A tale of two sites, siting optimal fish passage location at Ewen Maddock Dam

Lindsay Millard[1], David T Roberts[2], Steven Cox[3], Andrew Berghuis[5], Anna Hams[4]

[1-4] Seqwater, Queensland, [5] Aquatic Biopassage Services

Addressing historical impacts of waterway barriers on regional fisheries values is a major focus for fisheries regulators when assessing proposed water infrastructure projects such as dam safety improvements. To inform prudent investment decisions, it is essential to quantitatively determine the feasibility and benefits of various fish passage options to mitigate barrier effects. In Queensland, the regulatory frameworks require consideration of multiple options to achieve mitigation with the overarching goal to support and restore regional fish productivity. Addressing multiple objectives on large water infrastructure projects can be challenging, particularly for existing assets requiring retrofit solutions. There is a need to balance the requirements for dam safety, water supply reliability, while also mitigating the loss of fish habitat access upstream of barriers. Finding optimal fish passage solutions requires consideration of multiple options and using objective approaches that can weigh up the many aspects. The best solution may not always be the most obvious. Here we describe an approach that addresses multiple objectives through a novel off-site solution that provides increased benefit to the impacted fish community.

The approach involved weighing up various fish passage options, informed by stochastic hydrologic modelling to produce a range of probabilistic scenarios. 120 years of modelled water levels and discharges from the study site and the broader catchment, enabled an evaluation of the benefits and dis-benefits of different options in relation to dam safety, water supply reliability and fish migration opportunities. Inputs to the assessment process included fish habitat availability and migratory needs, capital and operational feasibility considerations. Numerous modelling scenarios were produced to assess a range of possible solutions, both on and off-site, to provide an objective weighting of the relative strengths of each scenario.

In this instance, while an onsite option could be feasibly engineered, it would be costly and given the hydrology of the system, would operate so infrequently as to provide limited opportunities for fish passage and minimal regional fisheries productivity benefits. The optimal solution found was to provide fish passage on a higher order stream within the same catchment area that has impacted fish migration and access to upstream habitats for the same fish community. This option improves fish habitat access to a larger proportion of the catchment and over a wide range of flow conditions, thus providing greater regional fisheries productivity outcomes.

Our method demonstrated an objective approach to balancing multiple project objectives for dam improvements. The use of hydrologic modelling combined with fish migration and habitat information, found an optimal solution for regional fisheries productivity goals, while also balancing the dam safety and water supply reliability goals.

Keywords: *dam safety upgrades, dam safety improvements works, fish passage, regulatory compliance, fishway, Ewen Maddock Dam*

Introduction

Seqwater completed "Stage 2A" of a dam safety improvement project at Ewen Maddock Dam (EMD) in early 2021 as part of a staged approach to bring the dam up to current industry dam safety guidelines, addressing the requirements of the *Water Supply (Safety and Reliability) Act* 2008. The dam, located 3 km upstream of the Bruce Highway on Addlington Creek, a tributary of the Mooloolah River, was constructed in 1976 to provide a water supply to Caloundra City. The spillway height of EMD at full supply level (FSL) is 25.38 m AHD and has a catchment area of 20.9 km^2, representing 9% of the Mooloolah River catchment area (223 km^2) and has a Full Supply Volume (FSV) of 16,587 ML. A fishway was not included in the original 1976 construction nor subsequent upgrades in 1986 and Stage 1 dam safety upgrade in 2012. The Stage 2A and Stage 2B dam improvement works preserved the existing spillway height but improved elements of the embankment, crest height, spillway guide walls and anchoring. The project triggered regulatory approval for waterway barrier works. As such, consideration of fish passage at the site was required to meet these regulatory requirements.

It is well accepted that waterway barriers impact regional fish communities by reducing access to habitats and restricting migration pathways to complete their life cycle (Harris, *et al*. 2016). This can lead to loss of regional fish productivity (i.e. fewer fish overall) and localised extinctions of certain species dependant on river connectivity (Kohen & Crook, 2013). The technology to mitigate fish passage in Australia has improved greatly in recent years, but despite these improvements, any fish passage solution has minimum requirements to effectively mitigate the impact of the barrier, including the provision of adequate water flow and suitable habitats upstream of the barrier to support the fish community. This is fundamental for large impoundments that have the capacity to store and drastically alter the downstream hydrology of a system and can impound large areas of an upstream catchment's former riverine habitat. It is also difficult to implement fish passage technology on an existing dam with existing water supply commitments when the upgrade does not result in increased water supply, as was the case for EMD.

Drivers for Dam Improvements

The driving legislation for dam improvements in Queensland is the *Water Supply (Safety and Reliability) Act 2008*. Under Section 353 of the Act, the chief executive of the Department of Regional Development, Manufacturing and Water (DRDMW) has the power to apply safety conditions to a referable dam, which includes EMD. The DRDMW developed the Guidelines on Acceptable Flood Capacity for Water Dams (DNRME, 2019) to ensure estimates of extreme rainfall and the resulting flood estimates are incorporated into dam safety planning.

