Provision of fish passage for sustainable pumped storage hydropower projects

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Key Points

- Pumped storage hydropower presents an enormous opportunity to power our clean energy future; however, it also presents numerous challenges.
- Minimising impacts of pumped storage hydropower projects on fish is an important factor that needs to be considered.

Abstract

Pumped storage hydropower (PSH) presents an enormous opportunity to power our clean energy future, however it also present numerous challenges in an era where fewer dams are constructed in Australia compared with last century. Minimising impacts of PSH projects on fish is an important consideration to satisfy sustainability measures for hydropower projects, particularly for open loop PSH schemes where at least one reservoir is located on a waterway.

Fish passage decision making for PSH projects requires comprehensive assessment of the impacts of PSH development on fish species, habitat, life history and mitigation strategies to evaluate whether, bi- directional fish passage is required at PSH sites. Different forms of design solutions must be assessed to determine feasibility for site conditions and suitability for existing fish community. This paper explores current industry practice, and gaps, for provision of bi-directional fish passage for PSH projects in Australia. This paper discusses the ecological impacts on fish due to PSH site selection, PSH design and operation and the current state of practice for selection of fish passage requirements for PSH facilities.

Fish passage technology options, the state of regulatory practice in Australia and decision-making criteria are presented herein.

Keywords

Pumped storage, hydropower, fish passage, sustainability, dams

Introduction

Pumped storage hydropower (PSH) presents an enormous opportunity to power our clean energy future, however it also presents numerous challenges in an era where fewer dams are constructed in Australia compared with last century.

One critical and emerging issue in Australia relates to how to best mitigate the impacts of PSH projects on fish, particularly for PSH projects constructed in waterways. For in-stream waterway barrier works, such as dams and weirs, the provision of safe and adequate fish passage is a critical component to satisfy sustainability principles and is strongly influenced by the specific regulatory requirements within different jurisdictions. Regardless of the design options selected, it is difficult, and at times impossible, to provide safe and adequate fish passage to achieve predevelopment conditions. Numerous fish passage solutions are well established in the dams' industry in Australia (e.g. fish locks, fish lifts, natural bypass, engineered rock ramps etc.); however, PSH projects present unique operating challenges compared with dams and may provide a habitat detrimental to the wellbeing of fish.

Greater guidance is needed for the dams' industry and Government regulators to plan for provision of safe fish passage for PSH projects. This paper discusses the potential impact of PSH on fish, under different location, design and operation contexts and considerations for selecting fish passage requirements for PSH facilities.

What is pumped storage hydropower?

Pumped storage hydropower (PSH) or pumped hydro energy storage (PHES) are terms commonly used to refer to a type of energy storage which relies on a pair of reservoirs, whereby one reservoir is located at a higher elevation and is used to store water from other energy sources (e.g. solar, wind, nuclear) and releases water through a powerhouse to generate electricity when demand is high. The PSH transfers water between the reservoirs to store and generate electricity depending on the storage capacity and demand profile, typically storing energy at night and generating energy during the day, however operations may vary depending on the requirements of the scheme, diurnal and seasonal variations. In Australia, there are a limited number of PSH projects. Two well-known examples include the Wivenhoe Pumped Storage Hydroelectric Power Station and Tumut 3 Power Station, part of the Snowy Scheme. There are numerous other projects under development including the Kidston Pumped Storage Hydro Project.

Closed and open loop PSH

PSH schemes may generally be defined by one of two main types; closed loop or open loop projects. Closed loop PSH refers to a PSH project which utilises two reservoirs that are both located off natural waterways such as rivers, lakes or wetlands and the water supply relies upon periodic withdrawal from surface water sources or groundwater (Saulsbury, 2020; NHA, 2021; DOE, 2023), such as the Kidston Pumped Storage project being constructed in Australia. Closed loop PSH projects may utilise either surface water or groundwater and be located either above or below ground.

Open loop PSH projects have one or more reservoirs located within natural waterways. Open loop PSH projects are more common in countries such as the United States where all 43 operating PSH projects are open loop (Saulsbury, 2020).

