Fish Passage Considerations for Retrofit of Baseflow Weir Gauges

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Key Points

- There are several existing baseflow weir gauges located across Council, which currently are fish barriers. There are several considerations to retrofit these existing gauges to create successful fish passage.
- Data regarding species-specific requirements is required for successful design of fish passage, but it not always available.
- At each stage of fish passage, there are multiple hydraulic conditions to consider, including: depth, velocity, turbulence, channel width, channel length, light, flow vectors, roughness, step down between pools, consistency of spillover without air voids / pockets, and distance between resting spaces.
- Base flow weir gauge accuracy is effected by drowned inverts, which are likely required for fish passage retrofits. Hydraulics and development of an accurate rating curve require consideration.

Abstract

Brisbane is one of the fastest developing areas in Australia [1]. The increase in impervious area and pollution point sources have put strain on our waterways. In the midst of this urbanisation and a new wave of infill progressing across the city, Council has recognised our waterways as assets to enable further funding and management strategies into the future. As with all asset management, monitoring and data collection regarding the condition and performance of the asset is critical. Fortunately, several waterways located within the Council land area have flow gauging weirs that are capable of recording baseflow, which have been installed for more than forty years. This baseflow information is now proving essential in understanding changes, which have occurred to catchment flow regimes since their installation. Unfortunately, the historical flow gauging weir designs did not include fish passage consideration; consequently, most of these weir gauges are classified as barriers to fish passage. As urban catchments have developed and baseflow regimes have modified, additional stress has been placed on native fish populations in urban waterways. To ease the stress on native fish populations, it would be beneficial to minimise the barriers encountered. The ambition to reinstate fish passage, as well as utilise existing infrastructure to extend existing historical flow data sets, are at odds with each other. This paper considers the connection between these two issues: providing successful, sustainable fish passage and maintaining reliable flow gauging station data points within urban catchments.

[Please note – publishing of this paper is contingent on Council approval.]

Keywords

Fish Passage, Environmental Flow, Stream Gauge, Brisbane, Retrofits

1 Introduction

Brisbane is a river city, which can be divided up into 38 major creek catchments with 630 kilometres of waterways [4]. Across these waterways, there are several flow gauging weirs capable of recording baseflow regimes. Some of these low flow weir gauges were installed in the mid-1970s, thus providing an excellent source of data for use in evaluating the modifications to environmental flows, over a period of significant development in Brisbane. Environmental flows are defined as the amount of water that flows through a river system, which includes the whole pattern of flows – from how long it lasts, to how frequently and how large it is [26].

The historical data collected by the existing baseflow weirs not only enables quantification of historical change within a catchment, but also assists in validating targets for planning and regional design outcomes. Consideration was given to the replacement of these structures to facilitate continued data capture, in addition to fish passage, however timing (i.e. planning, design, permitting) and cost issues are prohibitive. Therefore, designing a retrofit solution for the structures is a more achievable outcome.

Low flow gauging using weirs is primarily undertaken utilising depth gauges to measure water flowing over a structure, and cross-referencing this against a pre-determined rating curve. Unfortunately, the flow values determined by the rating curve for the weir depend on various hydraulic conditions, which are sensitive to change, particularly at low flow depth values. Traditionally, preference for locating low flow gauging weir sites went to locations where hydraulic disturbances (such as tidal backwater) could be minimised. This promoted the use of low flow gauging weir designs, which had elevation drops on the downstream side of the weir, to eliminate backwater effects at the spill over point and to provide a less disrupted flow regime.

Three of Brisbane's low flow weir gauges have been identified as low flow fish passage barriers [18]. This is primarily due to the designs featuring a large change in elevation between the spillover point and the downstream water levels, thereby creating a barrier to upstream fish movement during low flow or baseflow events. The weirs do not have controlled release mechanisms or gates and are located on un-regulated creek systems. In addition to the weirs being identified as barriers, the weirs are also located on high risk waterways, as per the Queensland Department of Agriculture and Fisheries (DAF) Barrier Risk Assessment Study [18]. The DAF assessment evaluates all major waterways across south-east Queensland and ranks them by the risk posed to species success, if a barrier was to be located in that waterway. The ranking order uses a traffic light colour coding system. Waterway categorization is based on stream order, stream slope, flow regime, number of fish species present and fish swimming ability [18]. Waterways that are designated green have the least risk of disrupting fish populations, while those with red designations have the highest risk. Two other colours are used – purple for higher order waterways and grey for tidal areas.

