Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) Stage 7 & Wetland Monitoring and Assessment Program (WetMAP) Stage 4 Summary Report (2021–2024)

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Arthur Rylah Institute for Environmental Research
Department of Energy, Environment and Climate Action
PO Box 137, Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

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Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) Stage 7 **& Wetland Monitoring and Assessment Program (WetMAP)** Stage 4 **Summary Report (2021–2024)**

Arthur Rylah Institute for Environmental Research
Department of Energy, Environment and Climate Action
123 Brown Street, Heidelberg, Victoria 3084

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Department of Energy, Environment and Climate Action

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1 Introduction

Context

There has been considerable investment in the management of river, wetland and riparian ecosystems for environmental, cultural, social and economic purposes in Victoria. Environmental water is a significant component of that investment, with environmental flows managed to achieve objectives stated within Environmental Water Management Plans (EWMPs).

The Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) and the Wetland Monitoring and Assessment Program (WetMAP) were designed with the aims of understanding the ecological responses to environmental water being delivered, analysing the outcomes, and informing the adaptive management of environmentally watered assets. VEFMAP and WetMAP began in 2005 and 2014, respectively, and concluded in June 2024. VEFMAP Stage 7 and WetMAP Stage 4 were undertaken between 2020 and 2024. In total, 17 projects were delivered through the program, focused on environmental water outcomes for fish, vegetation and waterbirds.

Program objectives

The overarching objectives for both programs for 2020–2024 were:

- To address knowledge gaps to improve the planning, delivery and evaluation of environmental water management in rivers and wetlands across Victoria
- To enable the Department of Energy, Environment and Climate Action (DEECA) and its delivery partners to demonstrate and communicate the outcomes of environmental water use in rivers and wetlands across Victoria
- To contribute to the fulfilment of Victoria's reporting obligations under the Murray–Darling Basin Plan (including Schedule 12, Matter 8).

Purpose of the Summary Report

For each project within the VEFMAP and WetMAP, primary outputs (including technical reports, journal articles, presentations, and fact sheets) were produced and shared with key stakeholders (such as the Catchment Management Authorities and the Victorian Environmental Water Holder). The purpose of this Summary Report was to provide an overarching, high-level summary of all the work undertaken through these two programs between 2020 and 2024. Reporting on the projects within the two programs has been organised according to taxa (fish, vegetation and waterbirds). The Summary Report provides a brief outline of the purpose and findings of each individual project delivered within the two programs, and implications for environmental water management. It is intended as a starting point for readers seeking to understand the breadth of the work that has been delivered. The final reporting outputs for each project, within which more detailed information can be found, are listed throughout this report.

2 VEFMAP fish projects

Under the VEFMAP fish theme, six projects were completed, which included a combination of annual condition monitoring, stochastic population modelling, literature reviews, hydraulic modelling, fish tagging, and tracking, and trends analyses of long-term datasets. These approaches were used to assess specific questions relating to the role of environmental flows in influencing the governing processes and dynamics of native fish populations. The key results generated for each of the projects are as follows.

2.1 Annual fish monitoring across priority Victorian waterways: assessing trends in population demographics to inform water management

2.1.1 Statewide trends for native fish species

Maintaining or improving native fish populations is a fundamental objective of many waterway management plans and interventions, including the management of environmental water. Many native fish species targeted by environmental water are long-lived (>10 years), breed once a year, and often have wide home ranges. Thus, assessing population dynamics requires data collected over multiple years, analyses that consider spatial and temporal scales that encompass the life history attributes of the target species, and information on drivers of change and associated management actions.

This project had two aims:

1. To assess long-term trends in the relative abundance, distribution and recruitment of priority native fish species within reaches, within waterways, and collectively across their riverine distributions in Victoria
2. To assess the role of flows in determining the within-reach abundance and recruitment of priority fish species, both annually and over the long term.

A comprehensive assessment of the long-term population dynamics of native fish in Victoria was undertaken, drawing on over 20 years of fish monitoring data from 26 waterways. Statistical modelling was used to assess the long-term trends in the abundance and recruitment of 18 priority native fish species in mid and lowland, regulated and unregulated river reaches, including the exploration of likely predictors of observed trends. This included the analysis of data for reaches where water for the environment is delivered, providing important insights into how river flows and flow management have influenced fish populations.

The results of the monitoring showed that, across Victoria, most fish species declined during the 2000–2010 period (the ‘Millennium Drought’), followed by increasing trends in abundances over subsequent years. In coastal Victoria, this increasing trend following the Millennium Drought was most notable for Eels (*Anguilla* spp.), Common Galaxias (*Galaxias maculatus*), River Blackfish (*Gadopsis marmoratus*), Tupong (*Pseudaphritis urvillii*) and Australian Grayling (*Prototroctes maraena*). In northern rivers, increases were most notable for Murray Cod (*Maccullochella peelii*), Trout Cod (*Maccullochella macquariensis*), Golden Perch (*Macquaria ambigua*) and Macquarie Perch (*Macquaria australasica*). In contrast, there were mixed trends (no change or decreases since 2010) for Unspecked Hardyhead (*Craterocephalus fulvus*), Silver Perch (*Bidyanus bidyanus*), Murray–Darling Rainbowfish (*Melanotaenia fluviatilis*) and Two-spined Blackfish (*Gadopsis bispinosus*).

