A COMPARISON OF AUSTRALIAN AND AMERICAN FISH PASSAGE DESIGN UNDER CHANGING REGULATORY REQUIREMENTS

Jon Williams[1]
Mark Wharry[2]
Lesa Delaere[3]
Leila Macadam[4]

ABSTRACT

Fish passage regulatory requirements continue to change for two reasons. The first is the ever-improving understanding of fishway biology and the definition of corresponding ecological criteria for riverine health. The second is the expanding population of stakeholders involved in the regulation and operation of dams and water resources. Case studies in Queensland, in the Australian tropic, and the Pacific Northwest of the USA are used to demonstrate how fishway designs are adapting to this regulatory change. On the Burrum River in subtropical Queensland, an old weir is to be retrofitted with a nature-like bypass fishway incorporating both an engineered low flow passage and a high flow passage for flood conditions. The Grain Camp Dam, an existing dam on the Donner und Blitzen River in USA, involved the design and construction of a twenty pool pool-and-weir ladder with provision for a new fish trap facility to allow for management of non-native species. In both countries, ecological and biological criteria are incorporated through identification of corresponding hydraulic design conditions. These are highly prescriptive at a regulatory level in the USA, but poorly defined at a national level in Australia. Fish species in the USA, such as salmonids, tend to be strong swimmers and move in a seasonal pattern. In contrast, Australia's fish, while regionally varied, are largely poor swimmers and move on flow cues. This has necessitated intensive and innovative Australian fishway design approaches. Both countries can learn from the methods of the other to best meet their own changing regulatory requirements.

INTRODUCTION

The design of fish passage infrastructure such as fishways and fish screens on dams and weirs experiences ongoing challenges in meeting the changing demands of regulatory requirements. These changes occur mainly in response to the ever-improving understanding of ecological systems and criteria required to maintain associated riverine health. This study compares two case studies to demonstrate similarities and differences in approaches to meeting these changing regulatory requirements and ensuring state-of-the-art fish passage. One is the retrofitting of a weir with a nature-like bypass fishway on the Burrum River in subtropical Queensland, Australia; the other is the retrofitting of a

[1] Manager – Dams Queensland, GHD Pty Ltd, 145 Ann Street, Brisbane QLD, Australia, jon.williams@ghd.com
[2] Regional Office Manager , GHD Pty Ltd, 15575 SW Sequoia Parkway, Suite 140, Portland OR, USA, mark.wharry@ghd.com
[3] Senior Dams Engineer, GHD Pty Ltd, 145 Ann Street, Brisbane QLD, Australia, lesa.delaere@ghd.com
[4] Civil Engineer[4], GHD Pty Ltd, 145 Ann Street, Brisbane QLD, Australia, leila.macadam@ghd.com

pool-and-weir fish ladder and associated fish screening at Grain Camp Dam on the Donn, er und Blitzen River in the Pacific Northwest of the USA.

Fish passage design criteria were originally developed in North America for migratory returning adult salmonids, principally anadromous salmon and steelhead populations that return to spawn in fresh water rivers and streams on a regular seasonal basis. In Australia, recent fish passage studies have demonstrated the inability of the majority of native species to utilize these salmonid-style fishways. This has created an imperative for new fishway designs to demonstrate operation for native species, encompassing a wide variety of species of differing sizes and swimming abilities (Mallen-Cooper and Brand 2007, Fairfull and Witheridge 2003). In the USA, regulatory changes are now recognizing the need to cater for the full aquatic life cycle. As in Australia, the resulting design challenge is to accommodate a range of fish sizes and swimming abilities from juvenile to adult. To achieve this, ecological knowledge and provision for environmental factors must be translated to engineering design criteria through an understanding of fish species abundance and biology and flow dynamics and hydraulics (Fairfull and Witheridge 2003). Practicalities such as weir stability, access, power, cost, operation and maintenance must also be primary considerations in order to produce a successful fish passage structure (Delaere et al. 2011, Fairfull and Witheridge 2003).

