replaced in order to serve the 1,650-hectare wetland.

The station was upgraded with two submersible axial fish-friendly pumps from Bedford Pumps in Europe, with cartridges fabricated in Canada. The new pumps operate identically to traditional axial pumps but operate at the lower end of the rpm spectrum for axial pumps and have a novel impeller design.

[2]Pitt-Polder Pump Station

Results: The pumps have a combined capacity of 7.12 cms. According to independent testing, fish should have a survival rate of ~98% for individuals under 15 cm and ~95% for individuals over 15 cm. However, no on-site fish survivability testing has occurred. The cost of the project exceeded estimates.

Key takeaways:

- This model of Bedford fish-friendly pumps is highly effective in lab conditions, though no in-situ test has been performed;
- Some components can be manufactured locally, reducing cost; and,

[2] Photo by City of Pitt meadows, 2020 https://www.pittmeadows.ca/our-community/about-pitt-meadows/location-maps/pitt-polder-pump-station

- The project went over budget, potentially reducing support for future projects with this manufacturer.

Reference: Bedford Pumps Ltd. 2020.

Oliver Pump Station

Location: City of Delta, B.C.
Cost: $1.5 million
Year: 2011
Pump: Archimedes screw pump, unknown manufacturer

Project Overview: The upgrades to the Oliver pump station were conducted in response to previous flooding and concerns over future flooding due to the increasing urbanization of the land. The existing pump infrastructure had insufficient capacity to drain the area and was not fish friendly. The goals of the project were to ameliorate flooding and to provide fish passage between the slough and the ocean at Boundary Bay.

The pump station was fitted with four Archimedes screw pumps from an unnamed manufacturer. Archimedes screw pumps are generally regarded as fish-friendly and have no special operating requirements (Hickey & Whyte, 1992). Closed Circuit TV and data gathering (SCADA) systems were also installed to monitor water levels and flow.

Results: The new pumps have a combined capacity of 3 cms. Fish passage is said to have increased, though no publicly available data was found. Habitat restoration work also took place inside the slough. The project increased the sense of security of farmers by increasing pump capacity for the region, thereby protecting both their homes and crops from water damage.

[3] Oliver Pump Station

Key takeaways:

- Archimedes screw pumps are a cost-effective solution relative to several other fish-friendly pump upgrade projects;
- Fish passage likely increased;
- Remote water level monitoring adds an extra layer of security; and,
- Farmers were supportive of this project.

[3] City of Delta, 2015. https://twitter.com/cityofdeltabc/status/590246252346011648

Reference: Carbonn 2011.

Miami Creek Pump Station

Location: Harrison Hot Springs, B.C.
Cost: $1,920,000
Year: 2016
Pump: Archimedes screw pump from Landustrie (2.8 m x 9.0 m)

Project Overview: The upgrade to the Miami Creek pump station was conducted due to the threat of flooding in the village of Harrison Hot Springs, and the desire for a fish-friendly alternative to the existing pump infrastructure. The existing traditional axial-flow pump provided a pumping capacity of 2.6 cms and a 0% survival rate through the pump.

The replacement pump consisted of two Archimedes screw pumps imported from the Netherlands with the rest of construction occurring locally. The project also included plans to add interpretive signage around the pump area to educate residents and visitors about the new pump infrastructure. Indigenous art was incorporated into the project as well, adding both cultural and aesthetic value to the area.

[4] Miami Creek Pump Station with artwork and benches

Results: The two screws have a combined capacity of 6 cms at 59 rpm. The contractors responsible for the installation report a 99% survival rate through the pump infrastructure for all aquatic life, though this may be lower among larger size classes. The screws were painted canary yellow, which the contractors had identified as a "fish-friendly colour".

Key Takeaways:

- Colour impacts fish behaviour and may affect their chance of entering a pump;
- Multiple co-benefits were realized including educational, recreational, cultural, and aesthetic – this allowed planners to maximize the value of the project; and,
- Costs were kept relatively low despite the use of an intercontinental supplier.

Reference: CTQ Consultants Ltd. 2016.

[4] Photo by Meghan Rooney, 2020

Case studies from other jurisdictions

Kempsey Pump Station

Location: Kempsey, Worcestershire, UK
Cost: £1,700,000 (~$2,900,000 CAD)
Year: 2012
Pump: Submersible axial fish-friendly pump from Bedford Pumps

Project Overview: In response to repeated flooding and new European legislation mandating the protection of migratory eels, a new pump station, flood gate (sluice), and earth embankment were constructed at the mouth of Hatfield Brook onto the River Severn. There was no previous flood control infrastructure on this site, and due to the known presence of eels in the brook, maintaining the existing habitat was a priority.