For many species, there were links between changes in fish population abundances and flow regimes. For instance, for Murray Cod, River Blackfish, Macquarie Perch, and most diadromous species, higher abundances and reporting rates were associated with fewer low-flow days per year, particularly in several highly regulated systems (the Glenelg, Campaspe, Thomson and Goulburn rivers). In contrast, for summer-spawning small species such as Murray–Darling Rainbowfish, higher abundances were associated with years of low discharge and a high number of low-flow days, likely due to a greater availability of warm water and higher concentrations of prey during their early life stages. However, due to gaps in the data, the models had limited ability to quantify the role of environmental water in governing these changes at annual time steps.

2.1.2 Insights for environmental water management

This work has provided information to support managers planning environmental watering actions to benefit fish. The following recommendations are provided to guide future work.

1. Given the regular recruitment and stable or increasing abundance of the majority of the priority native fish species, continue to follow current flow recommendations within Seasonal Watering Proposals and Plans, for the lower Goulburn, Campaspe, Broken, Glenelg, Moorabool and Thomson systems.
2. Given the lack of recovery post Millennium Drought in the lower Loddon River, review the current flow recommendations and objectives and test any such revisions.

These results will enable managers to track progress towards achieving the fundamental objective of maintaining or improving native fish populations as outlined in waterway management strategies and EWMPs.

2.1.3 Final report

Tonkin, Z., Yen, J.D.L., Kitchingman, A., Amtstaetter, F., Hackett, G., Harris, A., Koster, W., Lieschke, J., Lyon, J., Pickworth, A. and Raymond, S. (2024). *Assessing long-term population trends for priority fish species across Victorian rivers.* Arthur Rylah Institute for Environmental Research unpublished report for DEECA Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

2.2 Forecasting responses of priority fish species and their interactions to environmental water in Victorian rivers

2.2.1 Population models to inform flow management

Predicting species' responses to environmental water helps inform decisions about when, where, and how to use managed flows most efficiently. Population models use species' information (e.g. regarding reproduction and survival) to predict how populations will change over time, while considering the effects of other environmental conditions and actions (e.g. stocking, habitat quality, other flows) and future uncertainties.

This project had four aims:

1. To develop population models in a publicly available, open-source software package that allows the rapid updates required for model validation and forecasting
2. To validate the population models with existing and new data to quantify the uncertainty in the modelled outputs and to identify any knowledge gaps contributing to high uncertainty
3. To forecast population outcomes under managed flow scenarios to evaluate or forecast fish population responses to environmental water in monitored and previously unmonitored locations
4. To examine the interactions between target species and other groups of fish to determine whether species' interactions mask or offset the expected benefits of environmental flows.

This work provided insights into processes not considered within current models (e.g. flooding and hypoxia) and highlighted gaps in the current knowledge or existing data. Validation of the model outputs by comparing predictions with independent data (i.e. data not used to build the models) highlighted uncertainties in the predictions in some systems. A range of models and decision-support tools are used to inform waterway management, but very few of these approaches have been validated with independent data. Outputs from models (population models and alternative approaches) form only one line of evidence and therefore should always be interpreted in the context of local ecological knowledge.

Population models for three key species were found to be most accurate for: (1) River Blackfish in the Glenelg River; (2) Murray–Darling Rainbowfish in the Broken and Goulburn rivers and lower Broken Creek; and (3) Murray Cod in the Campaspe and Goulburn rivers and lower Broken Creek (based on an update of the existing model). The population models were found to be less accurate for: (1) River Blackfish in the Loddon, Macalister, Mackenzie, Moorabool and Thomson rivers; (2) Murray–Darling Rainbowfish in the Campaspe and Loddon rivers; and (3) Murray Cod in the Broken, Loddon and Ovens rivers.

Examination of species' interactions using population models for these three key species and a population model for the introduced Common Carp (*Cyprinus carpio*) showed a mix of positive and negative associations between species and size classes, with several key findings: (1) The inclusion of species' interactions for River Blackfish and Murray–Darling Rainbowfish reduced their recruitment and survival; (2) Common Carp show improved population outcomes when interacting with other species. The exact mechanism contributing to these outcomes is unknown and may reflect predation on other species or, more likely, a competitive advantage over other species under some environmental conditions; (3) The effect of species' interactions on Murray Cod populations varied between rivers—interspecies interactions had a positive effect in the Campaspe and Broken rivers and Broken Creek, and had a negative effect in the Goulburn, Loddon and Ovens rivers. These associations were stronger at the site scale than at river reach or waterway scales. The associations likely reflect multiple processes, including shared associations with environmental factors and direct and indirect species interactions.

2.2.2 Insights for environmental water management

This work has provided information to support managers planning environmental watering actions to benefit fish. The following recommendations are provided to guide future work.

1. Sustained baseflows are predicted to benefit Murray Cod in the lower Broken Creek and Goulburn River, including when future flows are uncertain.
2. Continued environmental flow delivery is predicted to support or further improve population outcomes for Murray Cod in the Goulburn River and River Blackfish in the Glenelg River.
3. Delivery of larger flow events (e.g. freshes) should avoid large increases in flow variability where these events coincide with sensitive fish life stages (in late spring and summer).