The dam safety improvement of EMD was to progress bringing the existing dam into compliance with current ANCOLD and Queensland industry guidelines and the requirements of the Act. Despite the principal characteristics of the embankment, spillway and the lake remaining the same, the dam safety improvement project triggered assessable development under the Queensland *Planning Act 2016* for waterway barrier works, which specifically relates to fisheries related impacts from barriers.

The development is assessed against the Queensland regulatory framework for waterway barrier works (State Code 18: *Construction or raising of waterway barrier works in fish habitats)*, which outlines a core purpose statement, including that "development … provides adequate fish passage including a fish way, if necessary". While the framework does not prescribe solutions, it provides the performance outcomes that a project is assessed against, and the project proponent must provide evidence that the performance outcomes have been met. Within this framework, there is scope for a proponent to propose an alternative solution to meet the performance outcome, though notably there is minimal guidance on evidence requirements for alternative solutions.

Given the complex and competing objectives needed from the EMD dam improvement project, meeting the performance outcomes for waterway barrier works were always going to be a challenge. Careful consideration of all available options, including non-standard solutions, was needed to meet the requirements.

Defining the challenge

An onsite fish passage was not initially considered in Seqwater's planning and design, as the dam safety improvement works did not change the spillway crest or introduce a new barrier to the Addlington Creek. Starting in 2016 planning for the dam safety improvement works looked at labyrinth and multi-level spillway crests before finally settling on an approach to strengthen the existing ogee spillway with post tension anchors. The design concept had substantially matured by 2018 and a development application was sought in parallel with construction contractor procurement activities.

Initial discussion and feedback on Seqwater's development application provided an apparently new regulator interpretation of waterway barrier works development for safety improvements on existing dams; which Seqwater had experienced on recently completed projects with like-for-like scope. A new fishway was not thought necessary because there was no change to fisheries impacts, however this was deemed not material to the requirement for reinstating fish passage. This initial advice required Seqwater to revise the design and consider providing an onsite fish passage solution. Addressing this requirement resulted in a 20% increase in capital expenditure (~$7M), a long-term operating and maintenance expenditure in the order of $50 000, expansion of the project footprint, a re-assessment of dam safety risks, and importantly impacted on the region's water security. These challenges led Seqwater to evaluate a wider range of possible solutions that would address the performance outcomes for waterway barrier works. This included the development of a multi-disciplinary approach that probabilistically evaluated each onsite and offsite option to determine the optimal solution that would satisfy the competing constraints. The use of a probabilistic approach provided objectivity in balancing the multiple goals of the improvement project and demonstrate the benefits and dis-benefits of fish passage mitigation solutions considered.

The optimisation approach was underpinned through use of stochastic hydrologic modelling. A long-term data set of rainfall, dam inflows and evaporation was utilised to build a model that would provide water level and discharge volumes under various operational configurations. The model enabled an evaluation of the different options on the water supply reliability metrics (e.g. no failure yield **Figure 1**.) and importantly, the frequency of fish migration opportunities. Numerous operational scenarios were conceived and run to assess many differing flow management rules and fish passage options. The outputs from this probabilistic scenario modelling provided an objective weighting of the relative strengths of each scenario.

Model Development and Approach

The methodology adopted was based around a continuous simulation water balance model built using GoldSim[1] v12.1 [GoldSim Technology Group, 2020]. This model could report, on a sub-daily timestep, the simulated reservoir behaviour and simultaneously implement a combination of rules for outlet works, spillway and target FSL for EMD and likely fishway operation. The model was calibrated against an independently built model used at Seqwater that modelled lake volume results over monthly time-steps. For practicality, Seqwater's water supply models are built to assess water security across the entire grid using a monthly time step. This also means that these models do not consider volumes above full supply and so cannot assess the duration of spillway flows or by what means they are discharged from the dam. A bespoke continuous simulation water balance model was developed that could calculate on a sub-daily step without the complexity required for a grid sized model. The following assessment only considers the hydrology of EMD in isolation to the rest of the water supply grid, which does not represent the full complexity of operations of the dam to meet the water grid requirement, however, it is suitable for the purpose of undertaking the feasibility assessment and simulations using the data appropriately.

The water balance model has used daily rainfall[2], Morton lake evaporation and inflow data from the Queensland Government's regional IQQM[3] model [Simons, 1996] representing the period of 1 July 1890 to 30 June 2011. These simulations provide an indication of the system's performance over a long period, using historical weather records. **Figure 1** compares the lake volume results from the bespoke water balance model daily output (blue line) with the monthly output from the Seqwater monthly water grid model (red).