Closed loop PSH projects have been assessed to have lower environmental impacts (Saulsbury, 2020; NHA 2021). This paper, focuses on open loop PSH projects which potentially have higher environmental effects on aquatic ecology, including fish. There are broadly two types of scenarios considered for open loop PSH in this paper:

- An existing instream lower reservoir which forms part of an existing or proposed PSH scheme.
- A new instream reservoir (or reservoirs) constructed on a watercourse as part of a new PSH scheme.

Each of these scenarios present challenges for fish passage. Existing instream reservoirs may have existing fish passage facilities or require a new fish passage facility to be retrofitted which meets contemporary design and legislative requirements. These fish passage alternatives are widely discussed in other literature, however the change in operating conditions due to provision of large intakes for transferring water between storages and reservoir level fluctuations associated with PSH projects have impacts on the suitability of conventional fish passage solutions.

Fish passage between lower and upper reservoirs is seldom required unless both reservoirs are in the same watercourse. The potential ecological impacts of transferring fish between a lower and upper reservoir should typically be avoided as later discussed in this paper.

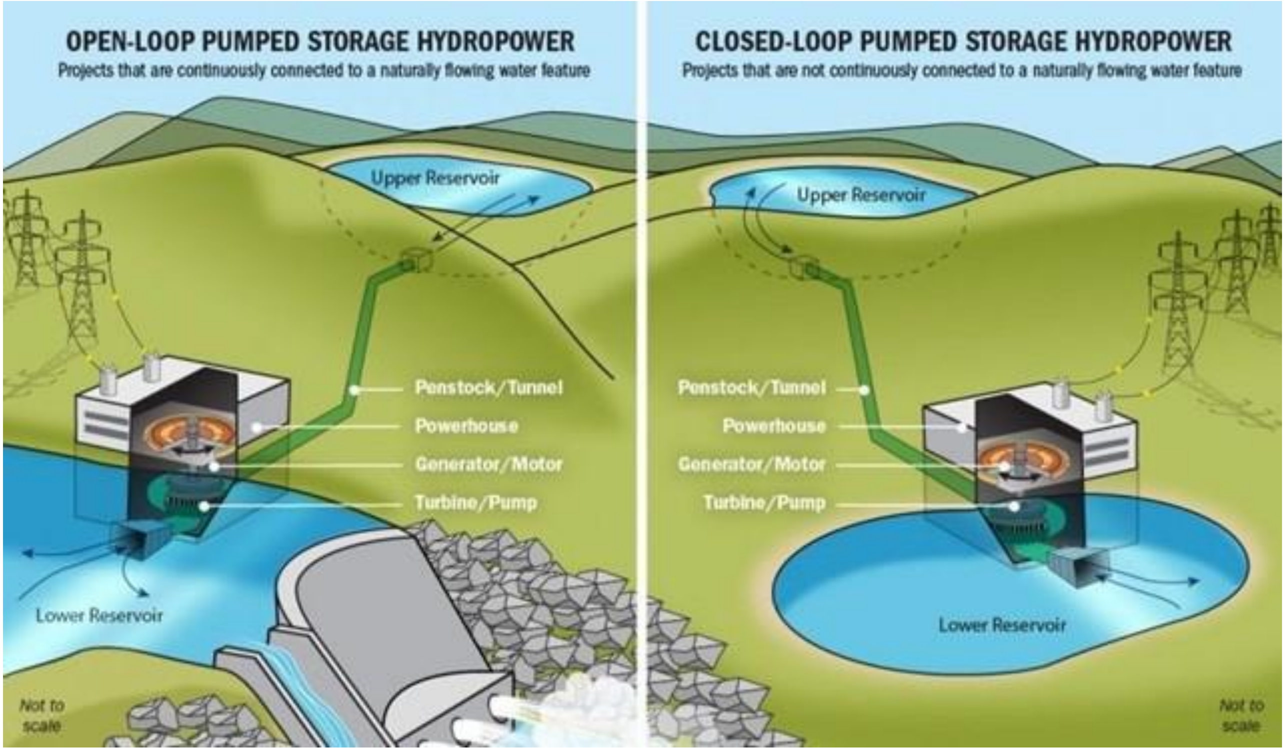

Figure 1: Comparison between open look and closed loop PSH facilities sourced from the US Department of Energy 2023 (https://www.energy.gov/eere/water/pumped-storage-hydropower)