2.2.3 Final reports

Yen, J.D.L., Todd, C., Wootton, H., Amtstaetter, F., Kitchingman, A. and Tonkin, Z. (2024). *Do species interactions influence outcomes from environmental flows? A case study in populations of Victorian riverine fish.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

Yen, J.D.L., Todd, C., Amtstaetter, F., Kitchingman, A. and Tonkin, Z. (2024). *Near-term ecological projections to inform environmental flows: a case study in populations of three native fish in multiple rivers.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

2.3 Investigating the key flow and habitat requirements of early life stages of native fish and crustaceans

2.3.1 Enhancing habitat to improve species recruitment

For many waterways, environmental flows are increasingly used to improve habitat conditions to enhance the recruitment of fish or their prey. There is a knowledge gap regarding the specific physical habitat requirements of early life stages for native fish and macrocrustaceans, as well as a lack of quantitative assessment of whether current flow recommendations effectively support these habitat needs.

This project considered the physical habitat attributes used by early life stages of native fish and macrocrustaceans in Victorian rivers, how specific habitat features contribute to recruitment, and whether flow management interventions that aim to enhance the habitat for early life stages and their prey achieve their objectives.

The specific aims of this study were to:

1. Quantify physical habitat attributes (such as hydraulics, depth, structural habitat, and aquatic vegetation used by early life stages of native fish and macrocrustaceans) at different scales within a waterway or reach
2. Assess how varying discharge levels influence the availability of key hydraulic habitat attributes using hydraulic habitat models (specifically addressing the physical habitat attributes defined in Aim 1)
3. Inform approaches for assessing flow recommendations across other Victorian river reaches in which flows are managed to achieve similar outcomes for native fish.

The influence that flow management interventions has in enhancing the habitat for early life stages of native fish and crustaceans was explored by assessing VEFMAP long-term fish monitoring data, undertaking a literature review, and hydraulic modelling.

The data assessment focused on 10 freshwater fish species at 70 sites in the Campaspe, Goulburn and Broken rivers in northern Victoria, and the Glenelg, Moorabool and Thomson rivers in southern Victoria. The analyses demonstrated that the recruitment of fish varies within and across waterways, and across species and life history stages, and is influenced by both flow and non-flow factors. How fish recruitment responds to flow attributes is often dependent on site-specific non-flow factors that influence habitat complexity, such as streamside vegetation and instream woody habitat density.

Hydraulic modelling was undertaken for the Goulburn and Campaspe catchments, which were selected due to the relatively high environmental water allocation in those catchments, relevant fish objectives, and the availability of data.

2.3.2 Insights for environmental water management

Waterway managers can use the results generated from this research to review and guide flow plans to enhance the recruitment of native fish populations across rivers in northern Victoria (Campaspe, Goulburn and Broken rivers) and southern Victoria (Glenelg, Moorabool and Thomson rivers). The following recommendations are provided to guide future work.

1. Environmental flow planning for priority species with differing requirements should take into account the timing of key ecological needs within and across years to manage potential conflicts.
2. Quantitative links between key spawning and recruitment habitat and discharge showed:
   - Increased flows can have a positive impact on the area of spawning habitat available for spring-spawning species: Murray Cod, Trout Cod, River Blackfish, Silver Perch and Golden Perch in the Goulburn and Campaspe rivers
   - Increased flows can negatively impact slackwater habitat, which is critical to the early life stages of shrimp, prawns, Murray–Darling Rainbowfish, Southern Pygmy Perch (*Nannoperca australis*) and Variegated Pygmy Perch (*Nannoperca variegata*).
3. Avoid extreme variation in discharge during the core reproductive periods for Murray Cod, Trout Cod, Freshwater Catfish (*Tandanus tandanus*), River Blackfish, Australian Smelt (*Retropinna semoni*) and Flat-headed Gudgeon (*Philypnodon grandiceps*).
4. Use environmental water to maintain summer discharge around the long-term average conditions, avoiding periods of extreme high flow or low flow.

2.3.3 Final report

Tonkin, Z., Arrowsmith, C., Harris, A., Kitchingman, A., Koster, W., Mole, B., Nystrand, M. and Yen, J.D.L. (2024). *Flow and habitat requirements of early-life stages of native fish and macrocrustaceans.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

2.4 Enhancing blackfish recruitment and population outcomes using environmental flows

2.4.1 Blackfish recruitment linked to flow attributes

Blackfish species (*Gadopsis* spp.) have experienced declines in abundance and distribution throughout the river systems of south-eastern Australia. These declines are predominantly attributed to overharvest, siltation, loss of structural habitat, reduction in riparian vegetation, introduction of pest species, and altered stream flow. A key management intervention for blackfish populations in Victoria is the management of flows to enhance natural recruitment. However, quantitative links between recruitment and attributes of the stream flow have not been established. Thus, water has so far been delivered based only on a conceptual understanding.

The key aims of this project were to:

1. Analyse long-term monitoring data, collected across a range of rivers within Victoria over the last 10–20 years, to determine the quantitative links between blackfish recruitment, water temperature, and components of the flow regime
2. Provide specific discharge rates for flow predictors for each river reach investigated, to assist managers in developing operational targets for waterways to increase recruitment success
3. Provide recommendations for managers to maintain and potentially improve blackfish populations in south-eastern Australia.

The analysis found that River Blackfish and Two-spined Blackfish recruited in most years, with the magnitude of this recruitment being influenced by specific components of the flow regime. Specifically, blackfish recruitment was influenced by: (1) flow variability during spawning, (2) water temperature during spawning and (3) flow conditions during summer (following spawning).