[1] https://www.goldsim.com/Web/Applications/TechnicalPapers/
[2] https://www.longpaddock.qld.gov.au/silo/gridded-data/
[3] https://www.business.qld.gov.au/industries/mining-energy-water/water/maps-data/modelling/hydrologic-data

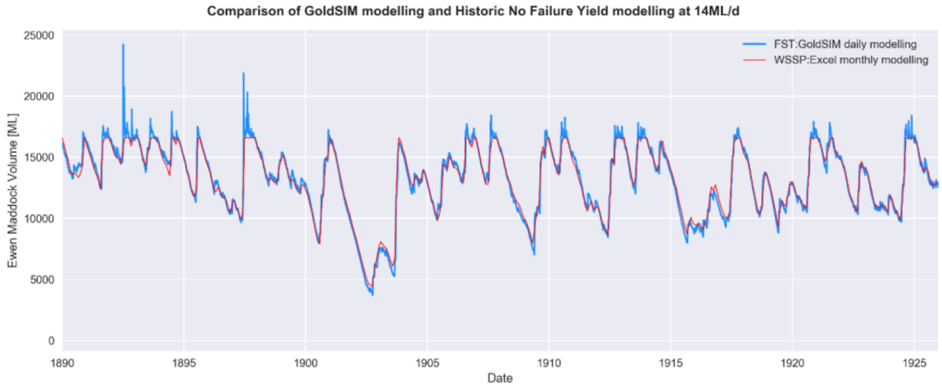

Figure 1 Extract [1890 – 2011] from validation modelling of this paper's sub-daily water balance model with monthly supply model from Water Supply Planning model.

The GoldSim model was considered fit for purpose and suitable for use in assessing EMD. Figure 1 is a useful approximation of the lake levels had the dam, as it exists today, been operated over the historical weather record.

Scenario Modelling

Continuous simulation analysis considered various scenarios at EMD that enabled quantification of the impact/benefits of a potential fishway to water supply reliability. The water supply extractions in the simulations are limited to the currently approved water allocation and maximum water extractions according to water licence conditions. A summary of the basis of the assessments and the different fishway operational regimes are as follows:

- Assumes EMD starts full in 1890;
- In accordance with *Water Licences 607478 and 605881;*
    - water extraction from EMD is 4,315 ML per annum (11.8 ML/d);
    - water may only be taken from EMD at the low rate of 210 ML/d per 30 day period when >72% FSV, otherwise maximum extractions of 20 ML/d.
    - The Minimum Operating Level of EMD is 523 ML, approximately 3.1% of full supply volume.
    - environmental flow releases of 0.25ML/d when inflow is greater than 2 ML/d, and 2 ML/d for inflows up to 20 ML/d.
    - No environmental releases occur when spilling >2 ML/d.
- Spillway overflows explicitly limited to spillway capacity as this provides better representation of periods when EMD is above FSL;
- Direct rainfall onto reservoir simulated separately to catchment inflows
- Post-processing results at daily time step, lake water balance at three hour time step. This smaller time step was necessary to achieve stable results when simulating overflows being limited to spillway capacity; and
- It is assumed that an onsite fishway would require between 20 and 50 ML/d for successful operation.

Modelled behaviour

The modelling of the existing dam scenario over the 120 year window aligns well with observed water level data at the dam (Figure 1). On average, the dam is at 100% FSV (FSL) for ~20% of the time and water levels greater than 12,000 ML (equal to 72% FSV) occur around 85% of the time. While the model shows the dam spills somewhat frequently, at around 20% of time, assuming future rainfall patterns continue to reflect historical patterns, across all seasons, spills greater than 20 ML/d occur <13.9% of the time and the average period between spills is 245 days. The mean annual water balance for the existing case in EMD are as follows:

- 15,686 ML/y mean annual inflow [including direct rainfall on lake];
- -10,045 ML/y mean evaporation, extraction and environmental releases; and,
- -5,620 ML/y mean annual spillway flows.

For the no fishway, pre-existing case, downstream flows of 20 ML/d occur 8% of time, and 50 ML/d, 5% of time. The modelling of the pre-existing hydrology, assuming no dam is present, is based on the flow duration of catchment inflows and provides a baseline giving context to the natural hydrology of Adlington Creek to compare against the current situation with the dam. Across all seasons, a no dam case shows that flows >20 ML/d would occur 21.5% of time, and 50 ML/d flows occur 12% of the time.

A range of feasible on-site fishway operating rules were proposed that reflect realistic scenarios based on the dam's hydrology and operating constraints under current water licences and the minimum flow rates (20 ML/d) for a typical fishway to provide adequate depth and attraction flow. Using 20 ML/d is a conservative approach, as any negative impacts would only be exacerbated under higher fishway flows. The selection of 100 ML/d as an inflow requirement was based on a suitable multiplier (5 x minimum flow of 20ML/d) and an amount that could be detected by the lake level gauge to infer inflows. The following on-site fishway operating rules were simulated to enable an objective evaluation of the implications on water security of the dam.