Brisbane City Council has undertaken an evaluation of the DAF Barrier Risk Assessment sites, as well as desktop and field assessments, to begin to locate high risk barriers across the city. Unfortunately, many man-made fish passage barriers have been identified, such as road crossings, weirs, culverts and causeways. All these structures have the ability to prevent or delay aquatic connectivity, which impacts long-term sustainability of fish populations, modifies fish community structure, reduces waterway health and creates environmental conditions that are favourable to invasive pest fish species. There are several documented methods to provide fish passage for these types of barriers; however, very little information is available to provide fish passage at low flow weirs.

An important component of fishway design is defining the performance objectives [5]. Successful performance of a retrofitted structure should result in reduction in the fish migration delay at the structure for all ranges of flow. This is, however, species dependant so the performance criteria of the design should be directly aligned with fish species requirements within the reach. Within Brisbane, this is quite challenging, as over thirty types of native fish have been identified through monitoring programs across Brisbane catchments [5], all of which have different migratory patterns and swimming capabilities.

Fish migration is an essential component of the life-cycle of many south-east Queensland fish species. Some of these migrations are short and confined wholly to freshwater habitats, while other migrations occur across vast distances and between varying habitats, including between freshwater and near-shore marine environments. Migration strategies between key habitats have evolved for a variety of reasons, including for feeding and reproduction purposes, to avoid predators, to utilise nursery areas and maintain genetic diversity. Therefore, unimpeded connectivity between aquatic habitats is important to sustain fish populations and ensure long-term health of local waterways. These types of fish community characteristics have been used to determine relative ecosystem health since the beginning of the 19th century [11].

This paper explores the options for preserving valuable low flow weir gauging stations, which have provided consistent environmental flow data over several decades of development across Council, whilst cost-effectively providing successful native fish passage.

2 Viable Fish Passage Retrofit Options for Low Flow weIrs

Weirs are section control structures that are often constructed across channels to allow for the measurement or capture of flow. They have various cross-sectional and longitudinal shapes that determine how the water flows over the structure. The spillover point (or control point) of the weir can be shaped into a profile, allowing for flow regulation, such as V-notch (triangular), trapezoidal, rectangular and broad-crested.

Weirs created across Brisbane are primarily mass concrete structures, with a v-notch section and limited tailwater influence, as the control point of the structure is usually elevated at least 0.5m above the tailwater. This is also true for the three low flow gauging stations in question, which have been constructed to monitor baseflow and higher stage flood flows, through the use of digital depth gauges and rating curves, and utilising mass concrete v-notch style setups.

With baseflow being highly variable and stream dependent, and weir cross-sections also being dependent on individual structures, several options for facilitating fish passage over a weir structure are seen as viable. These include (in order of priority based on cost): retrofitting the weir with a ladder/ramp, or bypassing flow around and past the structure, or replacing the weir with a different style of gauging structure.

Most of the low flow weir gauge retrofitting information available is in relation to Salmon migration in North America. Salmon are known to be adept at jumping relatively extreme heights. While the fish species in Brisbane will jump, it is not to the same extent as salmon. Therefore, solutions presented for salmon passage are, in general, not applicable to the fish species that occur in Brisbane. A more locally appropriate solution is required for fish that occur in the Brisbane area.

Recently, there have been several natural riffle-style fish passage systems installed in south-east Queensland, near Brisbane; specifically, at Hilliards Creek (Redlands), South Pine River (Moreton Bay), Bremer River (Ipswich), and Slacks Creek (Logan). Although the systems do contain level sensors, none of these systems incorporate low flow weir gauges. Results from monitoring completed at two of these fish passage systems show that 21 species (19 native and two pest) were able to navigate successfully between upstream and downstream reaches using the installed fish passage device. The native fish moving through the systems ranged in size from as small as 18mm (Crimsonhead Rainbow Fish) to 550mm (Longfin Eel) in length. At the Bremer River rock-ramp fish passage device, 3,514 fish were counted successfully migrating through the fishway over five days of monitoring [6], [7]. At the Slacks Creek rock-ramp fish passage device, 6,546 fish were counted passing through the fishway over five days of monitoring. Prior to the fish passage installation at Slacks Creek, only 18 fish were observed to successfully negotiate the barrier, which was removed when the fishway was installed. During periods of high flow fish have been observed resting at the edge of the creek, where water velocities are slower, then make the ascent through the fish passage, once the peak of flow events have passed [6], [7], [20].

In addition to the natural riffle-style systems located in south-east Queensland, there are several vertical slot weir systems and precast cone weir systems; however, these are not considered applicable for low flow weir retrofits. At this point, information regarding the successful passage of fish through the existing vertical slot weirs could not be found publicly.