The size and type of effect of each component of the flow regime on recruitment varied between the two species of blackfish, and between waterways, due to differing habitat preferences and inconsistent habitat condition (degradation and flow modification) across the waterways.

2.4.2 Insights for environmental water management

This work has provided information to support managers planning environmental watering actions to benefit blackfish. The following recommendations are provided to guide future work.

1. Deliver water for the environment to decrease the number of low-flow days and low summer flow periods to maintain water quality and habitat for blackfish during dry years.
2. Avoid the delivery of large flow pulses with rapid rates of rise and fall during the species' spawning period in late spring/early summer, where possible.
3. Avoid the delivery of substantially large volumes of water during summer, particularly over extended periods.
4. Avoid cold-water releases upstream of River Blackfish spawning areas during the species' spawning period.
5. Limit increases in water temperature during the blackfish spawning period by maintaining and increasing riparian canopy cover and decreasing water extraction.

2.4.3 Final report

Amtstaetter, F., Tonkin, Z., Yen, J.D.L., Lieschke, J., Sharley, J., Raymond, S., Koster, W., Harris, A., Crowther, D. and Ryan, S. (2024). *Flow regime and water temperature influence recruitment success of blackfish in south-eastern Australia.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

2.5 Reviewing low-flow recommendations to determine whether they support native fish populations in flow-stressed Victorian rivers

2.5.1 Review of low-flow objectives

Alterations to the low-flow components of flow regimes can have a range of deleterious impacts on aquatic plants and animals, by reducing connectivity and the availability of habitats, and by changing water quality (e.g. lowering dissolved oxygen). In Victoria, water management interventions often include low-flow deliveries to ameliorate some of these impacts, and to meet the objectives stated in the annual seasonal watering plans, such as maintaining water quality, habitat and connectivity.

This project had three aims:

1. To review and collate the available information on low-flow recommendations, including critical assessment of the objectives, supporting data, and evidence of outcomes for native fish in Victorian waterways with an environmental water allocation, thus improving access to information by waterway managers and researchers (to enable meeting of Aims 2 and 3)

2. To identify knowledge gaps, so that an approach to address them can be prioritised by waterway managers
3. To assess the key functional (e.g. water quality) and fundamental (e.g. fish population parameters) responses to environmental flows used to achieve low-flow objectives for native fish identified in Aims 1 and 2, to help inform annual flow management.

A review was undertaken as the first stage of the project, which involved collating low-flow recommendations and objectives related to fish from seasonal watering plans and FLOWS studies (environmental flow assessments). Recommendations and objectives were reviewed: (1) to undertake a preliminary assessment of whether they were SMART (specific, measurable, achievable, relevant, time-bound) and (2) to determine whether data (fish surveys, water quality) are available to support future assessments of whether targets have been met. It was not within the scope of this project to conduct a full assessment of whether objectives are SMART, nor to examine causal links between low-flow conditions and the status of fish populations.

2.5.2 Insights for environmental water management

This work has provided information to support managers planning environmental watering actions to benefit native fish through the management of low flows. The following recommendations are provided to guide future work (noting that a full assessment of whether the objectives were SMART was beyond the scope of the work, so these recommendations should be considered preliminary).

1. Interrogate water-quality datasets to assess whether low-flow management is achieving functional objectives in select reaches (Moorabool River; Broken River Reaches 1–3; Glenelg River Reaches 1a, 1b and 2; Campaspe River Reach 4; Wimmera River Reach 4; Latrobe River Reach 5, and Macalister River Reach 2).
2. Collect new information on:
   (i) Functional low-flow objectives, through water-quality monitoring from four reaches (Loddon River Reaches 4 and 5, Mackenzie River Reach 3, upper Mount William Creek and upper Burnt Creek)
   (ii) Fundamental flow objectives, through fish population surveys in six reaches (Barwon River Reaches 3 and 4; upper Broken Creek Reach 1, Coliban River, Serpentine Creek Reach 1 and lower Mount William Creek).
3. Examine all low-flow targets (e.g. for dissolved oxygen levels, riffle depths) for consistency among specific species and life stages across the state.
4. Regularly review and update flow objectives and targets in order to remain relevant to changes in catchments.

2.5.3 Final report

O'Connor, J. Cornell, G. and Tonkin, Z. (2025). *A review of low-flow watering recommendations to meet fish objectives across Victoria: an assessment of supporting data, and identification of priority knowledge gaps.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

2.6 Understanding the role of environmental flows and other influences in governing the downstream spawning migration of eels

2.6.1 Investigating eel migration across six Victorian rivers

The Short-finned Eel (*Anguilla australis*) holds immense cultural significance and supports commercial fisheries in south-eastern Australia. The species is listed as 'near threatened' in the International Union for Conservation of Nature (IUCN) Red List and faces multiple threats, including barriers to migration, habitat degradation and loss, overfishing, pollution, and climate change. Short-finned Eels migrate downstream and out to sea to complete their once-in-a-lifetime spawning migration. Using environmental flows to support eel migration has been included in management plans for regulated coastal river systems across Victoria.

However, gaining a detailed understanding of how eels respond to flows and environmental flow delivery requires long-term observations across a range of waterways and environmental conditions.

The project aimed to investigate the role of environmental (flow, lunar phase, season) and biological (body condition and length) attributes and patterns as key drivers associated with the downstream migration of Short-finned Eels across a large spatial scale.