1. Fishway only operates when dam is spilling >100 ML/d;
2. Fishway operates whenever the lake is above 70% FSV;
3. Fishway operates whenever the lake is above 80% FSV;
4. Fishway operates whenever the lake is above 90% FSV;
5. Fishway operates whenever the lake is above 95% FSV;
6. Fishway only operates when inflows exceed >100 ML/d and Lake is above 70% FSV;
7. Fishway only operates when inflows exceed >100 ML/d and Lake is above 80% FSV;
8. Fishway only operates when inflows exceed >100 ML/d and Lake is above 90% FSV;
9. Fishway only operates when inflows exceed >100 ML/d and Lake is above 95% FSV;

Table 1: Summary results for various operating rules. Values in red and orange fail and approach failure of the water reliability criteria for the storage.

	Fishway Operation time (@20ML/d)	Mean period between spilling events (days)	Time EMD >70% FSV	WTP Annual Extraction (ML)	% change in Water Extractions
No Fishway	21%		n/a		0%
Existing	**0%**	**245**	**58%**	**5,313**	**0%**
Rule 1	3%	245	58%	5,313	0%
Rule 2	41%	344	35%	4,219	-20.6%
Rule 3	29%	306	46%	4,723	-11.1%
Rule 4	20%	294	52%	5,036	-5.2%
Rule 5	16%	285	55%	5,166	-2.8%
Rule 6	6%	251	57%	5,275	-0.8%
Rule 7	5%	251	58%	5,297	-0.3%
Rule 8	4%	247	58%	5,309	-0.1%
Rule 9	4%	247	58%	5,311	0%

Rule 1

Operating the fishway only occurs when the dam is spilling at > 5 times fishway minimum flow capacity (equal to 100 ML/d). This rule represents a scenario that would have no impact on current water supply reliability. This flow rule limits the frequency the fishway operations to only 3% of the time (on average this is equivalent to 11 days per year) for a release of 20 ML/d. On average the no flow period between fishway operations under this rule would be 214 days. This rule did not allow for beneficial fishway operation and could be considered of little positive value for fisheries outcomes.

Rules 2 through 5

This suite of rules requires the lake to be above certain levels (70%, 80%, 90% and 95%) before the fishway commences operation. Noting the results of Rule 1, these results considered the trade-off between more frequent fishway operation and water security. The fishway would operate (20ML/d) any time the lake level is above the nominated FSV. The lake level would be drawn down to the nominated FSV of the rule. The spells of time between EMD spilling also increase due to this lower lake level. While greatly improving the frequency of operation, these rules came at a significant cost to regional water security. The higher FSV rules provided limited benefit with water security dis-benefits.

Rules 6 through 9

Expanding on rules 2 through 5, rules 5 to 9 include an inflow requirement that means fishway operation only commences when EMD inflows exceed 100 ML/d. Adding this condition aims to limit the impact on water supply reliability of the dam, and would constrain the fishway operation to between 4 - 6% of time for a release of 20 ML/d. There would be very little change to the dam spilling scenario, though this indicates that the fishway would also not operate very often, refer Figure 2 for an example of days in operation across seasons using Rule 7. Under these four scenarios, the period between fishway operations are indicated to potentially be between 53 and 104 days.