Both the USA and Australia have strongly developed and regulated waterways that form core economic resources. As a result there are increasing numbers of stakeholders at play creating often-conflicting operational flow requirements. These play a strong role in determining the hydraulic conditions under which passage for varying fish species, sizes and life stages must occur. Watershed behavior in the Pacific Northwest of the United States is generally predictable. Annual flow patterns vary from year to year, but generally the cycle is tied to typical snow melt runoff cycles. On the West Coast of the USA, resource management is characterized by construction of impoundment structures (large and small) that are operated by competing functions including irrigation and municipal water diversions, water storage, flood protection, power generation, navigation and recreation. In contrast, Australia is the driest inhabited continent on Earth with rainfall that is highly seasonal and variable from year to year. Droughts are frequently experienced but when wet periods occur they are considerable. The hydrology of Australian waterways reflects this climate with the majority of systems being either ephemeral or alternating between periods of low or no flow, and high flow. Australian dam operation is generally characterized by this propensity to drought or flood, resulting in a premium on water storage for supply and sale. Government management policy has a focus on storage and strict release efficiency to mitigate potential droughts and maintain constant supply to the extent possible with carefully defined and monitored release requirements. This often conflicts with environmental stakeholders that require minimum release requirements according to seasonally-defined schedules.

In both countries, potential fish barriers like these water impoundment structures are covered by legislation with a strong focus on water resource conservation and storage. This results in a requirement for fish passage in varying operational flows depending on the conservation or utilization of the water resource at a given time. The last 60 years in the USA have resulted in increasingly formalized fish passage requirements that are highly prescriptive as to the range of operational flows and the hydraulic requirements of new infrastructure. Currently, varying flows are incorporated into Australian fishway designs as a necessity to demonstrate efficient fish passage but are not specifically legislated. Both requirements have evolved due to the incorporation of additional technical and biological requirements and the ever-increasing involvement of an expanding population of stakeholders.

CHANGING ENVIRONMENTAL REGULATORY REQUIREMENTS

Fish ladders have been part of water resource policy in the USA for over a century. These early requirements were incorporated into much (although not all) of the original dam construction in the Colombia Basin, where the American case study is located. At a federal level, the *Rivers and Harbors Appropriation Act 1899* was the original authority providing jurisdiction to the U.S. Army Corps of Engineers and covering the construction of structures in waterways and navigable waters. The importance of wildlife resources to the nation was first recognized in 1934 with the *Fish and Wildlife Coordination Act* (FWCA). This required federal agencies to give equal consideration to fish and wildlife conservation when implementing water resource projects. The value of environmental resources was subsequently reaffirmed by the *Clean Water Act 1948* establishing that potential barrier installation should not impact fish species composition, demographics or habitat where aquatic life is present. The *National Environmental Policy Act 1969* established the requirement that Federal decisions be informed as to the environmental consequences of any proposed impact to fish habitat, while the *Endangered Species Act 1973* provides a means to conserve the habitat on which listed species depend.

More recently in the USA, the *Sustainable Fisheries Act 1996* (also known as the *Magnuson-Stevens Fishery Conservation and Management Act*) primarily directs States to work together to develop fishery management plans using an ecosystem approach. The plans must identify Essential Fish Habitat (EFH) for all life stages of the target species. In addition to this federal regulation, there are also regional, local or state regulations that apply to the design and installation of fish passage facilities. Policies vary from state to state but the most generally accepted passage criteria are developed by the National Marine Fisheries Service (NMFS). This Anadromous Salmonid Passage Facility Design criteria addresses passage requirements for salmon and steelhead by specifying standard design elements including ladder definition and type, structure placement within the river, periods of flow the ladder needs to be operating in criteria, minimum pool dimensions, hydraulic drop between pools, energy dissipation, ladder entrance and exit conditions and management of debris and sediment. These requirements have evolved over the years and are updated on a regular basis by NMFS, but have been fairly consistent over the last 20 years.