An acoustic tracking study of 173 tagged eels across six Victorian rivers (Hopkins, Barwon, Moorabool, Yarra, Thomson, Wingan) spanning 600 km was undertaken. The study revealed that downstream migration was associated with: (1) an increase in river flow, (2) a broad time period starting in early summer and peaking in autumn, (3) the third-quarter lunar phase, and (4) larger eels with a greater body condition. Most eels were found to move rapidly downstream in association with a single flow event, with a smaller number moving over a longer period associated with a series of flow pulses. Several eels stopped their downstream movement when flows declined, suggesting that changes in flow regimes due to river regulation have the potential to strongly impact downstream migration. This impact will likely be exacerbated by the influence of climate change.

2.6.2 Insights for environmental water management

This work has provided information to guide improved management of environmental water to maximise the likelihood of Short-finned Eel success in moving downstream and out to sea. The project provides the following suggested recommendations for environmental water managers.

1. Provide multiple flow pulses throughout the eel migration period when environmental water is available.
2. Take into consideration lunar phases (particularly the third-quarter lunar phase) when planning the timing of environmental flows, to meet eel objectives.

2.6.3 Final report

Koster, W., Dawson, D., Tonkin, Z. and Fanson, B. (2025). *Patterns and environmental and biological attributes associated with downstream migration of Short-finned Eels across multiple river systems.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

2.7 Fish theme overview

The VEFMAP Stage 7 fish theme projects have filled key knowledge gaps, advancing our understanding of native fish population dynamics and identifying the main drivers of population dynamics. Furthermore, by using statistical, population and hydraulic models, the collected work has demonstrated how environmental water can be more efficiently managed in Victorian rivers to enhance native fish populations. The trends and recruitment analyses underscore the value of maintaining long-term monitoring data, and show how the analysis of an integrated dataset can be used to understand population dynamics and their drivers across broad spatial scales.

The development or refinement of population models has provided insight into the long-term outcomes of flow management on fish populations, developed a tool for informing short-term decision-making around flow delivery, and has generated a useful starting point for further investigations of species' interactions. Statistical models are complementary to population models and provide a useful approach for estimating abundance and recruitment outcomes from field data. Ultimately, comprehensive collaboration with waterway managers is needed in order to embed models in real-world decision frameworks and link the relevant disciplines (e.g. management, hydrology, ecology). Such collaborations would support the design and refinement of novel flow regimes to achieve ecological objectives, while balancing the needs of other water users.

The projects support adaptive management by providing practical insights to guide both operational and strategic watering decisions. They show how population and hydraulic modelling can improve the outcomes of the delivery of environmental water for key species like blackfish, eels, and Murray Cod, while also highlighting how species' interactions can influence recruitment outcomes. The work also offers tools for refining flow recommendations, simplifying decision-making, and improving outcomes for native fish in regulated rivers. Importantly, they identify opportunities for better alignment of fish monitoring programs and management objectives, thus enabling greater ecological impact.

Collectively, the projects have also identified some remaining knowledge gaps that need further investigation, such as the complex interactions between streamflow, habitat requirements, and fish; the influence of interactions between species on fish population dynamics; the factors driving fish decline in low-flow, high-risk river reaches; and how best to improve population and statistical models through the use of more ecologically meaningful hydrological metrics, to better understand how flow regimes can build the resilience of fish populations—especially under the increasing threat of climate change causing more frequent and severe flood and drought events.

3. VEFMAP vegetation projects

Under the VEFMAP vegetation theme, six projects were delivered, which included a combination of event-based monitoring, data analysis and modelling, nursery and field experiments, literature reviews, and expert elicitation workshops. These approaches were used to assess questions related to the role of environmental flows in governing the processes and dynamics of native vegetation populations and communities. Four of the six projects were led by the Arthur Rylah Institute for Environmental Research (ARI), and the remaining two were led externally but in collaboration with ARI. The key results generated for each of the four ARI-led projects are as follows.

3.1 Evaluating the importance of summer/autumn low flows for aquatic vegetation recruitment

3.1.1 Low flows boost instream plant recruitment

Historically, periods of low flow were common in most Victorian rivers in summer and autumn. However, to meet consumptive demands, flows in regulated rivers are now much higher at these times of year. How these changes in low-flow periods affect riparian and instream plant recruitment is poorly known. There is work to suggest that elevated spring flows, followed by a drop in water levels in summer/autumn, may be important for the recruitment of some key groups of instream plants. A repeated absence of low flows in summer/autumn may lead to declines in seedbanks and, ultimately, a decline in the extent and viability of local plant populations. The maintenance and/or recovery of riparian and instream plants are an important objective in all rivers that have an environmental water reserve. However, current flow management generally does not consider plant requirements for low-flow periods. This project was set up to look at aquatic vegetation recruitment under summer/autumn low flows and the potential considerations for environmental water management.

This project had three aims:

1. To investigate plant recruitment (through field experiments) following partial exposure of riverbed sediments (low flows) in autumn
2. To investigate plant recruitment (through nursery experiments) by subjecting collected sediment samples to exposure and inundation treatments
3. To evaluate plant recruitment responses in the investigations, to inform how low flows in late summer or autumn can be provided for the successful recruitment of instream plants to support their long-term viability and persistence.

In field and nursery experiments, a 2-week period of exposure of riverbed sediments triggered rapid germination of flood-tolerant plant species, but aquatic plants showed little response. Terrestrial plant seedlings were uncommon within the riverbed substrate, an important finding given that possible mass deposition of terrestrial plant seed could occur at or prior to drawdown, which could be considered a risk. All seedlings tolerated re-inundation, but prolonged inundation led to the decline and death of non-aquatic plants.