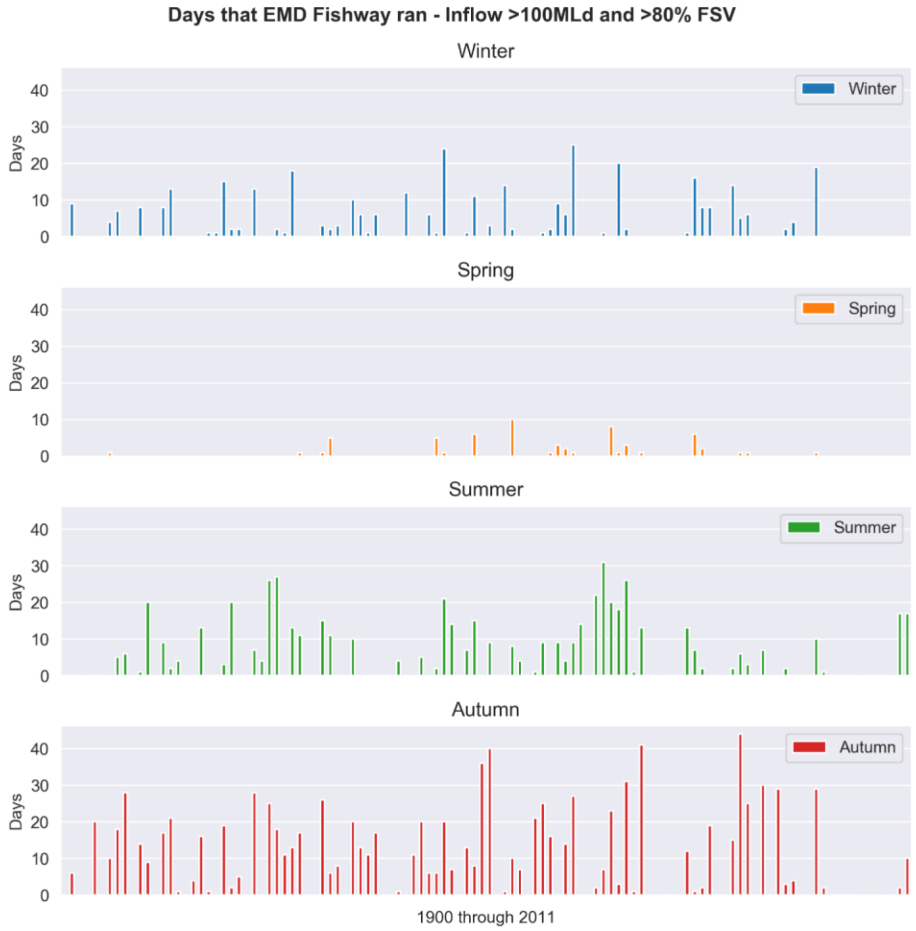

Figure 2: Graphical representation of Rule 7 results across seasons showing number of days that a fishway would operate in each season.

All of the rules were analysed per season to determine how many days an on-site fishway would potentially operate (**Figure 2)**. Rule 6 had the greatest number of days (44) in one season and the most days of operation would occur in Autumn. When expressed as an 'average' across all seasons, the on-site fishway never operated continuously for more than 10 days.

Summary of Ewen Maddock Dam fishway option

All scenarios have inherent limitations in the number of days of operation to preserve water supply security, one of the primary non-negotiable outcomes needed from this assessment (Table 1). Rules 6 to 9 include scenarios that have minimal impact on water supply but also limit operational time of a fishway to between 4 - 6% of the time. For the three scenarios this would be an average duration of between 97 and 128 days between independent fishway operations. Rules 4 and 5 see a marginal improvement in amount of time a fishway would operate (20 and 16% of time respectively) with relatively small impacts to water extractions (-5.2 and –2.8% respectively) but the duration of dry spells increases considerably (294 and 285 days respectively). This highlights the challenge of balancing water security needs with fishway operations to benefit the fish community. In a low flow catchment like Adlington Creek, it is not possible to have both, as one outcome is always going to need compromise.

Figure 3 provides a timeseries comparison of fishway operation for Rules 7, 8 and 9. The vertical bars indicate a day when the fishway was operating. The comparison demonstrates the progressive reduction in number of days of operation as the FSV trigger is reduced from 95 to 80% and highlights there are significant periods multi-year gaps where there will be no operations of the fishway.

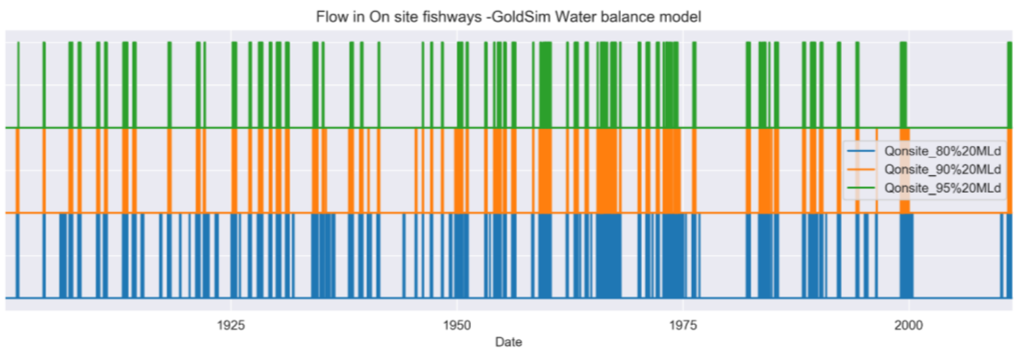

Figure 3: Comparison of results for Rules 7 – 9 showing Boolean representation for the number of days a fishway would run over 120 years. Daily operation of the fishway 'On' is represented by a vertical bar for each rule.

For all onsite fishway rules, there were significant periods where there is no operation of the fishway due to high demands on the reservoir and low catchment inflows. The modelling of the no dam case provided an estimate of flow frequency for downstream waterways. Due to attenuation by the lake, no fishway operation rule was able to replicate the no dam flow frequency or flood volumes. Rules 2 to 5 have the greatest impact on water reliability as inflows from the catchment are not required before the fishway is operated, so the reservoir is drawn down faster. All four rules would significantly impact on water supply security, resulting in the dam frequently reaching lower storage levels faster and impacting on water supply to the region and risk the lake approaching minimum operating levels more often. These scenarios are unacceptable and fail to meet regional water supply demands. Rules 7 to 9 provided a more conservative operating rule (e.g., only operates at higher storage levels and when inflows are occurring) the storage reliability was improved but resulted in a dramatic decline in average operating time.