Impacts to fish from PSH

Impacts on fish and other aquatic environmental values from closed loop PSH are primarily related to the initial withdrawal of surface water for reservoir filling (Saulsbury, 2020; Yang and Jackson, 2011). Open loop PSH typically result in substantially greater impacts to fish than closed loop PSH due to their direct impact on waterways, and their hydrological connectivity to the broader catchment (Saulsbury, 2020). Whilst impacts of open loop PSH on fish are similar to those caused by a water storage dam, the frequent fluctuation in water level and operation of the powerhouse and turbines within a PSH scheme result in additional risks including unsuitable habitat conditions, high risk of fish injury/morality, potential inter-catchment transfer of biological material, and reductions in provision of fish passage that can be achieved within the waterway. The nature, extent, frequency and duration of impact to fish is influenced by the size and frequency of water level fluctuations, the design of the turbine intakes, the hydrological connectivity of the site to the upstream and downstream catchment, and the characteristics of the existing fish community. These risks to fish from open loop PSH are detailed further below. The ability to sufficiently manage these risks will influence whether the ecological benefits of utilising an existing reservoir as part of a PSH scheme is better or worse than a new PSH dam.

Habitat suitability

Construction of PSH reservoirs within waterways results in the inundation of fish habitat, such as riffles, runs, pools, and the creation of a homogenous lacustrine environment. Large reservoirs typically have lower ecological value for fish than natural habitats due to limited variability in habitat resources, slow to zero flow, and poor water quality within the deep wide pools (Bunn, 2002). For any large instream reservoir, biodiversity is typically highest in the shallow littoral zones along the perimeter of the impoundment and in the upper reaches where water levels remain within the high banks of the existing waterways. However, in the case of PSH reservoirs, the constant fluctuation in water level will result in the littoral zone being either inundated or left high and dry depending on the generation cycle. As a result, habitat resources for fish, in the form of woody debris, root mats, overhanding vegetation and macrophytes will be limited within this zone. The volume, frequency and duration of water level fluctuations, also results in direct impacts on reservoir water quality and therefore habitat suitability for fish. Key impacts include, erosion and mobilisation of sediments leading to high levels suspended sediment and turbidity, changes to temperature and dissolved oxygen levels and stratification, increased concentrations of nutrients and heavy metals, changes in water circulation and hydrological conditions, and decrease is light penetration (Kobler et al. 20218; Patocka 2014; Bakken 2012; Pickard 2012; MWH 2009; DOI 1993; Dames and Moore, 1981). The changes in abiotic conditions that occur can lead to direct impacts on primary production in the form of chlorophyll-a concentration, carbon fixation rate, and phytoplankton populations, and subsequent impacts to the diversity and abundance of zooplankton, benthic organisms, shrimp, and fish populations (DOI 1993).

The release or /spilling of poor quality from PSH reservoirs and the alteration of the natural flow regime that occurs through river damming, can extend these impacts to downstream waterways and fish populations. Utilisation of existing dams for PSH projects avoids additional inundation of waterway and loss of habitat which occurs with the creation of new PSH reservoirs. However, site section for PSH schemes should consider the value that an existing storage provides for fish species and assess the significance of the loss or significant degradation of this habitat from PSH operations. Site selection should make comparison to the additional inundation of waterway that would occur from construction of a new PSH reservoir. This assessment must consider the existing ecological values of the two sites including the type of habitats present, the diversity and abundance of the existing fish community and the conservation status these values.

Injury and / mortality

In addition to the loss and degradation of fish habitat within and downstream of PSH reservoirs, PSH operations pose a high risk of fish injury and mortality from entrainment and impingement through the tailrace intakes and power generation turbines, (Pflugrath et al. 2020; Boys et al. 2014; Patocka 2014; Amaral 2013; EPRI 2013; OTA-ENV-641, 1995; DOI 1993; Ruggles and Murray, 1983). The risk of injury/mortality is dependent upon the size, shape, physiology, lift history, swimming ability, home range size, triggers to movement and abundance of the fish population. In general, smaller fish with weaker swimming ability are more at risk than larger species. The hydraulic conditions within and surrounding the intake screens, tailrace tunnels, and power generation turbines can also influence risk with fish injury/mortality positively related to velocity, turbulence and pressure changes (Pflugrath et al. 2020; Boys et al. 2014; Amaral 2013). Site selection for PSH schemes, including comparison of existing vs new reservoirs, should consider the abundance, diversity and ecology of the fish species that will be at risk and whether the effectiveness of design solutions at mitigating the risk of fish injury/mortality vary between options. These factors will also influence the selection of fish passage, exit location from fishways and general arrangement of the overall facility to reduce attraction to, injury and mortality associated with these features.

