OceanWatch Australia

Common Rail Proof of Concept and Baffle Field Trial Assessment Report

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1. Introduction

Fish migrations in Australia are stimulated by the seasonal flows that occur throughout all catchments. However, as fish undertake upstream fish migrations they may encounter one or more waterway barriers that prevents free movement. Migrating fish accumulate downstream of these barriers and often suffer high mortality rates due to disease and predation. Many of the Australian species migrating upstream do so when they are in their juvenile stages. Juvenile fish have neither the swimming ability nor stamina to scale large drops, steep gradients or high velocities for any great distance or length of time. Juvenile barramundi are only able to negotiate flows of around 0.66m/sec, while Australian bass are able to negotiate slightly faster flows of around 1.04m/sec (Mallen-Cooper, 1992), but both can only achieve this over a distances less than 1.0m. Based on research conducted in Australia it can be assumed that any structure or obstacle that contains vertical drops of more than 300mm or velocities greater than 0.6m/sec could be a considered a potential barrier to fish migration of most species (pers. comm. Claire Peterken).

Throughout every catchment in Australia there are thousands of barriers to fish migration from major dams and weirs through to culverts, causeways and floodgates. While many of these barriers are partially transparent to fish passage, others prevent all movement within the systems they block. Studies have clearly demonstrated that road crossings and in particular culvert crossings are the most numerous barriers (Peterbridge et. al. 1998, Gordos et. al. 2007, Moore and Marsden 2008 and White 2012). With an estimated 250,000 potential barriers to migration in Queensland (Marsden et. al. 2006) the cumulative effect of all these barriers on fish communities is considered to be significant.

Based on the likely high level of impact that culvert barriers are having on fish communities a number of state and federal jurisdictions are providing guidance on the provision of fish passage through culverts. In Queensland, there is a strong statutory basis requiring the provision of fish passage at waterway barriers and this (WWBW) legislation is widely and consistently applied for all new and upgraded barriers. A key step in the implementation of the legislation has been the development of a series of self-assessable building-type codes for more minor barriers, including culvert crossings. These codes incorporate fish passage design elements. If a proposal meets the criteria and is built and operated in accordance with the self-assessable code, then developers are not required to undertake the statutory planning assessment and approvals process. The Queensland WWBW codes have been in effect for over 5 years and have seen a significant increase in the provision of fish passage at culvert crossings throughout that state, with hundreds of new fish friendly culverts installed by the Queensland Department of Transport and Main Roads and regional councils.

The Department of Agriculture and Fisheries and Forestry (DAF) developed the specifications for fish passage outlined in the Queensland WWBW codes. These specifications were based on data collected on fish movement across barriers over 15 years of targeted and opportunistic sampling and observations by the department's two fishway teams. While this expertise was used to develop the codes, any experimental testing of the designs was curtailed when the teams were disbanded in

2013. To this end the experimentation outlined in this report is looking to build on the foundation commenced by the fishway teams, to provide a deeper understanding of the strengths and limitations of the baffle designs recommended under the self-assessable codes.

The OceanWatch project, *Performance monitoring and assessment of common rail field test components and baffle-type fish passage systems for culverts* forms part of the OceanWatch Culvert Research and Development Initiative and takes up the question of culvert fish passage through two elements:

a. The field trial of a common rail field test system, for installation into culverts and for testing different baffle configurations

b. Field trials to test and validate the baffle designs presented in the WWBW self-assessable codes.

The objectives of this project include:

1. Assessment of the prototype common rail field rig as a baffle testing tool, and its performance in situ
2. Assess the current WWBW baffle configurations
3. Comparison between variations on the WWBW baffle configurations
4. Identify opportunities to refine the current designs and their implementation and assessment methods
5. Produce a report outlining the findings of these studies.

These investigations will help continue the Culvert Research and Development Initiative and will build on the foundation work by DAF, to explore methods and tools for testing and validating culvert design criteria and in particular, to evaluate and verify the baffle designs recommended under the WWBWB self-assessable codes.

Common Rail Field Test System

The common rail field test system is a set of components that can be used to field trial culvert fishway baffle configurations rapidly. The system consists of a triple rail system that is affixed to the inside of a culvert barrel and to which baffles can be installed in various configurations. The design allows multiple configurations to be installed and removed rapidly using common brackets and baffles. Baffles are affixed in the desired setting to the rail using the incremental holes of the rail and can be placed at a variety of heights, angles and spacing's, providing a multitude of potential settings for experimentation.

Waterway Barrier Works

The WWBW legislation and self-assessable codes developed by Queensland DAF regulate the installation of culverts across waterways throughout the State, and their fish passage provisions. The configurations that must be installed vary depending on the risk rating of the waterway on which the barrier is to be installed. Throughout the state every waterway of concern to DAF has been rated on the level of risk to fish passage from the installation of a barrier. In general, smaller streams in the upper reaches of catchments have been attributed a lower risk rating than larger streams lower in the catchment. This is because the streams of the upper catchments are likely to have fewer fish species and the species present in these streams generally have a greater swimming ability than those of lower reaches. The waterways have been colour coded to represent the level of risk, and the statutory assessment that a barrier proposal such as construction or upgrade of a culvert would require. (see Table 1). Self-assessable codes have been developed for several types of minor barriers and these set out the construction and design criteria that will ensure appropriate fish passage for a given waterway. The self-assessable code for culverts includes different options for several design elements to provide flexibility for the implementation of the code. Of particular interest to the OceanWatch project is the culvert wall roughening element.

Table 1. Outline of assessment and key culvert construction requirements for each waterway type.