Finding an optimal solution

The modelling results for the on-site fishway option demonstrates that due to the hydrology of the catchment and water supply requirements of the dam, a fishway option on EMD could only be feasible under the most conservative fishway release rules, to not compromise water security objectives. Additionally, the design process for on-site fishway options highlighted many technical challenges that added significantly to the cost and engineering difficulty of the project so as not to compromise the dam safety objectives of the project. The prudency test for large public money expenditures such as this, requires that all possible options are evaluated to find an acceptable solution.

A waterway barrier prioritisation study (Moore & McCann, 2018) identified the top 50 highest impact fish passage barriers within the Sunshine Coast local government area, including the Mooloolah River catchment. EMD ranked 27th out of 50. The study also identified a nearby gauging weir on the main stem of the Mooloolah River (Mooloolah stream gauge 141006A) as a much higher priority barrier at 9th (Figure 4). For this reason, the Mooloolah gauge site was investigated as an option for mitigating the regional fisheries impacts of EMD.

To objectively assess if Mooloolah Gauge could provide a better outcome for regional fisheries productivity over EMD, a suite of characteristics was evaluated (Table 2). This highlighted that improving passage at the Mooloolah gauge could provide beneficial outcomes in terms of providing access to more habitat.

Table 2: Comparison of features of the waterways upstream of both Ewen Maddock Dam and Mooloolah gauge to inform beneficial outcomes for regional fisheries productivity

Feature	Ewen Maddock Dam site	Upstream Mooloolah Gauge site
Catchment Area (km^2)	21	39
Annual Average Flow (ML)	5,292#	24,409*
Total Habitat Available upstream of Impounded Waters (ha)	22	66
High priority Habitats Available upstream of Impounded Waters (ha)	0	34
Hydrology	Highly Regulated	Minimally Regulated
Period of Fish Connectivity post Fishway	Low/Intermittent	High/Regular

This modelled flow statistic represents average environmental releases and spill events, it is not inflow to dam
* Average of 49 years of data from DNRME Water Monitoring Information Portal.

The Mooloolah River upstream of the confluence with Addlington Creek has no major barriers other than the stream gauge and has almost twice the catchment area ($39km^2$), a more sustained flow pattern and a larger area of available habitat (Figure 4, Table 2). Although a small weir, fish passage is impeded or prevented on all flows below drown out, which is a significant proportion of time, as discussed below.

Figure 4: Site photo of Mooloolah gauge

Figure 5 depicts the topographic relief of the adjacent sub-catchments. The Mooloolah flow monitoring gauge (141006A) is located below about twice the catchment area as impounded by EMD.

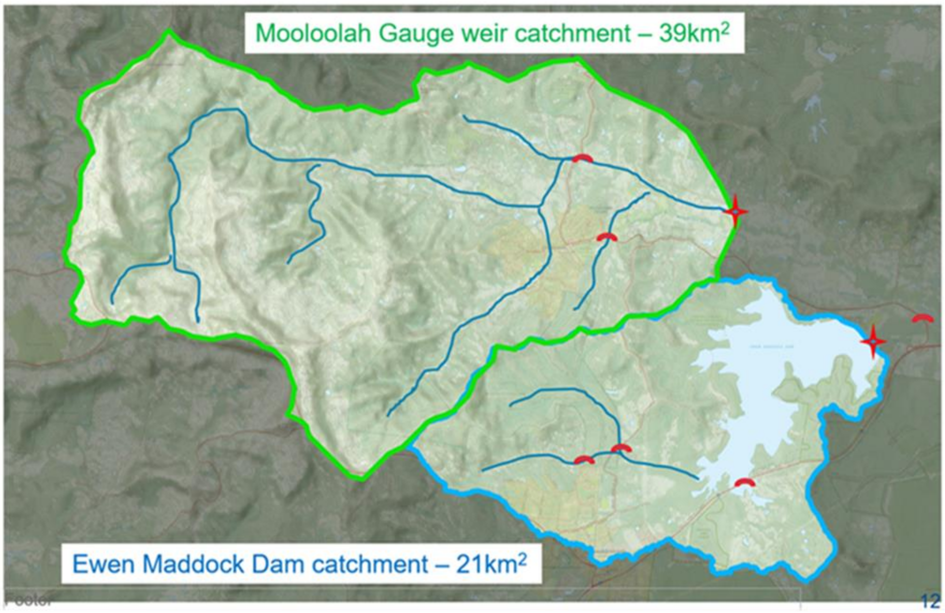

Figure 5: map of the Mooloolah River catchment upstream of the confluence with Adlington Creek, showing location of major barriers at Ewen Maddock Dam and Mooloolah River gauge (141006A) (star symbol) and minor barriers in road crossing pipe culverts (arch symbols).

A hydraulic model of the Mooloolah gauge was constructed in HECRAS 5.0.7 using a 1m digital elevation model from Sunshine Coast Regional Council. As the DEM includes the water surface, the in-bank channel was lowered to approximate the stream channel form observed during a site inspection. The details of the crump weir were input and calibrated with the gauging table provided on Water Monitoring Information Portal[3] .