Fishways were not legislated in Australia until the 1990s. Prior to this, fishway construction was voluntary and usually used designs adapted from American and European fishways. Currently, Australian water and environment is legislated through the overarching national framework of the *Commonwealth Water Act 2007* and the

Commonwealth Environmental Protection and Biodiversity Act 1999. The enactment of this legislation most importantly involves bilateral agreements that accredit State and Territory government assessment and approval processes. These agreements avoid duplication and allow regulatory legislation to be primarily created and enacted at a state level. This is in contrast to the federal-heavy nature of environmental legislation in the USA. State legislations in Queensland, where the Australian case study is located, include the integrated *Environmental Protection Act 1994* and the *Fisheries Act 1994*. These trigger fish passage approvals under the *Sustainable Planning Act 2009* for developments that may impact fish movement. Anything that poses a barrier may be a trigger, ranging from a dam or weir to a change in water level that alters the potential for passage through a culvert, for example. The development must then be demonstrated to allow the fish movement required for environmental sustainability to not be impeded by the works. Applications must address fish movement both upstream and downstream, according to the Fish Habitat Management Operational Policy (FHMOP 008).

More recently in 2012, the Marine Fish Habitat Offset Policy (FHMOP 5.2) was updated to allow the provision of environmental offsets as an alternative option to mitigate remaining or unavoidable negative impacts of proposed works on marine habitats. This offset policy has particular application for maximization of environmental benefit by improving fish passage at an alternative location, such as the tidal boundary of a system, where barriers pose the greatest ecological risk. If fish movement under FHMOP 008 or environmental offsets under FHMOP 5.2 are to be provided by the construction of a fishway, design criteria as specified in FHMOP 008 include requirements for the whole fish community (species, size classes and swimming abilities) and operation whenever there is flow in the river (inflow or release).

LINKING FISH BIOLOGY AND HYDRAULIC DESIGN

To design effective fishways, there must be an understanding of the habitat preferences, habits and swimming abilities of the fish communities that will use it. Early fish passage criteria in the northern hemisphere was focused on providing passage for returning anadromous salmonid adults that travel long distances against large flows and velocities (Cobb 1925). North American fish are generally excellent swimmer and jumpers (see Figure 1a) although this can vary between species. Burst speeds of adult steelhead can be up to 7.6 m/s compared with much slower speeds for brown trout (3.7 m/s) and adult herring (1.8 to 2.1 m/s). Migration patterns tend to be highly seasonal and driven by reproductive processes, with predicable migration routes and timing. In contrast, the native fish species of Australia have adapted to the low hydraulic gradients and sporadic flow availability of Australian waterways (Mallen-Cooper and Brand 2007, Delaere et al. 2011). Many small and large-bodied native fish such as the endangered Australian lungfish *Neoceratodus forsteri* (see Figure 1b) are poor swimmers compared to Northern Hemisphere salmonid species, with preference for velocities between 0.3 to 1 m/s and an upper limit of 1.4 m/s for large fish. Turbulence is also a significant barrier to the smaller Australian fish species. Both freshwater and anadromous fish species regularly move up and down water systems among spawning, feeding and refuge habitats. The migration patterns reflect the hydrological variation with movement occurring on both high and low flow events throughout the year but tending to be triggered by hydrological cues including variation in river height, tide, discharge, turbidity and the first rainfalls of the (pre)-wet season (Stuart and Berghuis 2002, Stuart et al. 2007). To maximize opportunity, different species have evolved to respond to different hydrological cues. This means there may be both a large biomass of fish requiring passage at low flows and a large biomass of different species composition requiring passage at high flows.

Figure 1. a) A jumping North American salmonid b) A native Australian lungfish.

Engineering criteria to match biological characteristics must be matched for the native species. The historical provision of connectivity through the construction of fishways in both countries was intended to ensure that wildlife was given the chance to move freely in order to complete life cycle functions and maintain long-term population viability (Mallen-Cooper and Brand 2007). As the understanding of fish biology has evolved, fish passage regulation in both countries has similarly evolved to incorporate a much wider range of species and life stages into the design of these engineering criteria. The generally strong swimming capabilities of US fish have led to the development of very specific governing fish passage criteria and guidelines. These guidelines concern elements including entrance location, configuration and orientation, debris management and trash racks, fish attraction flows, hydraulic drop and flow conditions, minimum pool dimensions and flow depth, transport velocities and transport channels and auxiliary water systems. The traditional American and European fishway designs have proven to be largely ineffective in Australia because, as described, the native fish have contrasting biological characteristics (Mallen-Cooper and Brand 2007). While there are no specific fish passage criteria and guidelines for use in Australia, the elements identified for the US are still relevant. However the difference in the native species between the two countries must be carefully considered. In order to tailor to the Australian context it is crucial to link the biological needs of the locally-identified Australian species to appropriate hydraulic characteristics when determining design criteria such as location, attraction flow, size and hydraulic conditions. The large variation in fish size and species requiring movement at different points in the varied hydrological cycle mean that a variety of migration preferences and flows must be catered and designed for. In this way, Australian fish species can be accommodated by artificially creating hydraulic conditions that incorporate variation in velocity magnitude, profile and resting locations according to fish swimming ability at different flows.