Attribute	Green Stream	Orange Stream	Red Stream	Purple/Grey Stream
Assessment Required	Self-Assessable	Self-Assessable	Self-Assessable	Development Approval
Culvert Floor	All cells at or below bed level	All cells 300mm below bed level or roughened to simulate natural bed	Option 1 - All 300mm below bed level, or: at bed level but roughened, or: Option 2 - 1 barrel 300m below bed others at bed but roughened	As approved by DAF, usually requires bridge
Culvert Width	Cell array > 1200mm or 100% main channel width	Cell array > 2400mm or 100% main channel width	Option 1 & 2 - minimum 75% main channel width, or: Low culverts - >3600mm or 100% main channel	As Approved by DAF, usually requires bridge
Culvert Invert	Minimum 300mm above bed	Minimum 300mm above bed	Option 1 & 2 - Minimum 600mm above bed Option 3 – Minimum 300mm above bed	As Approved by DAF, usually requires bridge
Deck Height	Any height	Any height	Option 1 & 2 – Any height but <750mm above culvert roof, or: Option 3 – <1200m above bed & no more than 300mm above culvert roof	As Approved by DAF, usually requires bridge

Culvert Wall Roughening	None	None	Option 1, 2 & 3 - Baffles (150mm)	As Approved by DAF, usually requires bridge

Culvert Roughening Techniques

The roughening of culverts for the provision of fish passage has been employed overseas for many years and is well developed in the USA for the provision of passage of salmon. However, in Australia the roughening of culverts is a relatively new phenomenon. Because the roughening of a culvert barrel inhibits the flow of water and reduces the hydraulic efficiency of the culvert, there has been a great reluctance within main roads departments and local councils to install roughening into culverts. Queensland is the only state in Australia that requires modification of new culverts in high risk waterways for the provision of fish passage. Through the WWBW codes, requirements for the installation of floor and wall roughening have been established and are being implemented throughout the State.

Roughening techniques generally focus on roughening with natural bed elements such as rocks or gravel on the floor of the culvert, or the installation of baffles on the floor or walls of the culvert. These two types of roughening elements both attempt to break up the laminar flow paths within the culverts to replace them, at least in a small section of the culvert, with slower flow zones that fish are able to negotiate (Figures 1 and 2).

Figure 1. Natural bed materials on the floor of a culvert provide roughening that assists in the movement of fish through the culvert.

Figure 2. Baffle configurations are many and varied, a. ¼ wall baffle (Vic), b. standard Qld wall baffle, c. wall baffle (Laos), d. full floor pipe baffle (USA), e. ¼ floor baffle (USA), f. centre raised baffle (USA), g. concrete herringbone floor baffle (Qld), h. full wall pipe baffle (USA), i. Full floor 'H' pipe baffle (USA), j. EL corner baffle (Qld), k. ¼ wall baffle (Qld), l. offset floor baffle (Qld).

While roughening the floor of the culvert with natural materials is relatively straightforward, the installation of baffles can take many forms and materials. In general culvert baffles consist of concrete, steel or plastic protrusions fixed to the wall or floor of pipe or box culverts either before or after construction (Figure 2).

In Australia roughening has mainly been placed on the walls of culverts due to the species of fish concerned and the reluctance of engineers to place baffles on the floors of culverts. In the USA, where floor baffles are common, fish passage is generally targeted towards large salmonid species on low to moderate flows and requires larger design elements. However, in Australia, provision of passage is more targeted to small and juvenile fish species, hence the option of providing passage in a narrow zone against the wall of the culvert.

The key construction requirements for culverts as outlined in Table 1 relevant to this project are the roughening elements on the walls of culverts found in red category streams. The principle of these roughening elements is to create a low velocity zone against the culvert wall, with velocities no greater than 0.3m/s extending for at least 100mm out from the wall. While the type of roughening elements is not restricted in the codes, if the elements are to be baffles they are required to conform to set dimensions.

Limited investigation of baffle configurations were undertaken by DAF prior to the development of the self-assessable codes. There were concerns about the placement of baffles on the culvert floor, due to the necessity for culverts to be self-cleaning in the Australian environment, so designs concentrated on simple culvert wall baffle configurations. These were considered the best compromise for provision of fish passage while maintaining the hydraulic capacity and self-scouring of the culverts.

At the conclusion of the DAF investigations, it was agreed that baffles with a maximum protrusion into the culverts of 150mm and having a maximum 10mm thick leading edge were most suitable (Figure 3). The baffle spacing within the culvert were at 4x the width of the culvert at the downstream end of the culvert barrel and 2x the width of the culvert close to the upstream end of the culvert., This change in spacing was to break up the drop of water flowing into the culvert barrel. This baffle treatment suits box culverts.

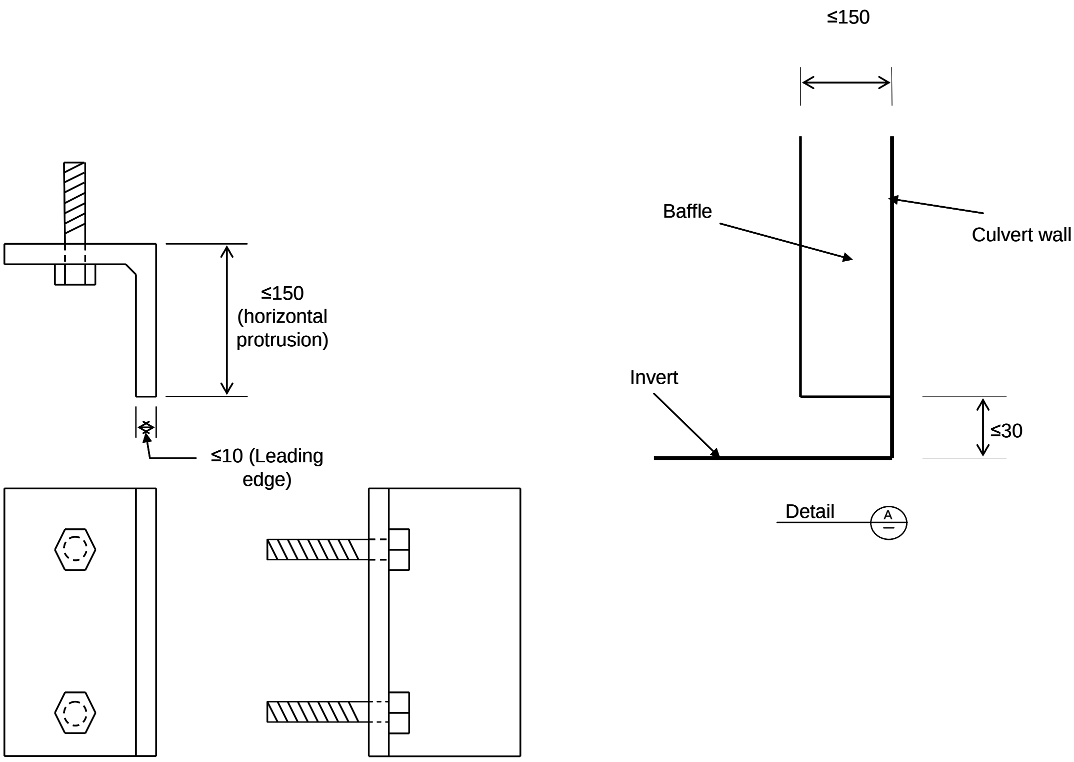

Figure 3. Detail and section of the culvert baffles as recommended by DAFF.