Environmental flow management needs to consider the suite of flow conditions, including low flow, that promote the establishment and growth of flood-tolerant and aquatic plant species, while considering ways to facilitate plant recruitment processes. The potential benefits of very low flows will differ between waterways. The type of waterway that would benefit most from a very low flow is an intermittent waterway with a regulated consistently low flow level that prevents plant recruitment. This is because the germinated aquatic plants are likely to persist once flows return, if an adequate period of very low flow has been provided. However, system constraints, unregulated flows, consumptive demands, and competing objectives mean low-flow conditions cannot be delivered for all waterways. For waterways where low-flow delivery is feasible, it may not be possible to achieve delivery in all years or with optimal timing.

3.1.2 Insights for environmental water management

This work has increased our knowledge on the responses of plants to low-flow conditions and provides the following initial guidance for any future work around low flows and aquatic and flood-tolerant vegetation recruitment.

1. Providing very low flows in rivers (exposing riverbed sediments) for at least 2 weeks may be important to facilitate the germination and recruitment of flood-tolerant riverine plants, noting that the event timing and re-inundation regime will influence the likelihood of successful plant establishment.
2. If a low-flow germination event is followed by stable elevated flows for several months, it is unlikely to yield substantial benefits, since many seedlings will be drowned or washed away.
3. Providing a longer period of low-flow exposure commencing earlier in the season, or several pulsed low-flow periods, may be required to enable the establishment of flood-tolerant plants at the water margin, an important finding given that possible mass deposition of terrestrial plant seed could occur at or prior to drawdown, and this could be considered a risk.
4. Consider that different species of aquatic plants may require different management actions to facilitate recruitment. For example, flooding disturbances that transport vegetative propagules may be an important component of dispersal.
5. Consider the potential risks of implementing low flow to some aquatic taxa—these risks need to be weighed against the risks of not exposing the riverbed (to plants or other biotic processes).

3.1.3 Final report

Jones, C.S., McKendrick, S.A., Vivian, L.M., Wijepala, P., Mole, B., White, D. and Greet, J. (2024). *Managing river low flows to enhance instream vegetation recruitment.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

3.1.4 Published paper

Jones, C.S., McKendrick, S.A., Vivian, L.M., Wijepala, P., Mole, B., White, D. and Greet, J. (2025). Managing river low flows to enhance instream vegetation recruitment. *Environmental Management* **75** (7), 1845–1858. doi:10.1007/s00267-025-02187-1

3.2 Vegetation responses to managed river flow events and regimes

3.2.1 Using flows to support riparian plant abundance

Protecting riparian vegetation is a priority for environmental flow management in most regulated Victorian waterways, in recognition of its critical functional role in riparian ecosystems. Vegetation objectives are included in most seasonal watering plans, but they often lack specificity in terms of providing measurable and time-bound outcomes. This can create challenges for evaluating responses and guiding future watering. To address this knowledge gap, generalised linear mixed models were used to evaluate vegetation responses in terms of richness and cover for four different plant functional groups (aquatic, emergent, riparian and terrestrial) within defined flow-elevation zones on the bank.

This project addressed key knowledge gaps regarding how flow events and regimes influence vegetation, and measured the impact of key factors that may limit responses to flows. Findings from 8 years of monitoring vegetation responses to environmental flows across waterways in Victoria were analysed.

The project had three aims:

1. To develop detailed descriptions of vegetation trends associated with environmental flows, seasonal variations, bank position, livestock grazing, and plant origin
2. To quantify vegetation responses to individual flow events and broader flow regimes
3. To provide evidence-based recommendations for waterway management in regulated rivers to optimise ecological outcomes.

The work has provided insights into the complex interactions between flow regimes, flow events, and the broader environmental factors that shape riparian vegetation communities. The analysis of an extensive dataset of vegetation cover and species richness across multiple waterways found a range of responses. In general, environmental flows supported greater abundance of riparian plant cover, but the strength of the influence varied within and between waterways, due to climate and site factors. Consequently, the absence of environmental flows sometimes had the opposite effect, whereby flow delivery resulted in reduced extent and cover of desirable riparian plant communities. These findings can help inform the management and restoration of riparian ecosystems, particularly in regulated rivers where flow manipulation is a key tool.

3.2.2 Insights for environmental water management

The following recommendations are provided from this work.

1. Delivery of individual managed flow events may produce modest short-term vegetation responses, but there is a cumulative impact over time (in terms of increases in vegetation condition and resilience).
2. Delivery of short-duration freshes directly benefit aquatic and emergent vegetation and indirectly benefit fringing riparian species via increased recruitment and reduced competition from terrestrial species.
3. The use of prolonged elevated flows requires careful management to avoid damage to both riparian and terrestrial species.
4. The effectiveness of environmental flows is not uniform across all vegetation groups or sites and is highly influenced by local environmental conditions, flow constraints, species-specific traits, and the interplay with non-flow factors (e.g. grazing, soil properties, and the presence of exotic species).
5. Consider integrated management strategies that address both hydrological (flow events and regimes) and non-hydrological pressures (e.g. livestock grazing and dominance of exotic species) to promote the long-term health and functionality of riparian ecosystems at a landscape scale.