ENGINEERING DESIGN OUTCOMES

Case Study 1: Grain Camp Dam

Background. The Malheur National Wildlife Refuge (NWR) in a remote area of Eastern Oregon, provides sanctuary for almost 400 fish and wildlife species. In particular, the Donner und Blitzen River supports the largest migratory population of redband trout in the Great Basin region (Anderson et al. 2011). Within the refuge, a series of four diversion dams, operated by the U.S. Fish & Wildlife Service (USFWS), run the length of the Donner und Blitzen River and divert water into the refuge to irrigate aquatic wetland and support migratory wildlife. One of the lower dams, Grain Camp, lacked screening facilities and had aging passage infrastructure that did not meet current criteria (Oregon Administrative Rules [OAR] Division 412). A comprehensive regional fish habitat improvement project was initiated including an upgrade of the screening and passage structure on Grain Camp Dam and the other two lower dams.

Challenge. The existing 3.6-metre Grain Camp Dam is the highest of the refuge diversion structures, housing a forebay for two diversions which had previously been unscreened. The two diversions were closely located on the same side of the river and so were both consolidated into a single 8.5 m^3/s diversion and configured with a new, vertical flat panel, “double-array” screen facility that was constructed in a vee formation (see Figure 2). The new screen facility complies with ODFW fish screen criteria by incorporating porosity control and multiple water control valving at each canal. Finally, a bypass downwell and pipe system returns fish and debris to the river.

The existing fishway had ten pools of about 183 cm wide by 167 cm long with eleven 25.4 cm hydraulic drops, much higher than the 15.2 cm able to be traversed by juvenile fish according to the ODFW. Insufficient pool depth and excess energy in lower pools were also problematic. A new, modified pool and weir fishway was designed with 20 shorter drops of 15.2 cm. The ladder was designed to juvenile criteria and to operate at variable flows of between 0.2 and 0.7 m^3/s as required by prescriptive exceedence flows, based on a recommended 25 years of mean daily streamflow data. In consultation with State and federal fishery agencies, a new fish trap and sorting facility were provided to allow for collection and monitoring of multiple fish species in the basin at the ladder exit.

Figure 2. a) and b) View of the Grain Camp Dam screening facility

Result. The upgrade of Grain Camp Dam fish passage structure, in combination with the other dams, provides a model for wide-reaching habitat improvements in the still-undeveloped topography of eastern Oregon. The project created improved movement opportunities for native fish through 20 miles of the refuge and opportunities to limit movement of non-native fish. This was celebrated for helping to advance the stated goals of the refuge including the improvement of conditions for native fish, the reduction of invasive fish species, and the protection of refuge water rights.

Case Study 2: Burrum Weir #1

Background. Burrum Weir #1 is located at the tidal boundary of the highly regulated Burrum River system, upstream from the town of Howard (near Hervey Bay, Queensland). The Burrum catchment has a subtropical climate resulting in ephemeral conditions, with flows only occurring in the wet season (Delaere et al. 2011). With 34 native species, the diversity of freshwater fish in the region is relatively high by Australian standards (Unmack 2001). The existing Burrum Weir #1 was constructed around 1952 and is a concrete gravity weir approximately 5 metres high with a central spillway (see Figure 3a). Operationally it acts as the pumping pool for the system water storage of Lenthalls Dam, with the intervening Burrum Weir #2 acting as the balancing storage (Delaere et al. 2011). Retrofitting of a fishway on Burrum Weir #1 was proposed as an environmental offset (FHMOP 5.2) to the raising of Lenthalls Dam upstream.