The wall baffle criteria stipulated in the DAF self-assessable code were developed in conjunction with the Queensland Department of Transport and Main Roads (DTMR) during a revision of the self-assessable code prompted by a massive road and culvert reconstruction program as a result of the flooding events in 2008-2010. In situ testing of the efficacy of these design criteria for assisting fish passage and comparison with alternative baffle configurations is one of the two key elements for investigation by the OceanWatch project.

2. Common Rail System

The culvert research initiative initiated by OceanWatch Australia has developed a semi-portable culvert baffle testing system, the common rail system, to allow the testing of a variety of baffle configurations. The rig consists of three steel angle rails that are fixed to the wall of a culvert and to which brackets and baffles are affixed (Figure 4). The brackets control the angle of the baffles, with four different bracket types made for the experiments. This allows for different configurations to be tested by the single set of rails and baffles. These configurations are (Figure 4):

1. Baffle at 90º to wall and angled 30º from the vertical.
2. Baffle at 60º to wall and angled 30º from the vertical.
3. Baffle at 90º to wall and vertical.
4. Baffle at 60º to wall and vertical.

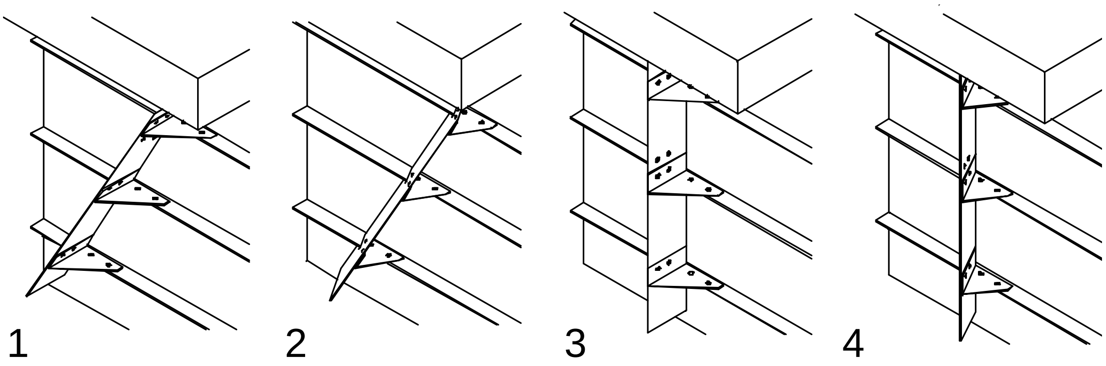

Figure 4. Layout for common rail culvert baffle testing system.

In practice the alignment of the number 2 configuration (60º from wall, 30º from vertical) was problematic and difficult to manufacture into the common system. So this configuration was excluded from the testing

Methods

The current investigation assessed the application of the common rail system in testing baffle configurations. For this, the system was set up in a test culvert located on Denman Creek 10km northwest of Mackay during wet season flows. This culvert consisted of four, 1.8m wide by 1.8m high barrels that spanned the double lane road with a total length of approximately 8m. This established the ease of assembly and then tested to observe the effects of the water flow and how this may influence the movement of fish.

Results

In general, the system did fit together as designed and was well engineered, however the system displayed a number of deficiencies that made it unsuitable in its current form for use as a testing system. These issues could be broken down into three areas: gaps and holes, system robustness and alignment of the system.

Figure 5. Common Rail system installed in demonstration culvert

Gaps and Holes

To ensure the system fits together in all of the configurations it is necessary to have a large number of holes and slots within each of the baffles to provide for the different configurations. The effect of this is that each of the baffles allows large quantities of flow around the baffle in ways not encountered in standard installations. The most troubling of these is the flow between each of the baffles and the wall, generated by the baffles sitting off the bracketing system (Figure 6). This flow along the wall has a significant impact on the ability of the baffle to provide a low flow velocity zone against the wall, with water jetting around the baffle and creating higher flow against the wall. This particularly affects smaller fish that use the wall zone as a resting area. Creating deeper profiled slots for the rail to fit into would allow the baffles to sit flush against the wall and prevent the movement of water around the baffle.

The other issue with the baffles is the large number of holes in each baffle (Figure 5 and 6). These holes are there to accommodate bolts and brackets for each possible configuration. However, the holes and slots that are not being used in a particular setup let water through the baffles. The largest unintended flow results from the extra slots in the baffles cut to accommodate the baffles in a sloping configuration. All of these extra flows create different hydraulic conditions behind the baffle from that of a standard baffle installation. This could be addressed by having plugs that fill each of the vacant holes in the baffle, or by providing baffles for each configuration that only have the relevant holes in them for that configuration.

Figure 6. Gap between the wall and baffles in the vertical configuration, with extra holes and slots also visible.

System Robustness

The engineering that was applied to the test system was extensive and thorough, with the system being made from components that will survive all conditions that could be expected to occur within a culvert during high flows. However, it is unlikely that baffle assessments would be carried out under all flow conditions, as the trapping of fish becomes very difficult and the safety of staff may be compromised at high flows.

The components of the test system are made from heavy gauge steel, with even the smallest pieces quite heavy and strong. Unfortunately, this means that installing the test rig into a culvert system is a laborious process, requiring the movement of very heavy components into the bottom of a culvert. While initial installation can be achieved, any adjustment of the system is time consuming and difficult due to the large number of nuts and bolts and the alignment process. An equally robust system could be achieved with far fewer nuts and bolts and lighter materials than is currently used.

As such, future test rails could be made more workable by using fewer fixing points and lighter grade materials (such as aluminium or plastic). As the system is a temporary testing rig, it does not need to be engineered to withstand all the flows that would occur in a culvert system, and using lighter, more easily worked materials will make it a more flexible test system.

Alignment of system

Due to the level of engineering that has been applied to the system, to achieve each of the design configurations requires the alignment of 12 holes for each baffle to be affixed to the common rail. Unfortunately aligning these holes in the horizontal and vertical plane was problematic, as many of the holes had not been drilled in the correct position. It was common for several holes to not align when used in the vertical arrangement, with even more misalignments in the sloping arrangements. Omitting a number of bolts to the brackets reduces the structural strength of the system, defeating the purpose of constructing the system from such robust materials. However it did not particularly affect the operation of the baffles.

The alignment of the baffles into their set configuration was also challenging as, depending on the alignment of holes, the baffles often could not be placed at their correct spacing, requiring the redrilling of extra holes into the system.