Inter-catchment transfer

In cases where the upper and lower reservoirs are located in different waterway catchments, the movement of water between the reservoirs can introduce risks from the translocation of water and biological material (e.g. plant fragments and seeds, eggs/larvae) between waterways (Patocka 2014). This process can result in the introduction and spread of non- native species. Where invasive species are present in one catchment but not the other, PSH operation can also cause biosecurity risks associated with the introduction and spread of weed and pest species. Locating upper and lower reservoirs in different waterway catchments should be avoided wherever possible and existing biosecurity risks should be evaluated as part of the PSH site selection process.

Restriction of fish passage

As occurs with any instream dam, PSH dams located within waterways restrict fish movement through the physical barrier created by the dam wall and change in natural flow regime that triggers migration in many species (FAO and DVWK, 2002; Francfort et al., 1994; OTA-ENV-641, 1995). In general, fish migration revolves around the need to breed, disperse from nursery habitats and feed and ecological consequences of the restriction of movement can include declines in abundance, species distribution truncation, localised extinction events and a reduction in species diversity (Lowe- McConnell 1987; Lucas and Baras 2001; Mallen-Cooper and Brand 2007; Marsden and Power, 2007). Utilisation of existing dams for PSH schemes avoids the creation of a new barrier to fish passage that would be created through construction of a new PSH reservoir. However, large and frequent water level fluctuations associated with PSH operations can substantially limit the provision of fish passage that can be achieved through historical fishway designs potentially resulting in residual impacts to fish passage. Therefore, site selection for PSH must consider the ecological consequences of restrictions in fish passage at a particular site based on the migration requirement of the fish community and the existing hydrological connectivity of the site to fish habitat upstream and downstream. An existing dam located within the lower or middle reaches of a catchment that is converted for use in a PSH scheme is likely to higher ecological impacts than a new or existing dam located in the upper reaches, due to greater impact on the movement of diadromous species (species that move between freshwater and marine environments), and larger areas of habitat disconnection that can occur through residual impacts to fish passage at the site (EPRI 2013). The ability to manage risks of fish injury and /mortality and maintain suitable habitat conditions within PSH reservoirs (existing or new reservoirs) will also directly influence the approach to fish passage at a site and whether facilitating fish movement into a PSH reservoir achieves ecological benefit. If risks cannot be sufficiently mitigated, then exclusion of fish from the reservoir may be a preferred option, which may be incompatible with sustainability objectives and legislative requirements.

Regulatory requirements for fish passage at PSH sites

Whilst PSH projects promote sustainability by facilitating greater penetration of intermittent renewable energy into the electricity grid, thereby achieving carbon emission reduction targets, environmental impacts can be large. Management of impacts can result in significant restrictions on project design and operation from regulatory requirements. Understanding and managing potential risks early and prioritising avoidance of environmental impacts is critical to the assessment of project feasibility and minimising risks to project approvals, schedule and cost.

The Hydropower Sustainability Guidelines on Good International Industry Practice (Locher and Costa, 2020) detail how sustainability practice should be defined and measured in the hydropower sector. The overall intent for environmental management of hydropower is that impacts are identified and assessed; avoidance of negative or adverse impacts is prioritised; minimisation, mitigation, compensation and enhancement measures are designed, implemented, monitored, and demonstrated to be effective; and environmental and social commitments are fulfilled (Locher and Costa, 2020). This process and the prioritisation of avoidance and mitigation of adverse environmental impacts is also reflective of the Australian Environment Protection and Biodiversity Conservation Act 1999 (EBPC Act). Under the EPBC Act, threatened fish species, and important areas (such as world heritage areas, national heritage areas, wetlands of international importance) are protected as matters of national environmental significance (MNES). PSH projects that have the potential to impact MNES are required to demonstrate avoidance, mitigation and management of potential impacts. Fish, waterways and fish passage are also protected to various extents under State legislation with PSH projects required to meet environmental outcomes to obtain various permits and approvals. These requirements vary throughout jurisdictions.