Challenge. Two flow conditions are experienced due to the high regulation of outflows. One is a low flow release condition of approximately 10 ML/day when the storage level in Lenthalls Dam is at or above a prescribed level and the headwater is less than full supply level. The second is a high flow release condition (spillway flows) when the headwater is less than full supply level and releases are uncontrolled with volumes as per the spillway rating curve. Headwater conditions were analysed for the past 15 years of data, through which the system regulation was representative of current conditions. Since it is a storage facility, it was confirmed that the headwater may be regulated with an achievable future maximum variation of 400 mm below the crest (Delaere et al. 2011). Maximum variation above the crest was chosen according to the statistics of delays to fish migration, based on the recorded spill events. Impedance to upstream fish passage five times in a 15 year record was considered acceptable. Tailwater conditions vary with typical tidal variations of 2.5 m lapping at the toe of the weir. A natural rock bar located approximately 100 m downstream acts as a barrier at low tide, causing a pool to form downstream of the weir and restricting fish access to the base of the weir (see Figure 3b). The challenge was to design a fishway for a diversity of fish species that operated when most low discharges occurred, with the flexibility to move a high biomass of larger fish at high flows (Delaere et al. 2011). The selected hydraulic criteria were confirmed through consultation with the relevant regulatory authority through the duration of the design.

Figure 3. a) Existing Burrum Weir #1.   b) View downstream.

<u>Result</u>. A natural bypass fishway solution was selected over a fishlock or vertical slot design due to the ability to incorporate a low-flow, low velocity and turbulence channel for small fish as well as a high flow channel for spilling flow events and large-bodied fish. Rocks were placed to create resting pools. A computational fluid dynamics (CFD) analysis was undertaken to assess the hydraulic characteristics of the low flow channel as it incorporated riffle pool sequences. Modelling of this complex flow profile was not able to be undertaken using empirical methods. Slight meandering of the low flow channel with constrictions produced acceptable hydraulic results with variable velocity profiles to accommodate fish of various swimming abilities. This also provided a continual flow path through to the next riffle pool with low velocities for the passage of small fish. The optimum layout for the 'natural' bypass fishway is shown in Figure 4a, with corresponding CFD low-flow velocity transect shown in Figure 4b. This demonstrated the ability for native species to move through the retrofit fishway and verified the design as a viable environmental offset measure for the Lenthalls Dam.

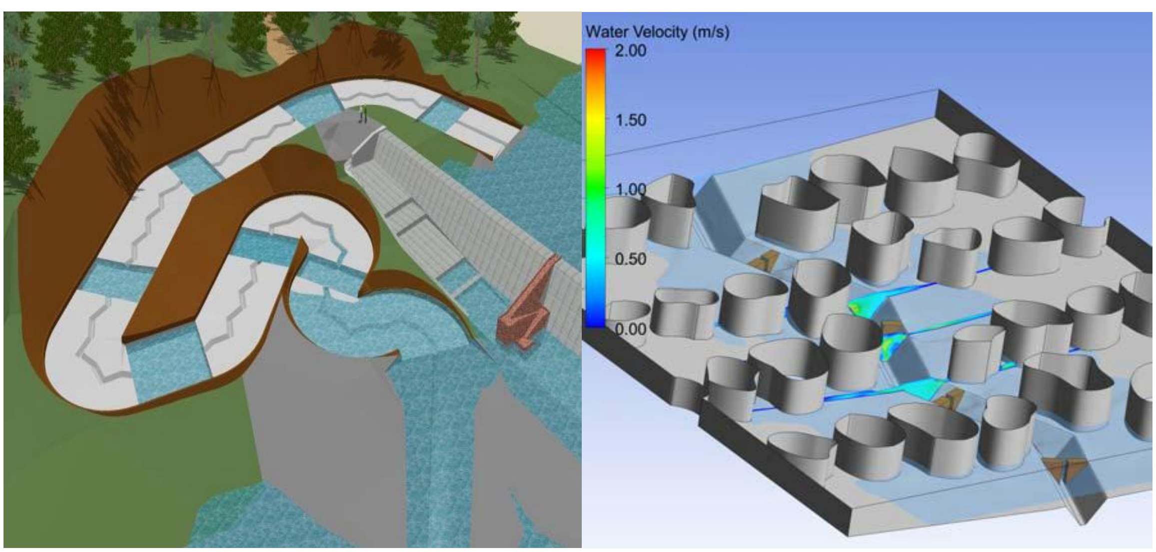

Figure 4. a) Proposed nature-like bypass layout   b) Computational fluid dynamic modelling velocity transects (Delaere et al. 2011)