The sloping baffle arrangement was the most problematic, as the alignment of the slots in the baffles with the vertical and horizontal bolt holes was difficult to achieve. In this arrangement, many of the bolts could not be placed properly and the baffles were often held by only two bolts (Figure 7).

Figure 7. Due to slot non-alignment, the sloping baffles were difficult to line up and often only two bolts could be fixed in place.

Having a system that relied less on a series of bolt holes would be beneficial, this could be achieved by having a clamp system attached to each baffle that could be clamped anywhere along the rail, allowing the correct spacing to be easily maintained.

Overcoming these deficiencies of the common rail system should be achievable and would make the system more functional for experimentation.

Alternative Test Baffle System

The issues encountered with the prototype common rail system meant that it did not support the second element of investigation (namely verification of the WWBW baffle criteria). An alternative system was therefore developed that was more test-friendly, fitted into the portable fishway flume and was able to be rapidly reconfigured for changing experimental situations.

This system consisted of fitting a false wall made of concrete fibreboard into the experimental channel (to mimic a concrete culvert) and then affixing plastic baffles to the wall with angle brackets and tech screws (Figure 8). This system was very lightweight and flexible, allowing the baffles to be placed in any orientation required.

Figure 8. Lightweight baffle system affixed to a concrete fibreboard false wall within the experimental fishway flume.

The alternative system had the flexibility to change the baffle arrangement as required by the experimental design, quickly and easily, reducing between-replicate downtime. Baffles were also solid with no gaps or holes that affected the experiments, using a different baffle set for each configuration. The plastic baffles were stiff enough to withstand the velocities required to be tested, with very little deflection. The baffles could also be lowered to determine if under-baffle flows affected fish.

The alternative system was suitable to test velocities up to 1.0m per second in the experimental flume. As such the lightweight wall and plastic baffle system was a good match for the experimental flume under controlled flow conditions, while in a real world culvert experiment expected to be subject to high flows, the common rail system would be more enduring.

3. WWBW Baffle Assessment

The second assessment element of the current project is the testing of the self-assessable code WWBW baffle configuration and comparison with other baffle configurations. The common rail system was designed to test the current configuration, 150mm baffles 90º to wall and vertical, against two alternative designs, 150mm wide baffles 60º to wall and vertical and 150mm wide baffles 90º to wall and angled 30º from the vertical. These configurations were therefore replicated in the experimental culvert using the alternative test baffle system. A control configuration that had no baffles installed was also tested for comparison.

Methods

Flume Configuration

The experimental culvert flume sampling was conducted in the lower reaches of the O'Connell River, where flows were available and a good supply of migrating fish could be expected. The experimental flume was placed into the river channel and supplied with water from the river flow.

The experimental flume was placed to one side of a flat run and the stream channel was then sculpted around the flume to supply the flume with water (Figure 9). The configuration directed the majority of flow through the culvert channel (depending on the experimental replicate), with the rest of the flow diverted past the flume via the flow control gate. This gate could be opened and closed to regulate the flow, and hence velocities, down the flume. In this way it was possible to create flow velocities in the flume from near zero to 1m/s.

Fish that were moving upstream through the river were guided towards the flume by means of a guidance fence (Figure 9) made from fine mesh netting (shade cloth) that allowed water through but was capable of stopping fish as small as 15mm passing through upstream. Fish were allowed to pass through the entrance of the flume upstream and out through the flume exit unimpeded.

Underwater Video recording

Underwater video recording and visual observation was used to count fish that used the flume, as this data collection method does not affect the flows within the flume, or the behaviour of the fish. The location of sampling in the O'Connell River was chosen as the water within the river was relatively clean and clear, allowing visual methods to be used successfully. A GoPro Hero 3+ underwater video camera placed at the exit of the flume visualised all fish exiting the flume, while the camera operator observed from above all fish entering the flume. The video was positioned to allow observation of the full width of the exit of the flume, as well as several baffles down the flume, allowing some observations of the behaviour of various fish around the baffles in the flume as they passed upstream. An estimate was made of the length of each of the fish that passed through the flume and exited past the video observation position. This was based on a size gauge in the videos view on the side of the flume past which fish must swim. A sub-sample of fish were captured by netting outside of the experiments to provide a physically measured comparison to the video monitoring to ensure the estimated lengths were accurate. Video from each replicate was analysed post sampling to determine the species, number and size of fish that used the flume during the replicate. Staff observed all experiments and provided backup to the video monitoring. Observations of fish that were unsuccessful at passing through the flume were made by staff while monitoring the flume experiment. All fish that entered the culvert were noted by staff, with those unsuccessful in ascending recorded by staff and those successful recorded by video.