The flood gates at the new pump station allow water to flow back from the river into the brook until a certain level is reached, at which point a sluice gate is automatically closed. If the water continues to rise, the pumps are automatically activated, and the brook drained.

Results: The pumps were fish-friendly and had a combined capacity of 4.2 cms. No publicly available study of the impact of the project on eel populations took place. Issues with the sensors occurred a few years after installation causing the automatic function to fail, and the town experienced flooding. Manual operation was put in place until the error was resolved.

Key takeaways:

- This infrastructure was built to be fish-friendly;
- Automatic sensors can fail, backups (manual or automatic) should be in place to ensure flood protection

Reference: Bedford Pumps Ltd. 2012.

Orchard Rd. Pump Station

Location: Waikato, New Zealand
Cost: N/A
Year: 2018
Pump: Submersible axial fish-friendly pump from Bedford Pumps

Project Overview: The Waikato Regional Council procured a private contractor to evaluate the in-situ effectiveness of the Bedford fish-friendly pumps. The pumps evaluated ran quicker (~800 rpm) compared to the pumps used in the original tests (~400 rpm) commissioned by Bedford. The pump is also reportedly smaller than the one used in the original tests commissioned by Bedford.

The contractor noted significantly lower external damage to eels passing through, though internal damage was still high, with 16% of eels estimated to be unable to complete migration after passage. There was a vast increase in survivability of the pump from 0% in the original pump to 95% in the Bedford pump.

Results: The consultant recommended slower operating speeds for the pump as well as a larger pump size in areas where larger fish are known to live. They also suggest alternative routes around the pumps if possible and stress the uncertainty of the operational fish-friendliness of pumps.

Key takeaways:

- Follow up monitoring is important and can reveal unexpected results. This is especially important when conducting multiple pump upgrades;
- In-situ survival / injury rates are not always equivalent to laboratory testing; and,
- Pump size and speed are important fish-friendly factors to consider when purchasing any type of pump.

Reference: Vaipuhi Consulting, 2017.

Uckinghall Pump Station

Location: Uckinghall, Worcestershire, UK
Cost: £1,500,000 (~$2,560,000 CAD)
Year: 2012
Pump: Radial-flow submersible fish-friendly pump from Hidrostal

Project Overview: Extensive flooding prompted the creation of an embankment, flood gates, and a pumping station to protect the town of Uckinghall from the high water of the River Severn. There was no existing flood control infrastructure at the outset of the project. EU Legislation required eel and fish-friendly pumps.

Results: The new pump station was fitted with two Hidrostal radial-flow pumps with a novel impeller design. The pumps had a combined capacity of 0.125 cms. The fish-friendliness of Hidrostal pumps has been demonstrated in several studies, however no in-situ studies were carried out in Uckinghall, nor did any monitoring of eel populations take place.

Key takeaways:

- This type of Hidrostal pump is considered an off-the-shelf fish-friendly solution;
- Hidrostal pumps typically operate at lower capacities than other options.

Reference: Hidrostal Fish Friendly Pumps 2012.

Red Bluff Pump Research Facility

Location: Red Bluff, California
Cost: N/A

Year: 1994
Pump: Two Archimedes lifts and one large Hidrostal pump

Project Overview: A testing facility in Red Bluff, California was outfitted with three pumps, two Archimedes lifts and one large Hidrostal pump for the specific purpose of testing fish-friendly flood control infrastructure. All pumps delivered equal pumping capacity at 2.3 - 2.8 cms. The Archimedes pumps rotated at 26.5 rpm while the Hidrostal pump operated at 350 - 375 rpm. All pumps transported fish an equivalent vertical distance to a sluice way.

Results: All pumps were found to be extremely fish-friendly with little to no difference observed between fish that were passed through the pump and control fish. While the Hidrostal pump inflicted some detectable damage, the authors of the study concluded that it was not significant.

Key takeaways:

- Archimedes lifts and Hidrostal pumps are both excellent fish-friendly options;
- The study uses a very large Hidrostal pump operating at relatively low speeds; smaller, faster pumps would likely have higher injuries; and,
- Chinook salmon between 28 mm and 74 mm passed safely through both pump types.

Reference: McNabb *et al*. 2003.

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