3.2.3 Final report

Jones, C.S., Vivian, L. Wootton, H., Gould, E., Yen, J., Mole, B., Thomas, F., Backstrom, A. and Just, K. (2025). *Vegetation responses to managed river flow events and regimes*. Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

3.3 A State and Transition framework to guide riparian woodland vegetation management and environmental water decisions

3.3.1 A model to guide environmental water management

Understanding how riparian vegetation shifts between different states in response to environmental flows and other interventions can improve management in highly modified, regulated rivers. State and Transition Models (STMs) describe and predict how ecosystems change over time (using a system of common community condition states) within a landscape or ecosystem and the transitions between them. STMs provide a framework for planning, highlighting knowledge gaps and uncertainties to drive hypothesis testing, and clarifying management goals.

This project aimed to develop a Riparian Woodlands Model to provide a decision-support framework for managers. This tool can help in specifying and communicating objectives, in prioritising the spatial and temporal management actions required to achieve objectives, and in the conducting of more effective monitoring and evaluation of flow and non-flow site-level management interventions undertaken for the maintenance and/or improvement of riparian woodland vegetation.

The Riparian Woodlands Model was derived from a ‘floodplain and riparian’ subgroup of a General Woodland Model. It outlines the Riparian Woodland states found within the vegetation communities of a waterway, specifies which states are desired, clarifies which attributes need to be changed (using a suite of flow and non-flow factors), and which attributes need to be monitored to detect transitions. Examples of the resulting decision trees are provided in the final report to show how to extract information from the model to clearly structure management decisions.

The model captures the importance of plant functional groups in riparian systems and the complexity of the multiscale management required for transitions to occur. It also clearly shows that a management system that includes strategic use of environmental flows (or other flow management) and non-flow management actions (e.g. revegetation, weed control, livestock exclusion) can achieve objectives. Frequent and targeted monitoring is essential when flows are altered and the understorey composition is in flux, to ensure that highly competitive riparian exotic species do not establish and become dominant.

3.3.2 Insights for environmental water management

The Riparian Woodlands Model provides a framework to guide management of riparian woodland vegetation with strategic use of environmental water (and non-flow management actions). The framework:

1. Provides a decision-support tool for managers to make clearly structured decisions at various scales (site versus reach or river) to assist management of riparian woodland vegetation to meet clearly defined objectives
2. Helps identify priorities for monitoring and evaluation so that adaptive management and evaluation of outcomes can be conducted as required by managers and funders
3. Simplifies the complex system of management, monitoring and evaluation for clearer stakeholder and community engagement.

3.3.3 Final report

Good, M. and Jones, C.S. (2024). *A State and Transition framework to guide riparian woodland vegetation management and environmental water decisions.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

3.4 Investigating how flow and non-flow factors affect riparian vegetation responses to environmental flows

Many factors influence flow management outcomes and the achievement of vegetation objectives, but it is unclear how important the various factors are for vegetation communities. This project has addressed the need for a comprehensive, evidence-based understanding of the relative influence of flow and non-flow factors, the strengths of their effects, how they interact with each other, and how their impacts may vary under different circumstances. This understanding can guide management on when and why complementary management actions are needed together with flows in order to achieve objectives.

The project aimed to quantify the relative magnitude of the influence of environmental flows and non-flow factors on vegetation communities across two climate scenarios using expert elicitation. Specifically, expert elicitation was undertaken to identify and quantify the effect of various environmental flow components [baseflows, high spring freshes (i.e. high flows), and low summer freshes (summer pulses)] and relevant non-flow factors, on three vegetation groups (aquatic, emergent and amphibious) across two climate scenarios (using high and low rainfall as a proxy). Eight non-flow factors were considered. These were: the presence of livestock grazing, bank slope, bank aspect, water quality, presence of Common Carp, canopy density, exotic riparian vegetation cover, and terrestrial vegetation cover.

The experts estimated how the various factors or factor combinations were likely to influence vegetation responses relative to the defined climate scenarios. Several key findings were apparent, including consistent effects of flow on vegetation responses. Specifically, baseflows, spring freshes and summer freshes were considered to have an overall positive influence on all vegetation groups, across both climate scenarios, but typically more so in dry, low-rainfall areas. In contrast, all non-flow factors had an overall negative or neutral effect, across all vegetation groups. The strongest non-flow factors influencing aquatic vegetation were Common Carp density, water turbidity and exotic aquatic vegetation, whereas grazing and increased exotic riparian vegetation were considered to have the strongest negative effect on emergent and amphibious vegetation. Despite flows having large individual relative effects, detrimental non-flow factors were predicted to reduce or reverse the beneficial effects of flow, so that the intended outcomes of environmental flows were not fully realised. These general results were similar for both low- and high-rainfall systems, suggesting that many of the outcomes may be applicable across a wide range of lowland regulated waterways.

3.4.1 Insights for environmental water management

The following recommendations are provided to guide future work.

1. Both flow and non-flow factors should be considered when managing waterways for the benefit of riparian vegetation—multiple management actions may be required (e.g. livestock removal and exotic weed control) to reach the desired positive outcomes.
2. Consider adjustment of management objectives and targets in systems where negating factors are present but are not currently manageable due to financial or other constraints.