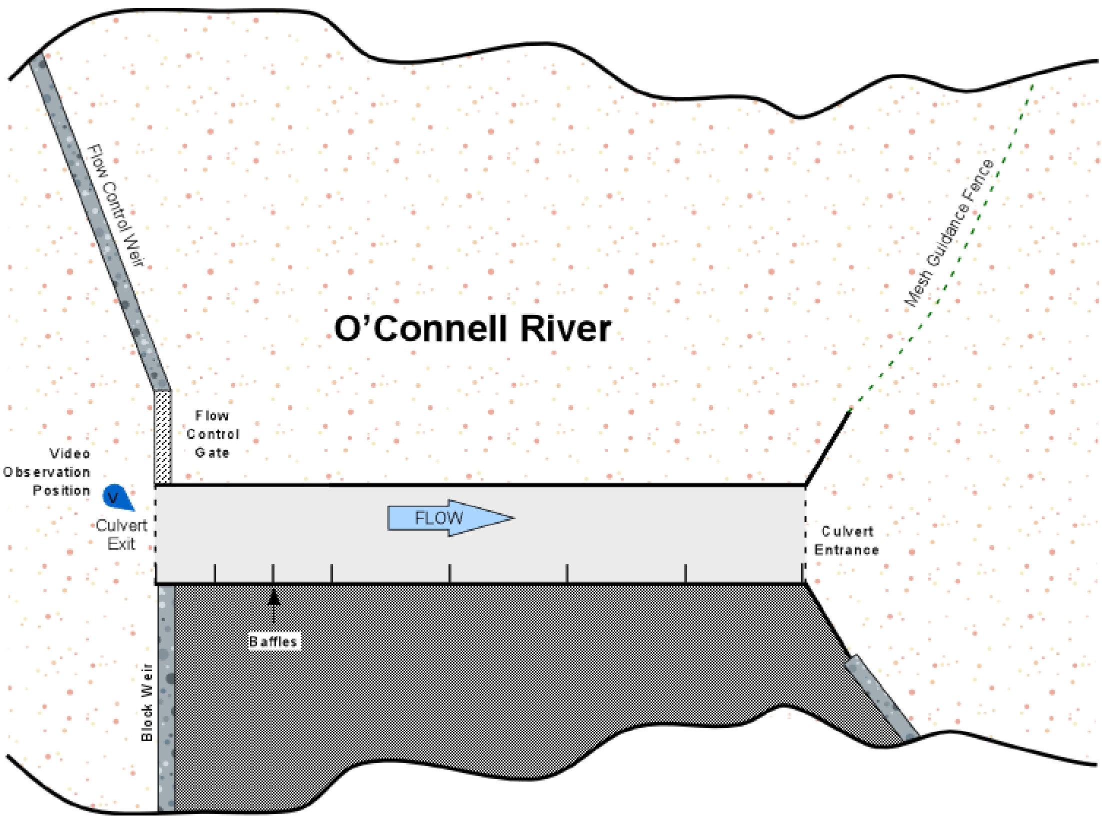

Figure 9. Layout of experimental culvert test rig showing guidance fence, flow control gate and video observation position.

Experimental Design

To test the four baffle configurations, a multi replicate random block sampling design was used. This system randomised the velocity and baffle configuration used in each experiment. The four baffle configurations tested during the sampling were:

1. No baffles, natural culvert
2. 150mm baffles, 90º to wall, 60º from floor, at standard spacing
3. 150mm baffles, 90º to wall and 90º from floor, at standard spacing
4. 150mm baffles, 60º from wall and 90º from floor, at standard spacing

The complexity of manipulating velocity within the experimental flume dictated that once a velocity was set for each replicate, that the full set of baffle configurations needed to be tested at that velocity before reconfiguration to a new velocity (Table 2). This compromised the randomness of sampling slightly.

Once each experiment was set up, the rig was allowed to settle as movement around and within the flume stirred up sediment. Movement around the flume was minimised to create as little disturbance as possible, however some disturbance was required in the process to swapping out baffles and retrieving and setting video. Movement at the downstream end of the flume was kept to a minimum at all time to avoid disturbing fish approaching the flume.

Once the water clarity had settled, the experiment was then started and recording of fish that exited the flume was conducted for one hour. After the one hour of recording was completed, the video was reset, the baffle configuration changed and the test rig was again allowed to settle before commencing the next experiment.

Each replicate block took two days to complete and the sampling of three complete replicates was completed over a non-contiguous six-day period.

Table 2. Random block sampling design used in testing the experimental flume.

Replicate 1		Replicate 2		Replicate 3	
Velocity	Exp No.	Velocity	Exp No.	Velocity	Exp No.
0.5m/s	2	1m/s	4	0.5m/s	2
	4		1		4
	1		2		1
	3		3		3
0.75m/s	3	0.5m/s	4	0.75m/s	2
	4		1		1
	1		2		4
	2		3		3
1.0m/s	4	0.75m/s	4	1.0m/s	4
	3		1		2
	1		2		3
	2		3		1

Results

A total of 2454 individuals of 10 species were recorded during the flume sampling. Empire gudgeons (*H. compressa*) dominated the catches, accounting for 2307 individuals (84%). Only eastern rainbowfish (*M. splendida*), Pacific blue-eye (*P. signifier*) and fly-specked hardyhead (*C. stercusmuscarum*) were captured in any great number, accounting for a further 139 individuals. All other species were only recorded in very low numbers.

A variation in the number of fish was observed associated with the three different flows of the individual experiments. The greatest numbers of fish from all baffle and non-baffle treatments were encountered during 0.75m/s flows, with 1589 individuals, while

0.5m/s flows were markedly lower in fish numbers, with 788 individuals. Flows of 1.0m/s were lower again, with 321 individuals and had the least number of fish from all experiments. There was no significant association of fish numbers with baffle treatments throughout all the experiments.

The installation of baffles of all kinds into the flume resulted in higher success rates for fish successfully passing through the flume and past the video station versus those that failed to pass. In general, 30-40% more fish were successful at passing through the flume when baffles were installed as compared to the flume with no baffles. With no baffles in the flume, 64%, 78% and 65% of fish were successful at passing through the flume at 0.5m/s, 0.75m/s and 1.0m/s respectively (Figure 10).

Table 3. Average number of fish encountered from each of the experimental treatments showing fish the successfully ascended the flume (Success) and those that were unsuccessful (Unsuccess).

Velocity	0.5m/s		0.75m/s		1.0m/s	
Treatment	Success	Unsuccess	Success	Unsuccess	Success	Unsuccess
No Baffles	49	28	123	35	18	9
90° Wall 60° Floor	53	1	115	5	30	0
90° Wall 90° Floor	89	0	165	1	20	0
60° Wall 90° Floor	40	1	87	0	28	2

While baffles at 90º to wall, 60º from floor had 99%, 96%, 100% of fish successfully passing through the flume at 0.5m/s, 0.75m/s and 1.0m/s respectively. Baffles set at 90º to wall and 90º from floor had 100%, 99%, 100% of fish successfully passing through the flume at 0.5m/s, 0.75m/s and 1.0m/s respectively. Baffles set at 60º from wall and 90º from floor had 98%, 100%, 93% of fish successfully passing through the flume at 0.5m/s, 0.75m/s and 1.0m/s respectively.