The 2012 Keller *et al.* method was used to assess drown out and minimal useful flow rates flow rates to assess the adequacy of fish passage at the Mooloolah gauging weir. From these calculations, the limits of beneficial flow at the gauge site are as low as ~0.06m^3/s (4ML/d) up to 2m^3/s (17 ML/d). Flows below 5 ML/d are at considered the lowest useful flow amount for attraction flows in the fishway. Flows above 2m^3/s result in drown out the weir and allow unimpeded fish passage. The flow record as shown in Figure 6 show that a fishway option to replace the Mooloolah gauge weir would provide greatly improved fish passage and access to a larger area of high-quality habitat than a fishway on EMD would provide.

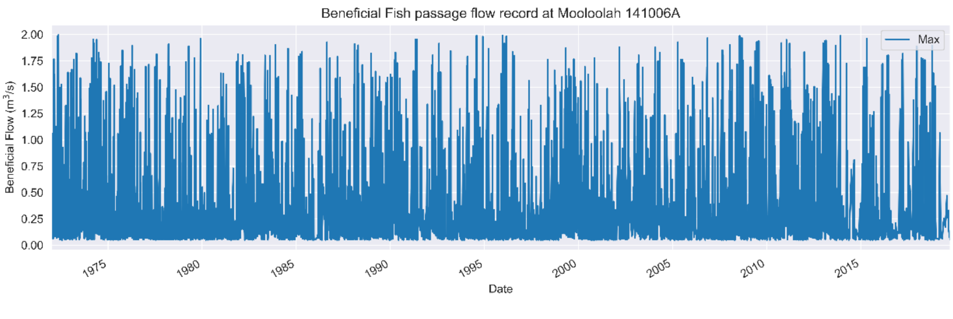

Figure 6: Beneficial flow record at Mooloolah gauge weir

[3] https://water-monitoring.information.qld.gov.au

A comparative analysis of operational fishway days for both the EMD and the Mooloolah gauge fishway options was undertaken and is presented in **Figure 7** and **Figure 8**. The analysis demonstrated a clear differentiation in beneficial outcomes in terms of total number of days of potential fishway operation and therefore days of fish connectivity between the lower and upper parts of the catchment.

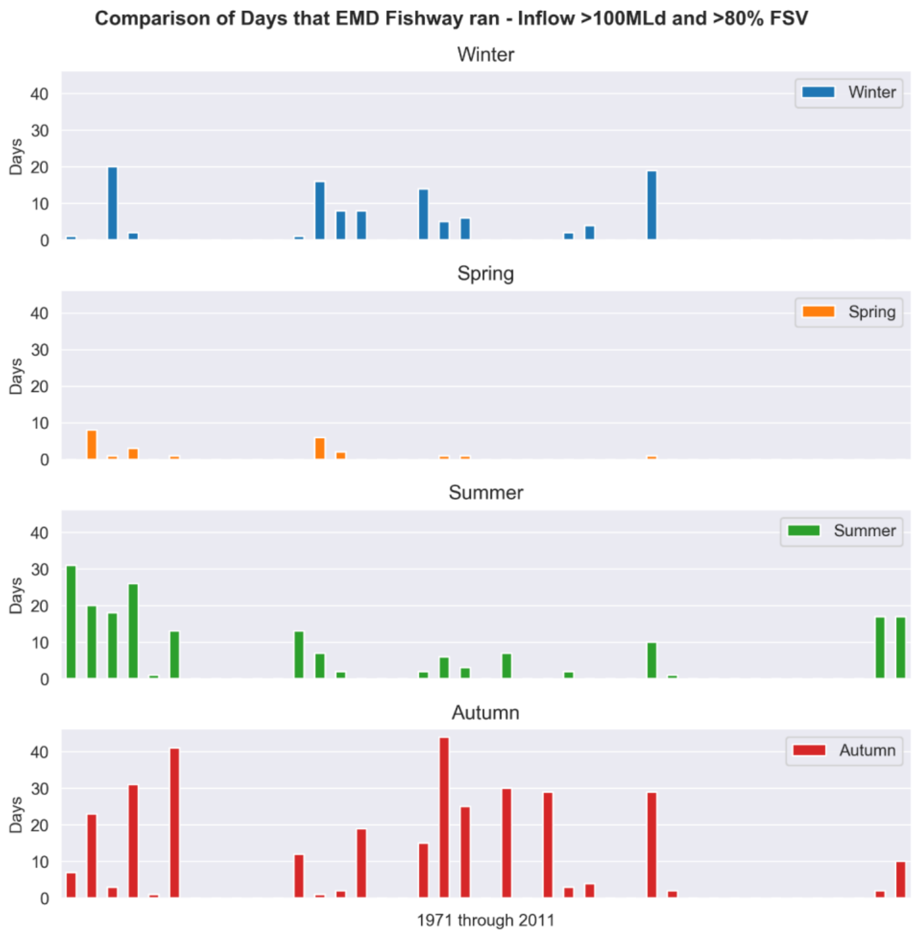

Figure 7: Comparison of days of fishway operation for the Ewen Maddock Dam on-site option (rule 7) over the period 1971 to 2011