In the context of avoidance of impacts to fish and fish passage, closed loop designs that avoid impacts to waterways and fish should be selected over open loop designs wherever possible (MWH 2009). Where open loop PSH cannot be avoided, evaluation of existing reservoirs versus new reservoirs should consider the position of the reservoirs within a catchment in relation to fish diversity, abundance and movement requirements, habitat value and hydrology connectivity. All aspects of design, construction and operation should then target effective mitigation and management solutions that achieve ecological benefit.

As environmental legislation within Australia was not developed with consideration of PSH projects, the Australian *Climate Change Act 2022*, or associated policies, compliance of open loop PSH with regulatory requirements for the protection of fish and fish passage may be unachievable. Reform is likely to be required to achieve project environmental approvals and support progress towards Australian and State Government commitments to renewable energy targets. Achievement of ecological benefit and nature positive outcomes should drive decision making across the hydropower industry and within the approvals process. Additionally, ecological sustainable development is a principle of the EPBC Act and should be considered.

Site selection for new in-stream reservoirs

Strategies to minimise environmental impacts on aquatic fauna may most practically be achieved early in a project at the site selection stage. The evaluation of sites for impacts on fish should consider but not be limited to:

- Site selection in waterways of lower environmental significance, within a single catchment area and at the uppermost extent of the catchment.
- Conservation status of fish species potentially impacted.
- Soils and geology, including potential for erosion and sedimentation control.
- Topography and scheme characteristics including operating range and location of key PSH infrastructure (e.g. inlets, dams, spillways, etc.).

Where site selection studies have demonstrated that an open loop PSH project is required to achieve performance requirements and balanced against environmental outcomes, provision of bi-directional fish passage should be considered to satisfy sustainability principles and regulatory requirements. The purpose of downstream fish passage for open loop PSH projects is threefold; to enable fish to migrate downstream; to discourage fish to enter turbine intakes; and to allow them to pass through the reservoir (FERC, 1995). Bi-directional fish passage for an open loop PSH project refers to:

- Provision for or upgrade of fish passage to an existing instream lower reservoir which forms part of an existing or proposed PSH scheme.
- Provision for fish passage to a new instream reservoir (or reservoirs) constructed on a watercourse as part of a new PSH scheme.

The individual characteristics of the site should be considered in all cases to assess the type of fish passage required, and whether the preferred type will offer a net ecological benefit compared with alternative measures such as exclusion (barrier) or offset strategies, including habitat restoration or enhancement in other areas.

Fish passage technology

Options for bi-directional fish passage may be catered for with options that function in both upstream and downstream directions, or combinations thereof. Upstream fish passage options may broadly be categorised into trap and transport, bypass (volitional) or bypass (non-volitional). Each of these broad categories of fish passage technology are widely described in literature for dam, weir and conventional hydropower applications (e.g. O’Connor et al., 2017). Specific considerations and design issues for selection of fish passage technology at PSH projects include:

- The operating range of the reservoir may fluctuate both rapidly and regularly, impacting fish passage exit conditions, and duration of fish passage.
- Intake and outlet structures for the powerhouse may provide competing attraction flows, both upon exit from a fish passage and for downstream passage.
- Fish passage water requirements may be high, whereas water balance and reservoir yield requirements to operate the scheme may be relatively marginal.
- Water quality, sedimentation, debris and temperature variability arising from operating conditions (e.g. reservoir fluctuations).

Fish guidance and exclusion

Fish guidance and exclusion technologies should be considered for PSH projects for two primary purposes: to attract fish to downstream fish passage facilities in reservoirs; and, to divert fish away from intake structures.

Fish *guidance*

Fish guidance technologies in PSH reservoirs must function under fluctuating reservoir levels and conditions to direct fish to safer areas of the reservoir and/or collection facilities for downstream passage. Surface collectors, or collection facilities comprise fixed inlet, floating surface or floating screen type structures which direct fish to collect, hold and transport fish to a downstream location. Collection facilities may be located within the reservoir, or at the upstream extent of the reservoir to capture fish before they enter an open loop PSH scheme while migrating downstream. Surface collectors may be supplemented by specific guidance devices which divert fish towards the downstream attraction facility, away from intakes, turbines and spillways. Thus, this technology may be used to reduce the potential for inter- catchment transfer of fish exclusion between reservoirs, and/or facilitate downstream passage, either through, or around the headwaters of the reservoir, depending on the scheme requirements.