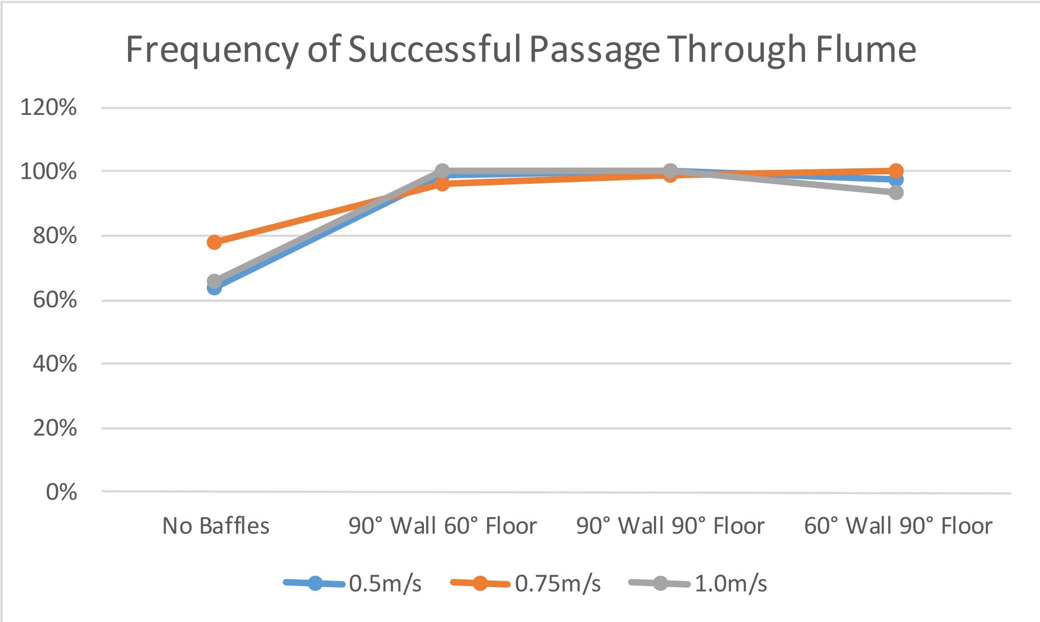

Figure 10. Frequency of successful passage through the experimental flume for all treatment types at all velocities.

4. Discussion

Common Rail System

The common rail system for the testing of baffles on the side walls of culverts was a system that, with some modification, could be used to test baffle configurations within culverts. Unfortunately, in its current configuration, the common rail system had a number of issues that affected the passage of fish through the system. Most concerning of these were the gaps and holes created by the tolerances and multi-configuration nature of the system. The gaps against the wall allowed large volumes of water to pass between the wall and the baffle, which interfered with the water flow patterns behind the baffles and created conditions unsuitable for small fish. The multi-configuration nature of the system also led to some alignment issues that defeated the purpose of the high engineering levels.

The fix for these problems is relatively simple, by creating a set of baffles for each configuration and sculpting those baffles to better fit the rails and to fit tighter against the wall. In this way, the testing rig would better duplicate the way baffles are currently installed within a culvert barrel and would eliminate the gaps and holes and allow

In addition, the whole rig could be built from different (lighter), equally robust materials to make the system easier to transport and move from place to place. The current system lends itself to being installed in one set of culverts and left in place to test many different configurations. However this leaves the rig, as an experimental tool, vulnerable to the vagaries of flow within a natural channel. The ability to move the system easily from site to site, would give the flexibility to pursue flows within a system. This would increase the usefulness of the common rail system as it could test multiple configurations in different locations and at different flows as chosen by the timing of the experiment rather than subject to flow conditions at a single site.

Experimental Flume Performance

The project was undertaken in north Queensland due to the availability of the portable experimental flume and drought conditions in southern Queensland at the time. In general, the experimental flume performed as expected and was easily set up. However, a number of issues prevented the experiments being performed to their fullest potential.

Lack of Flows and Fish

Unfortunately, after the project was initiated, north Queensland also entered an extended dry spell, with little flow during the 2014/15 wet season. This delayed testing and meant that sampling had to be conducted without the usual flood cues that trigger fish migrations within the local systems. As a result, the numbers of species and individuals that were encountered during the sampling period were well below what would normally be expected during this time. Undertaking further sampling during a more normal wet season would supply a greater variety of fish species and size classes available to for testing by the experimental set up.

Due to the lack of flows and the reduced number of migrating species, results from this project generally reflect the swimming ability of 20-40mm empire gudgeons. While this species is a staple of fishway sampling projects and a good indicator species for swimming ability trials, testing on a broader range of species would be preferable. Also testing on a smaller size range of empire gudgeons (10-20mm) would be useful, as it is at this size that the species is generally inhibited the most by instream barriers.

Conducting further studies in other systems and during normal “wet” periods would be a useful extension of the project.

Fish Data Collection

The large volumes of water that are passed through a culvert during flows is problematic from the perspective of the trapping and collection of fish. The aim of experimentation is to test the swimming ability of the fish affected by a culvert at relatively high velocities. As experimentation also targets the small fish who are most affected by culverts, traps are required to have relatively fine mesh to be able to catch them. In natural systems this fine mesh quickly becomes clogged, as even in clear water streams, the flow carries a great deal of debris and algae. Once the traps become clogged with debris they then inhibit the flow through the culvert and result in a reduction in velocities through the culvert over the course of the experiment. This makes the experiment invalid as velocities have changed over the course of the experiment. Another issue is the trapping of fish at the downstream entrance to the experiment to gather comparative data on successful/unsuccessful fish passage. Traps in the downstream entrance location are hard to place as the velocities are high and the trap can interfere with fish moving into the culvert. The use of entrance traps is problematic and this limits the experimental designs available to test the success or otherwise of fish passage through a culvert.

To counter this, sampling in this project used a combination of visual observation and video monitoring to record fish as they moved through the culvert. This method did not impact the flow through the culverts, allowing a set velocity to be maintained throughout the time period of the experiment. The visual observation/video provided an accurate record of the species that passed through the experimental flume, however, it also had a number of issues that should be noted. Measurement of fish lengths from the video sampling was only approximate, based on measurement against the gauge on the side of the flume and comparison to a sub-sample of fish that were collected at the same time and physically measured. This method reduces the accuracy of the size measurement of fish, but significantly decreases the influence the traps have on velocity and fish trapping. Also, video monitoring can only be conducted in clear water streams, which limits the application of this methodology.

Implementing a method that traps and measures all fish at the top and bottom of the flume, without affecting velocities, is unlikely to be cheaply resolved. The use of hydro acoustic methods may be the best way to ‘trap’ and measure fish entering and exiting the experimental culvert, as they can perform accurate measurements in turbid water without affecting flow. While hydro-acoustic sampling requires investment in specialist equipment, this should be considered for future experiments in order to optimise and improve results.

Baffle Performance

The results from the testing of different baffle configurations demonstrates a clear benefit from the inclusion of baffles in a culvert, with up to a 40% increase in the number of fish that were successful at passing through the baffled experimental flume. This was apparent for all velocities tested, up to 1.0m/s. These results imply that the placements of baffles of any configuration on the wall will improve passage over an un-baffled culvert barrel.