In the last few years, there have been low flow fish passage systems installed in the United Kingdom, which have incorporated low flow weir gauge systems. The systems are 'low cost baffles' that can be bolted on to existing structures to facilitate fish passage without any impacts on flow gauging. These low cost baffles are also applied as an interim measure on 'non-gauge' weirs, or weirs where other fish passage solutions will be difficult to develop/achieve. In these instances low cost baffles provide a fish 'easement' until an opportunity for a alternative solution arises, or while a preferable, multi-species and multi-age class fish passage solution, is developed. [20]

Option selection and evaluation is dependent on success of achieving required conditions for fish species present and suitability within the waterway.

3 Design Considerations – Fish Passage

Brisbane City Council creeks contain approximately 30 native fish species. For the purposes of this paper, these are split into five main categories (Amphidromous, Catadromous, Marine, Marine Vagrant and Potamodromous), based on their migration requirements. Some of these categories do not have migratory requirements for a critical life cycle phase, so evaluation of design parameters should be tailored to understanding the specific requirements of those that do.

There is limited information about native fish swimming capabilities, such as maximum swim speed and sustained swim speed, which makes design of successful fish passage a challenge. Biological attributes of fish that form key criteria in design, such as swimming capability data is available on some species, however, it is limited. The two primary parameters utilised to define the swimming capability of fish are Maximum Swim Speed (MSS) or Burst speed, and Sustained Swim Speed (SSS). The MSS is the highest speed a species can reasonably achieve, which is utilised when accelerating through a fast flowing section of water, such as a weir or spillover point. Data analysis has been completed for fish passage systems in south-east Queensland to demonstrate typical behaviour of fish as they pass through the systems (ie. resting vs darting swim velocities). Data has shown that fish swim at a maximum speed for short periods up to 20 seconds, or a prolonged resting swim mode for a period of up to 200 minutes [17]. Table 1 provides a list of the limited available information gathered for fish species found in Brisbane. Documentation for each species' swim speed during juvenile and adult phases could not be found.

Table 1. Migratory Status and Swim Speed for Fish Species Found in Brisbane [3, 9, 10, 14, 17, 21]

Species (Common name)	BCC Native (and aquatic asset) or Exotic	Migratory Status	Swim Speed Maximum	Swim Speed Sustained
Gobiomorphus australis (Striped gudgeon)	Aquatic asset	Amphidromous	0.87	0.1
Leiopotherapon unicolor (Spangled perch)	Aquatic asset	Potamodromous	0.75	No data
Gobiomorphus australis (Striped gudgeon)	Aquatic asset	Amphidromous	0.87	0.1
Leiopotherapon unicolor (Spangled perch)	Aquatic asset	Potamodromous	0.75	No data
Mogurnda adspersa (Purple-spot gudgeon)	Aquatic asset	Potamodromous	1	0.07

Myxus petard (Freshwater mullet)	Aquatic asset		No data	No data
Rhadinocentrus ornatus (Ornate rainbowfish)	Aquatic asset		No data	No data
Acanthopagrus australis (Yellowfin bream)	Native	Marine Vagrant	No data	No data
Amabassis marianus (Estuary glassfish/perchlet)	Native		No data	No data
Ambassis agassizii (Agassizis glassfish)	Native	Potamodromous	0.84	0.09
Anguilla australis (Short finned eel)	Native	Catadromous	No data	No data
Anguilla reinhardtii (Long-finned eel)	Native	Catadromous	0.87	0.39
Butis butis (Crimson tipped gudgeon)	Native	Marine Vagrant	No data	No data
Craterocephalus majoriae (Marjorie's hardyhead)	Native		No data	No data
Craterocephalus stercusmuscarum (Flyspecked hardyhead)	Native	Potamodromous	0.85	0.3
Gerres subfasciatus (Common silverbiddy)	Native	Marine Vagrant	No data	No data
Hypseleotris compressa (Empire gudgeon)	Native	Amphidromous	1.4	0.12
Hypseleotris galii (Firetail gudgeon)	Native	Amphidromous	No data	No data
Hypseleotris klunzingeri (Western carp gudgeon)	Native	Potamodromous	No data	No data
Megalops cyprinoides (Tarpon)	Native	Amphidromous	No data	No data
Melanoteania duboulayi (Crimson-spotted rainbowfish)	Native	Potamodromous	No data	0.12
Mugil cephalus (Sea mullet)	Native	Catadromous	No data	1.45