Fish exclusion

Fish exclusion or diversion technologies should be considered for PSH projects where fish passage is sought to be prevented between reservoirs, either to reduce fish injury and mortality or to prevent inter-catchment transfer.

Fish exclusion considerations include various types of screens, barrier nets, velocity barriers, bubble curtains and behavioural devices such as light, sounds or electric fields.

Bi-directional fish passage for new or existing instream reservoirs

Bi-directional fish passage technologies are generally consistent with those for dams and weir projects, however with bespoke adaptations to address the design issues for PSH projects mentioned previously. These technologies are summarised below and evaluated thereafter.

Upstream passage

The purpose of upstream fish passage is to transport fish from the toe or downstream of the toe of the waterway barrier and to transport the fish either into, or upstream of the reservoir. PSH projects present conditions for fish which may present health or mortality risks, which requires the option selected to consider the exit location whether the system will achieve an ecological benefit. A list of potentially feasible fish passage options for PSH projects is provided below:

- Trap and transport
- Fish ladders or fishways (e.g. natural bypass, Denil, cone, vertical slot, rock ramp etc.)
- Fish lock
- Fish lift
- Fish pumps

Each of these options may be designed to accommodate downstream fish passage with varying degrees of effectiveness. Descriptions of these options are widely available in literature (e.g. FERC, 1995, Therrien & Bourgeois, 2000, O'Connor et al., 2017). Both trap and transport facilities, and bypass fishways, provide many favourable ecological services (Twardek et al., 2022), and potentially allow the hostile environment of the PSH storage to be avoided; however, may be outweighed by practical construction and economic limitations at some sites.

Downstream passage

Downstream fish passage options for PSH projects include:

- Trap and transport
- Fish ladders or fishways (e.g. natural bypass, Denil, cone, vertical slot, rock ramp etc.)
- Fish lock
- Fish lift
- Fish pumps
- Surface collectors
- Bypass systems (e.g. natural bypass, channels or conduits other than fishways)
- Spillways

Technology summary

A summary of each broad passage options with respect to PSH project specific considerations is provided in Table 1. General comparison of performance between options for regular dams, weir or hydropower projects is omitted for clarity. A site-specific evaluation is required for all options, and hybrid (i.e. combinations of options) should be considered when selecting a preferred fish passage technology for an open loop PSH project (e.g. fish ladder and fish lock).

Table 1. Suitability considerations of fish passage technologies for PSH reservoirs constructed in waterways

Type of passage	Primary direction	PSH considerations
Trap and transport	Bi-directional	Handling, sorting and sampling possible to remove invasive fish species. Not influenced by reservoir level fluctuations. Multiple and selected release points which may readily avoid areas of reduced water quality, poorer habitat and competing attraction flows.
Volitional options: Fish ladders, fishways and bypass systems	Bi-directional	Multiple exits potentially required or mechanically controlled holding areas at upstream release to accommodate reservoir level fluctuations and may impact viability. May bypass reservoir. May require a relatively substantial amount of water to operate.
Mechanical options: Fish lock and lifts	Bi-directional	Exit typically at upstream face of waterway barrier at an elevated release level. May be designed to accommodate fluctuating reservoir levels, however with potential multiple exit chambers and complexity. Fish locks may require a relatively substantial amount of water to operate.
Fish pumps	Bi-directional	Exit typically at upstream face of waterway barrier. May be designed to accommodate fluctuating reservoir levels. May bypass reservoir or have multiple exit points. Relatively new technology and not demonstrated for PSH projects across Australian fish species and operating conditions.
Surface collectors	Downstream	May be designed to accommodate fluctuating reservoir levels. May bypass reservoir. May assist with exclusion around intakes and competing attraction flows, improving effectiveness of fish passage in isolation or combined with other technologies.
Spillways	Downstream	No significant unique considerations for PSH projects.