In contrast, the performance of the different baffle configurations was similar, with all baffle configurations passing nearly all the fish that attempted to move through the experimental flume. However, there was some indication that at the highest velocity, the 30^{o} vertically sloped baffle gave a noticeable reduction in successful fish passage. It appears that because the sloping baffles had their base further downstream into the culvert barrel (Figure 11), they did not break up the initial 'fall' of water into the culvert barrel as effectively as the vertical baffles. The vertical baffles create small resting zones through this transition zone while the sloping baffles do not influence the headloss area and fish are required to traverse this zone without any assistance. The placement of partial height baffles through this zone could resolve this or just using the WWBW recommended vertical baffles would also address the issue.

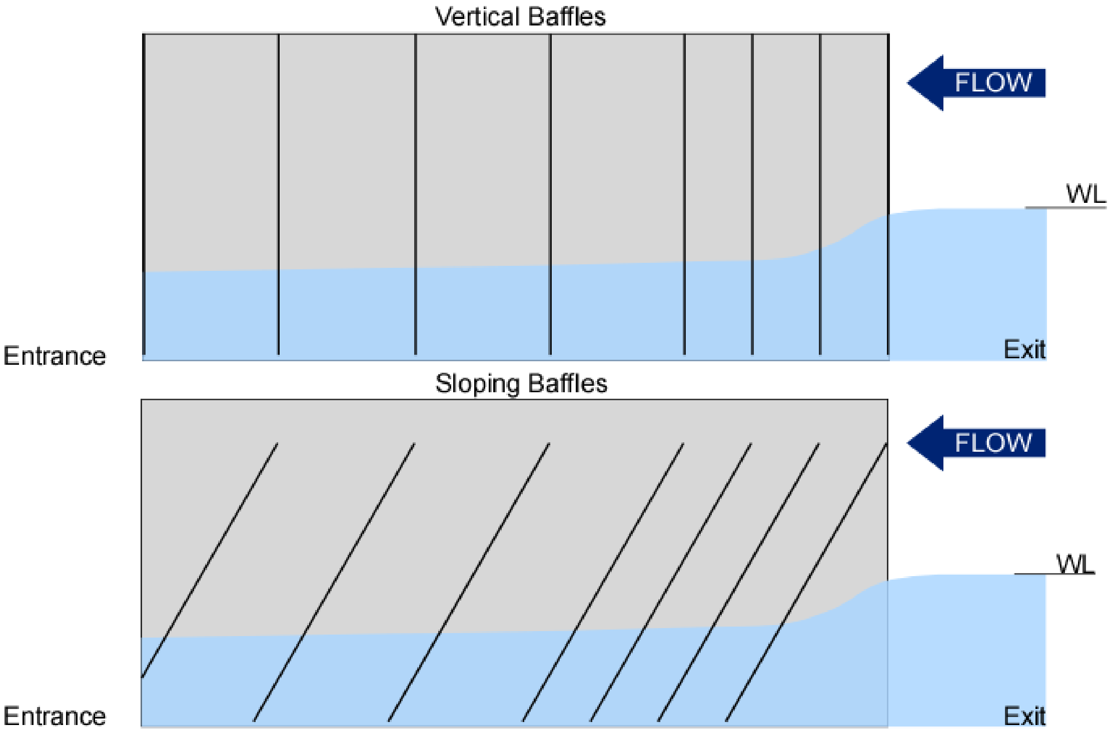

Figure 11. Culvert inlet with vertical (top) and sloping baffles (bottom). Note how the WWBW recommended vertical baffles interact with the water 'fall' into the culverts more than sloping baffles.

The sampling successfully demonstrated that the inclusion of baffles on the walls of the experimental flume had a positive impact on the passage of fish through the culvert. Given the shorter length of the flume (4m) to that of a typical culvert (12m), it could be expected that the inclusion of baffles in real world culverts would have an increasing impact and benefit in longer structures.

Future Research

The success of including baffles for fish passage, demonstrated by this sampling however does not resolve all issues associated with baffles in culverts. There are a number of areas of research that were beyond the scope of this project that should be undertaken to further refine how baffles are used in culverts in Australia.

High Velocities

Due to the experimental setup with the portable flume, the maximum velocity that could be tested was 1.0m/s. At this velocity, a number of larger fish were able to successfully pass through the flume, with and without baffles. Sampling during high flows of 100 sites around Mackay, North Queensland, recorded that over 20% of the culverts reached velocities higher than 1.0m/s. As 1.0m/s is commonly exceeded in installed culverts and some fish are known to successfully pass through at this velocity, it is suggested that further sampling be conducted in situ at locations where these higher velocities are available, using the (modified) common rail system . This information will measure the success of baffles in culverts at higher velocity regimes than could be tested in the experimental flume.

Culvert Length

The length of the experimental culvert (4m) was much shorter than a typical road culvert installation (12m) due to the nature and portability of the experimental flume. While the fish species and size classes encountered by this study were generally able to negotiate the experimental flume, there are still question marks over the ability of these fish to pass through a culvert stretching across a standard two-lane road width or further.

The majority of fish traverse through a culvert in a single burst, utilising their fast twitch muscles to swim against the velocity in a single movement. However, the longer the distance that fish are required to traverse, the more likely they are to become fatigued. Once fatigued, fish drop back downstream to rest, before attempting to traverse the culvert again. This problem is particularly apparent for smaller fish species and life stages and at high flows.

To establish the threshold for fatigue distance would require a much longer experimental facility than the flume used in this project. Ideally this setup would be more than 20m long, could produce various high velocities up to 3.0m/s and have the ability to monitor the maximum upstream penetration of individuals before they fatigue (by multiple video points for example). Further investigations should also be undertaken to establish the maximum un-baffled and baffled distances a variety of species and size classes can negotiate, in order to define design criteria based on culvert length.

Baffle Width

Previous experiments conducted by DAF to determine baffle sizing for the WWBW self-assessable codes have shown that the wider a baffle is the more turbulence is created behind the baffle. This turbulence disorientates fish that are attempting to move through the culvert. During these experiments, 300mm baffles created larger reverse circulations that led to fish orienting themselves in a downstream direction while behind the baffle (Figure 12). Once these fish attempted to pass around the baffle they were rapidly swept downstream as they were orientated perpendicular to the flow and their bodies caught the full force of the flow. While the circulation patterns behind the baffle appeared suitable for fish, they actually hindered upstream passage.