Neoceratodus forsteri (Australian lungfish)	Native		No data	No data
Notesthes robusta (Bullrout)	Native	Amphidromous	1.4	0.23
Philypnodon maculatus (Dwarf flathead gudgeon)	Native	Potamodromous	No data	No data
Pseudomugil signifier (Pacific blue-eye)	Native	Amphidromous	1.3	No data
Redigobius macrostomus (Large mouthed goby)	Native		No data	No data
Retropinna semoni (Australian smelt)	Native	Potamodromous	1.4	0.9
Tandanus tandanus (Freshwater / Eel-tailed catfish)	Native	Potamodromous	1.4	0.13
Gambusia holbrooki (Mosquito fish)	Exotic	Potamodromous	No data	No data
Oreochromis mossambicus (Tilapia)	Exotic	Potamodromous	No data	No data
Poecilia reticulate (Guppy)	Exotic	Potamodromous	0.95	0.29
Xiphophorus helleri (Swordtail)	Exotic	Potamodromous	No data	No data
Xiphophorus maculatus (Platy)	Exotic	Potamodromous	No data	No data
Gobiomorphus australis (Striped gudgeon)	Aquatic asset	Amphidromous	0.87	0.1
Leiopotherapon unicolor (Spangled perch)	Aquatic asset	Potamodromous	0.75	No data
Mogurnda adspersa (Purple-spot gudgeon)	Aquatic asset	Potamodromous	1	0.07
Myxus petard (Freshwater mullet)	Aquatic asset		No data	No data
Rhadinocentrus ornatus (Ornate rainbowfish)	Aquatic asset		No data	No data

Acanthopagrus australis (Yellowfin bream)	Native	Marine Vagrant	No data	No data
Amabassis marianus (Estuary glassfish/perchlet)	Native		No data	No data
Ambassis agassizii (Agassizis glassfish)	Native	Potamodromous	0.84	0.09

Other species specific biological parameters that need to be considered when designing fish passage include: total fish height, fish distribution and abundance, and correlation to life stage. As reflected within the table above, little is known about many of these attributes for Brisbane species, thereby resulting in the potential need to make realistic assumptions, until further research and data collection is completed. [13]

Fish passage development should also consider physical factors, which are also species dependant, and for which even less is known for Brisbane species. These factors include species specific preference for length of fishway, roughness, light availability, width/space of the pools and flow area of the fishway. [13]

Performance of the fishway is also determined by the ability to facilitate suitable conditions for the above, whilst also enabling suitable hydraulic conditions that provide passage and appropriate attraction and exit characteristics for the fishway. These characteristics include: turbulence, hydraulic gradient, depth of flow and flow direction (vectors) [13]. Many of these characteristics and requirements are not known for Brisbane species, so guides for other states and territories will be used, where relevant, until research is completed to fill data gaps.

Seasonal flow variability provides a number of challenges for the hydraulic conditions experienced at the fishway. Whilst many of the attributes may meet the desired performance criteria during times of minimal / baseflow, many of the hydraulic conditions experienced in the creek will vary significantly during medium and high flow events. This can change based on time of year and spatial location across the city, as they are primarily dependent on catchment specific soil conditions, connected impervious areas, groundwater connectivity, geographical rainfall variability and associated waterway characteristics. As baseflow/low flow conditions offer the minimum condition for fish to migrate upstream, it is most critical in the design considerations for passage and, therefore, is considered the design condition. [24]

Table 2 provides a summary of hydraulic considerations and associated fish attributes. As discussed, information regarding species- specific swimming speed is critical.

Table 2. Summary of Hydraulic Considerations for Each Stage of Fish Passage

Stages of Passage	Hydraulic Consideration	Fish Attribute
Attraction Downstream	Depth Velocity Turbulence	Swim Speed (sustained and burst)
Riffles	Depth of spillover Velocity of spillover Turbulence Step down between pools Consistent spillover without air voids / pockets	Swim speed (sustained and burst)
Pools	Depth Velocity Turbulence	Resting swim speed

	Width Length Light Flow vectors Step down between pools Roughness	
Passage over Crest of Weir	Depth Velocity Turbulence	Maximum swim speed Height of fish
Upstream Exit Point	Depth Velocity Turbulence Gradient Change	Swim Speed (sustained and burst)
Bank Treatment (applicable for high and medium flow conditions	Distance between resting space Velocities between resting space	Swim speed (sustained and burst)

4 Design Considerations – Weir Gauging with tailwater influence

To ensure successful long-term gauge data collection, the following should be considered:

- **Development of a Rating Curve** – Traditionally, rating curves were established by making use of standard hydraulic features (i.e. v-notch weirs or broad crest weirs). Depth-discharge relationships at these features are defined by making use of empirical equations and velocity flow meter devices (i.e. pitot tubes or rotameters) to estimate flow rates over the structures at various depths [23]. Due to the introduction of additional complex hydraulic regimes resulting from facilitation of fish passage over the structure, traditional methods may not be the most appropriate for these types of systems. It is understood that Computational Fluid Dynamic (CFD) models have recently been used to aid design of various fish passage systems. Further investigation has shown that the development of rating curves within the complex hydraulic systems of fish passage systems using a CFD model for evaluation significantly reduces possible anomalies and errors. Although specific test cases for using CFD in the development of rating curves at fish passage systems could not be located at the time of writing this paper, the model seems feasible, but will require field measurements of existing structures for validation and calibration.
- **Telemetry Instruments** – Collection and storage of data recorded from the weir is also a key consideration within design. If depth is to be measured, where will the receiver and telemetry be located, what is the recording frequency, and can the existing equipment measure the low flows with accuracy due to the sensitivity requirements etc.?
- **Hydraulic Conditions** – As is typical at any gauging station, it is essential to make sure that hydraulic conditions can be successfully measured. In order to ensure consistent and repeatable measurements over time, avoid designs that would likely experience the following: uncontrolled bypass conditions, debris or blockage (e.g. vegetation, etc.), unstable hydraulic conditions (i.e. sand or sediment deposits / scour upstream or downstream), excessive turbulence and changes in surface roughness (such as algal accumulation). The remaining key factor in determining a rating curve for the structure is whether it is operating in free flowing or drowned (submerged) conditions [25], of which the latter is likely if fish passage is to be provided.
- **Geomorphic Conditions** – It is important to consider if the geomorphic conditions are stable or in a state of change within the reach where the gauge is located. Urban streams are in various stages of evolution and, therefore, significant sediment movement may be affecting the location chosen for a gauging station, even though these impacts may have been triggered by catchment changes from 30 years ago. If there are sand or sediment deposits, erosion upstream or downstream of the gauge, it may affect the long-term success of the gauging station data, and result in additional access or maintenance requirements.
- **Maintenance Access** – As part of the design or modification of existing weirs, it is important to consider how the structure will be maintained and what type of equipment will be required to complete

maintenance routines. If possible, an adequate visual line-of-sight should be available to the weir, as well as adequate access for long-term maintenance, which will result in better data collection over time.

- **Stakeholder Engagement** – Input from various stakeholders, including those involved with operations, monitoring and maintenance should be factored into the design, to ensure a successful sustainable design is achieved.

5 Conclusion

When considering solutions to improving fish passage over existing low flow weir gauges (where they are identified as priority barriers), there are primarily three main options –removal, replacement or retrofit. Removing the structure can sacrifice a valuable historical data capture location and replacement/relocation of the structure can result in significant cost and time implications. However, retrofitting the structure to facilitate passage through engineered modifications, as well as rating curve modification to facilitate continuation of the existing data capture, has multiple benefits. Whilst each of these options are likely to provide successful, sustainable fish passage; there are many additional considerations, such as cost, time and planning/permits that need to be considered. Therefore, based on the likely speed and cost gains, retrofitting is the only option that has been explored in detail in this paper.

Several styles of retrofit are available and whilst the selection is likely dependant on site and species specific conditions, there remains a general lack of information regarding the performance of each structure. Options for retrofit include: rock ramp, fish lifts, denil fishways, vertical slot and 'low cost baffle' type systems.

Aquatic species that would be targeted for fish passage provision, are likely to be native fish and eel species that inhabit the catchment and functional zone in question. There are 30 native fish species that occur in Brisbane waterways and whilst detailed information is available for some species, a number of data gaps are still present. In particular, swimming capability data is missing for the various life stages of each fish species that occur in Brisbane waters.

Design of fish passage devices is a developing field and whilst some fish passage devices are currently being or have recently been constructed in the Brisbane area, monitoring of the performance of these structures is the critical next step in validating future designs. This monitoring also needs to consider species dependant variables.

Engineering design parameters associated with the monitoring of low flow / baseflow across the weirs, are also becoming an easier to monitor with the introduction of new technologies, such as CFD modelling. Evaluation of multiple parameters within an often condensed complex hydraulics environment, means that greater processing power is required to evaluate the system effectiveness. Models could also be used to develop rating curves that can be utilised (and field validated) for multiple hydraulic conditions, as opposed to current single flow regime style curves.

A summary of the key research topics, information requirements and data gaps identified as part of this work, include:

- Swim speeds for key fish species (including different life stage requirements) within Brisbane / south-east Queensland;
- Case study to retrofit or replace existing gauging points and develop rating curves; and
- Verification of CFD modelling as a tool for fish passage design and gauge rating curve definition.

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