CONCLUSION

Both case studies were challenged to incorporate changing regulatory requirements to operate under increasingly varied flows and to accommodate the ecological needs of native fish species. For Grain Camp Dam, the fish passage hydraulic criteria were provided by OAR Division 412 which defined attraction flows, maximum velocities at transitions (2.4 m/s), maximum water surface elevation difference, minimum water depths, minimum pool depths and energy requirements. The resulting fishway was able to incorporate these requirements through an empirical design that reduced the hydraulic drop between ponds to the required 15 cm, increased the number of ponds and enlarged a pool in which to trap and segregate non-native species. The Australian legislation, while stringent in the requirement to demonstrate the ability to pass native fish, is much less prescriptive. Even should it have been more definitive as to the hydraulic requirements, the large variation in operational flows and tidally-influenced 3.8 m variation in tailwater conditions made it difficult to use empirical design methods for the Burrum Weir #1 fishway. Sophisticated CFD modeling was undertaken to detail a low-velocity, low-turbulence fishway matched uniquely to the identified local species. The striking differences in the resulting designs for each case study are typical of the differing hydraulic conditions required by the native species in each country. The higher velocities and less flow sensitivity allowed for the stronger US fish species, and lower velocities and a more tailored approach for the less energetic Australia native species are a case in point.

While the Burrum Weir #1 fishway developed ecological and hydraulic design criteria during the project based on knowledge and observation of the preferences and life cycles of local species, this takes time and money to collect and produce. Australia’s fish passage provision continues to be challenged by its characteristically unpredictable hydrology and lack of extensive fish biology observation. Identifying the relevant fish communities to be considered also poses a significant challenge as there are large gaps in the understanding of Australian fish species movement. This is primarily for two reasons being a) data gathering is ad hoc as much fish movement occurs on flood flows rather than seasonal patterns such as snowmelt in North America and b) flood events create access issues for data collection. For this reason the precautionary principle is generally applied in the determination of fish biology for fishway design. Workable, environmentally-beneficial fishway designs that allow movement of the full fish community at varying flows is crucial to achieving the goals of these policies and approvals for waterway infrastructure or environmental offsets. As yet there are no generally-accepted criteria for the design of fishways in Queensland or Australia as a whole.

In the USA, a country with a long history of fish passage provision, the highly prescriptive Federal agency design criteria are undergoing evolution to accommodate wider ranges of species and life stages. There are a range of fishway designs that are commonly accepted to deliver environmental benefit for adult salmonids, however increasing consideration to non-salmonid species and juvenile fish is causing need for revision. The challenge is therefore to change designs and management to meet these new prescribed criteria and provide more comprehensive regional fish habitat, such as provided by the Camp Grain Dam fish screen, fishway and fish trap retrofit. The more monitoring and modeling-intensive approach of Australian fishway design might provide inspiration to US designers to develop innovative, alternative fishways that incorporate a wider range of velocity and turbulence limits to suit a larger range of species. Likewise, progress towards more standardized and prescriptive design criteria in the evolution of Australian fishway legislation could provide multifold benefits. Tighter regulation of acceptable hydraulic criteria could improve the acceptance of alternative fishway designs and ensure provision for native fish movement, while reducing the need for extensive analysis of hydraulic criteria on a project-specific basis as undertaken for the Burrum Weir #1 fishway. The regulatory expectation of acceptable fish passage performance would be clarified, streamlining the approval process both from a design and approvals perspective. In these ways, sharing knowledge and design methodologies may lead to progressive fishway design approaches to meet changing regulatory requirements in both Australia and the USA.

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