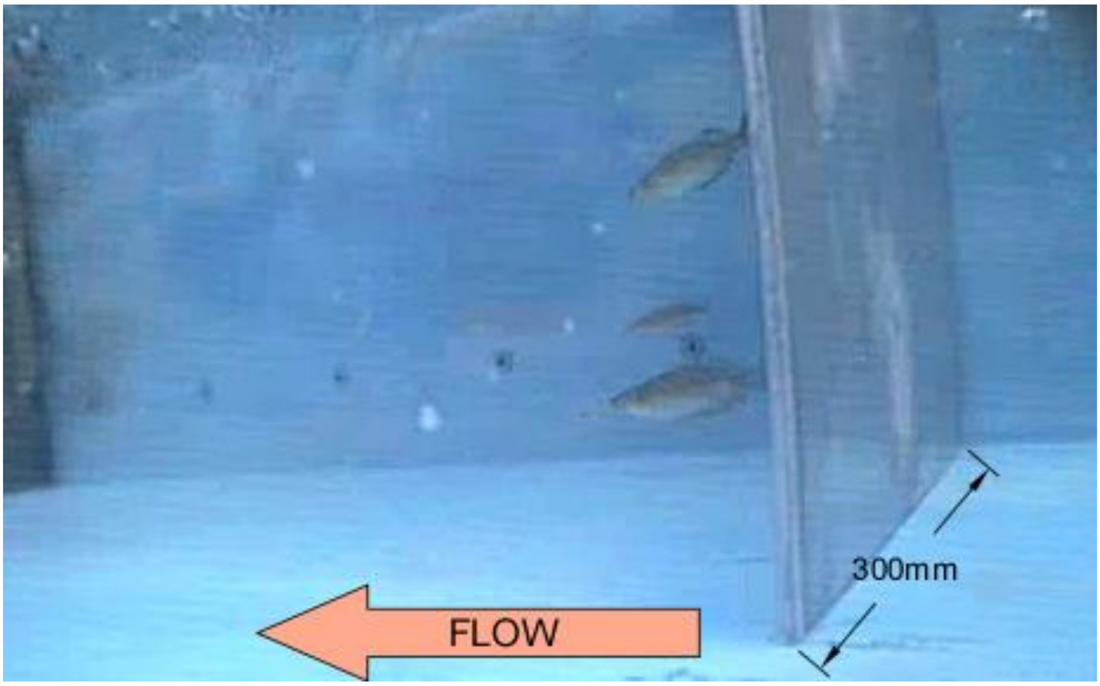

Figure 12. Fish in a 300mm wide baffle experiment orientating themselves downstream behind the baffle.

These observations led to the current WWBW recommended 150mm baffle width. At this width the circulations that occur behind the baffle are reduced and fish continually orientate themselves in an upstream direction and easily pass around the next baffle. What was noted during this experimentation is that most larger fish (>40mm) only used the outer edge of the turbulence field to pass all the baffles in a single traverse, while smaller fish (<20mm) tended to cling close to the wall behind each of the baffles to rest before moving past the next baffle. As only the very small fish are utilising the low velocity zones behind the baffles, there is some potential to further reduce the recommended width of the baffles used in the culverts. Reducing the baffle width down to 50mm-100mm may have no impact on the passage of larger or smaller fish, but could provide better culvert performance through reduced debris accumulation and a greater volume of flow through the culverts. Further investigations into the efficacy of narrower baffles (less than the WWBW recommended 150mm) in culverts should be undertaken to determine the optimum baffle width.

Baffle Type

While the standard steel angle baffle has been demonstrated to be effective at providing fish passage, investigations of alternative baffle types may be useful to develop configurations that can be precast into standard box culverts. This would reduce the requirement for baffles to be bolted to the walls of culverts, where they are vulnerable to being detached during high flows or through the impact of debris. Bolt-on baffles are unlikely to have the same lifespan as that of the box culverts, increasing the maintenance costs of culverts.

Depending on the outcome of investigations into smaller baffle widths, a baffle design that creates a saw-tooth effect on the wall of the box culvert may be feasible (Figure 13). This design should be relatively easy to create in a concrete mould and would alleviate many of the issues of concern with retrofitted steel baffles. Further investigation of alternative wall roughening designs that can provide adequate fish passage at a variety of flow velocities is warranted.

Figure 13. Saw-tooth concrete casting (on a retaining wall) that may be suitable for providing wall roughness in a box culvert.

Gaps Under Baffle

The current Queensland WWBW culvert baffle configuration allows for up to 30mm gap between the base of each baffle and the culvert invert. This was promoted by stakeholders in response to concerns of sediment accumulation within the culvert barrels. In theory sand and gravel is able to pass under the baffles, keeping the floor of the culvert clear, reducing the requirement for culvert floors to be cleared manually during maintenance.

However, it was noted during the current flume experiment that the gaps under the baffles created high velocity jets, which negatively affected small fish sheltering behind the baffles by preventing them resting as they do behind sealed baffles. In order to reduce the impact that these gaps have on small fish, investigations should be undertaken to confirm the role of these gaps in culvert hydraulics and self-cleaning. If it were demonstrated that the gaps had little impact on sediment accumulation or culvert discharge volumes, then in terms of small fish passage, it would be advantageous to remove the gaps and extend baffles all the way to the culvert invert.

5. Conclusions

The *Performance monitoring and assessment of common rail field test components and baffle-type fish passage systems for culverts* project successfully tested the common rail culvert baffle test system and the Queensland WWBW baffle configurations.

The common rail culvert baffle test system is a well-engineered test system that could be successfully used to test baffle configurations with some minor modifications. The system would be best suited to permanent installation in a culvert located close to the mouth of a coastal creek system, where there is a good supply of water and abundant migratory small and juvenile fish species. In this location the system would be able to the perform as designed and with the new baffle designs produce results at a greater level than the portable flume system

The baffle designs as recommended by the Queensland WWBW codes were also demonstrated to successfully pass fish and compared equally with or better than various other baffle configurations. All baffle systems were demonstrated to be superior for providing fish passage to a culvert without baffles.

These investigations also highlighted a number of areas for further research that could further refine the design of culvert baffles and optimise their performance for fish passage. These include:

1. Testing baffle configurations at higher velocities to validate their success at these velocities.
2. Investigating further the maximum culvert length that various fish species and life stages are able to negotiate.
3. Investigate the minimum baffle width that successfully can provide adequate fish passage.
4. Research other baffle types that may be cast into a culvert barrel to reduce construction and maintenance costs.
5. Determine if the gap under the baffles as prescribed by the WWBW codes actually benefits culvert sediment removal and hydraulics, given its deleterious impact on fish passage.

To help to drive forward the recommended research areas described in this report, consideration should be given to reinvigoration of the OceanWatch Culvert Research and Development Initiative. This initiative would be best placed to determine the direction of future research based on this initial scoping study of culvert baffle configurations.

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