Fish passage decision making for PSH

Open loop PSH projects present challenges to safe fish passage and impacts to the quality of habitat available for fish within project footprints. The ecological benefit of providing fish passage in open loop PSH reservoirs may be limited if additional regional or local factors are impacting fish population health. The first decision that should be made is whether fish passage will provide ecological benefit, and in what direction, at a proposed PSH facility. Current regulations in some jurisdictions may require fish passage for any PSH facility located in a waterway, regardless of the ecological benefit or potential consequences of providing passage after construction of the PSH, presenting a challenge for regulatory authorities and decision makers for PSH projects.

The impacts on fish from a PSH project require further evaluation of the entire scheme including:

- The ecology of native fish species, including dispersal and migration within the waterway of interest
- Siting of intake structures to not impact fish passage along in-stream watercourses and reservoirs, such as by reducing competing attraction flows.
- Assessment of fish exclusion technologies to reduce injury, mortality and/or inter-catchment transfer of fish species between reservoirs through intakes.
- Consideration of fish-friendly pump turbines (depending on capacity, head and transfer considerations) where fish cannot be excluded. Consideration should be given to turbines which reduce blade strike, rapid decompression and fluid shear (Pflugrath et al., 2020).

Where fish passage is required to facilitate migration along an in-stream reservoir (typically the lower reservoir) the assessment of technologies will include:

- Assessment of upstream fish passage technologies, including bypass of the reservoir
- Assessment of downstream fish passage technologies
- Evaluation of dam intake and outlet structures
- Operational considerations (reservoir fluctuations, pump rates, time of pumping, etc.).

Key considerations for provision of fish passage specific to PSH projects are:

- Exit location(s) – Multiple exits may be required to accommodate reservoir fluctuations or to bypass the reservoir.
- Water supply – Some options (such as fish locks and lifts) require larger volumes of water which may impact upon the water balance for the scheme.
- Handling and sorting – May be required to be considered to mitigate against inter-catchment transfer of species (in some locations).
- Reservoir fluctuations – Reservoir fluctuations may impact upon hydraulics, fish movement and delays, exit conditions and effectiveness of upstream attraction.

Each of these considerations increase the complexity, operational considerations and potentially so too the reliability of the fish passage facility, except for bypass and trap and transport type options which can negate some of these issues. A detailed options analysis and multi-criteria assessment is recommended when evaluating fish passage technology alternatives presented in this paper including the following:

- Ecological function – Cycle times, period of operations, effectiveness at catering for entire or target fish community, injury and mortality risk.
- Design – Complexity, past performance, hydraulic considerations, attraction, conveyance and exclusions.
- Operation – Skills, training, ability to monitor, complexity and attendance of staff needed for operation.
- Maintenance – Skills, training, reliability, complexity, frequency and availability of parts to maintain the structure.
- Constructability – Complexity, health and safety considerations for construction.

Where other options have been exhausted, offsets may be a viable alternative to fish passage at open loop PSH facilities, depending on the particular State regulatory requirements in Australia. These offsets may comprise waterway barrier works or habitat restoration that may provide greater ecological benefit than fish passage at an open loop PSH facility, and should be considered within the regulatory requirements the project is operating in.

Conclusions

This paper outlines the current state of practice for assessing fish passage requirements at PSH projects in Australia. Current environmental legislation within Australia has not been developed specifically for PSH projects. Regulatory requirements for the protection of fish and fish passage may be unachievable at some sites, and reform is likely to be required to achieve project environmental approvals and support progress towards Australian and State Government commitments to renewable energy targets. Achievement of ecological benefit and nature positive outcomes should drive decision making across the hydropower industry and within the approvals process, as early in the project as possible, in line with good sustainability practice for hydropower projects.

Fish passage technologies need to be assessed on a project basis, particularly at the site selection stage. Thereafter, if an in-stream reservoir is part of the scheme, key issues specific to PSH projects need to be addressed such as high reservoir fluctuations, operating requirements, possible water supply limitations, fish passage exit locations (and potential to bypass the storage), fish attraction and issues associated with inter-catchment transfer. A multi-criteria assessment approach is recommended to be adopted. Bypass technologies, surface collector systems and measures which exclude fish passage from the reservoirs present opportunities for reduced ecological impacts on fish for open loop PSH projects in Australia.

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