Figure 8: Comparison of days of fishway operation for the Mooloolah Gauge Weir option (off-site) over the period 1971 to 2011

Conclusions

Preliminary investigations into the feasibility of onsite fish passage options at EMD determined that these options would significantly increase the overall dam safety improvement project capital costs by ~40% (~$7M) and leave a legacy of high operational and maintenance expenditure. But more importantly, due to the nature of the hydrology of the system and its primary function as a water supply dam, any onsite fish passage option could seriously impinge on the water security objectives of the dam and also reduce the fishway operating range to a very narrow window of time. These objective investigations highlight the challenges of retrofitting major water supply infrastructure, while balancing the multiple objectives of dam safety, water reliability, legislative compliance and effectively mitigating historical impacts from dam infrastructure on regional fisheries resources. This paper successfully employed an objective data analysis approach to explore a range of options and develop one that achieves this delicate balance and provides for tangible beneficial outcomes for regional fish productivity goals of the regulator.

Developing optimal fish passage outcomes requires an input from a range of key specialty areas and a thorough analysis of available information to enable an objective assessment of the options that leads everyone with a stake in the outcome, to agree on the optimal solution. Often waterway barrier works solutions can become constrained by considering a narrow range of possible mitigation options when it comes to retrofitting old water supply assets. We hope to demonstrate in this paper that by taking a broader approach and using objective analysis tools and considering the needs of the fisheries resources of the region, new and novel alternative options that can provide much greater beneficial outcomes for regional fisheries productivity can be discovered and provide the most prudent use of public funding for dam improvement projects, dam safety and fisheries regulators and ultimately regional fisheries resources.

Acknowledgements

The authors gratefully acknowledge Seqwater for permission to publish these details. In addition, this project was a team effort and the input and counsel to this project, especially that of Nigel Smith, Senior Project Manager (Seqwater) Michel Raymond, Senior Operations Engineer (Seqwater) Barton Maher, Engineering and Technical Manager (Seqwater), John Williams, Senior Principal Dam Engineer (GHD) is duly acknowledged.

Commented [LM1]: Reviewer 2: Again it would be good if you could quantify the cost reduction and also what the cost of the completed works on the Mooloolah Gauge were for comparison to the estimated cost if fish passage was constructed at EMD

Commented [LM2]: Reviewer 2: There must have been a lot of interaction and discussion with the Regulator during this process. It would be useful to include some commentary on this in the paper and also a statement that the Regulator was (presumably) satisfied with the outcome.

Commented [LM3]: Reviewer 2 - did you see the Regulator as part of the broader project team

References

Department of State Development, Manufacturing, Infrastructure and Planning, 2020 State Development Assessment Provisions v2.6. Available at https://dsdmipprd.blob.core.windows.net/general/sdap-version-2.6.pdf. Accessed 14 July 2021.

Department of Natural Resources, Mines and Energy (2020). Guidelines on Acceptable Flood Capacity for Water Dams. Available at https://www.dews.qld.gov.au/__data/assets/pdf_file/0003/78834/acceptable-flood-capacity-dams.pdf. Accessed on 15 July 2021.

Harris J. H., Kingsford R. T., Peirson W., Baumgartner L. J. (2016) Mitigating the effects of barriers to freshwater fish migrations: the Australian experience. *Marine and Freshwater Research* **68**, 614-628. https://doi.org/10.1071/MF15284.

Keller, Peterken and Berghuis (2012) *Design and assessment of weirs for fish passage under drowned conditions* Ecological Engineering https://doi.org/10.1016/j.ecoleng.2011.06.037

Koehn, J. D., and Crook, D. A. (2013). Movements and migration. In 'Ecology of Australian Freshwater Fishes'. (Eds P. Humphries and K. Walker.) pp. 105–129. (CSIRO Publishing: Melbourne.)

Moore, M. and McCann, J., (2018) Sunshine Coast Fish Barrier Prioritisation. Catchment Solutions. Sunshine Coast Council.

O'Connor, J., Stuart, I. and Jones, M. (2017). *Guidelines for the design, approval and construction of fishways*. Arthur Rylah Institute for Environmental Research. Technical Report Series No. 274. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Ivor G. Stuart and Timothy J. Marsden, (2019) *Evaluation of cone fishways to facilitate passage of small-bodied fish* Aquaculture and Fisheries, https://doi.org/10.1016/j.aaf.2019.02.003

Simons, M., Podger, G. and Cooke, R. (1996), IQQM- A hydrologic modelling tool for the water resources and salinity management?, Environmental Software, 11(1-3): 185-192. https://www.sciencedirect.com/science/article/abs/pii/S0266983896000196