3.4.2 Final report

Nystrand, M., Bruce, M., Vivian, L., Liu, C. and Jones, C.S. (2024). *Assessing the relative influence of managed flow components and non-flow factors on riverine vegetation: an expert elicitation approach.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

3.5 Vegetation theme overview

The outcomes of the VEFMAP Stage 7 vegetation theme provided valuable insights for managers, evidence demonstrating management outcomes, and guidance for decision-making, and addressed important knowledge gaps. The combination of field data, field and nursery experiments, and expert elicitation provided a cost-effective and targeted approach to meeting the program objectives.

The four projects outlined above have collectively explored where, when, and how much environmental flows may influence the riparian vegetation communities that are the focus of waterway management objectives in most regulated Victorian waterways. Many vegetation communities increase in cover and richness because of environmental flows, when other limiting factors are absent. In many cases, we also determined the mechanisms for how the impacts occur, which is critical for effective management and the specification of objectives.

A major focus of Stage 7 was to obtain a broader understanding of flow and non-flow drivers of vegetation communities, so that managers can have a more comprehensive understanding of what can be achieved through flow management alone, and what complementary measures are needed to enhance or enable outcomes. As summarised above, this was addressed through a suite of projects, using empirical field data, as well as expert elicitation and conceptual frameworks. We identified what typically constitute the most important flow and non-flow drivers of vegetation communities and how management can be used to maximise outcomes for environmental flows.

The hydrological and hydraulic assessment of the waterways in Victoria, led by Streamology (Streamology 2023, 2025), quantified the magnitude of the change in flow attributes and hydraulics made by environmental flows. The outputs from this work highlighted where objectives to deliver environmental flows for vegetation communities will be most effective. The outcomes indicated wide variation among waterways and suggested that environmental flows are very important in some systems, seasons and years, but less so in others. This information can help to optimise flow regimes within and across waterways to improve the impact of environmental water.

4. WetMAP fish projects

Under the WetMAP fish theme, two projects were completed, requiring both annual condition monitoring and data analysis. This approach was used to assess specific questions related to the role of environmental flows in influencing the processes that may drive changes in native fish populations within wetlands. The key results generated for each of the projects are as follows.

4.1 Evaluating whether connectivity of wetlands with their source water facilitates the immigration of adult fish or the dispersal of juvenile fish

Connectivity between rivers and floodplain wetland habitats has potential benefits for native fishes through enhanced movement opportunities for feeding, spawning and recruitment. In regulated river systems, natural connecting flows may be substantially altered or lost, and in some cases these connections are controlled by regulators between rivers and wetlands.

This project aimed to determine whether providing connectivity between floodplain wetlands and rivers is effective in facilitating the movement of adult fish into wetlands to spawn and the subsequent dispersal of juvenile fish to rivers.

Fish sampling was undertaken within wetlands to investigate any changes in fish catch rates resulting from the provision of lateral connectivity. Sampling was also undertaken in flood runners and creeks (connecting wetlands or wetland complexes with rivers) to investigate the directional movement of Australian Smelt and Carp Gudgeon (*Hypseleotris* spp.).

This work found that the catch rates of adult Australian Smelt (but not adult Carp Gudgeon) increased in wetlands connected to the Murray River during late winter/early spring, relative to those that remained disconnected. In complex forest flood runners and creeks, adult Australian Smelt moved against the current when connectivity was provided. No directional movement was detected towards or away from wetlands that were close to the river (i.e. wetlands with short connections of <150 m) where water tended to flow into the wetlands. No directional movement was detected for adult Carp Gudgeon. Where connectivity was available, juveniles of both species dispersed towards the river in large numbers in spring following spawning and recruitment in wetlands.

Management of connectivity through regulators can help improve lateral connectivity and potentially increase the benefits of environmental water. This work has demonstrated that management of hydrological connectivity between the Murray River and floodplain wetlands facilitated: (1) an increase in the abundance of adult native fish in wetlands prior to their spawning season and (2) large amounts of emigration of juvenile native fish to the Murray River following spawning and recruitment. This movement is likely to result in an increase in fish abundance in the river and contribute to broader riverine food webs.

4.1.1 Insights for environmental water management

This work has provided improved knowledge of how native fishes respond to connectivity between wetlands and rivers. The following recommendations are provided to guide future work.

1. Consider enabling water flow through wetlands, rather than inflow and outflow at the same location, and target flow that imitates the natural hydrological patterns of wetlands—this is likely to result in larger responses by native fishes, primarily by attracting more adult native fishes into wetlands during pre-spawning connection events.
2. Consider creating more specific objectives/targets for managed floodplain connectivity in the Murray River system to support native fish movement and to increase the spatial extent of floodplain connectivity.

4.1.2 Final report

Amtstaetter, F. and Cornell, G. (2024). *Connectivity between a river and floodplain wetlands through regulators enhances bidirectional migration of two species of small-bodied fish.* Arthur Rylah Institute for

Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

4.2 Evaluating whether Murray Hardyhead persists in saline wetlands where environmental water is used to maintain salinity levels within the range required for successful spawning and recruitment

Murray Hardyhead (*Craterocephalus fluviatilis*) was once widespread in the Murray River system, but is now listed as critically endangered in Victoria under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act) and restricted to a few isolated, permanent wetlands, two of which are Lake Elizabeth and Round Lake in North Central Victoria. It is a short-lived species, with an approximately annual life cycle (up to 18 months). Spawning begins in spring and can continue through autumn. Given this short lifespan, lack of successful spawning and recruitment in two consecutive years can potentially lead to population loss in isolated wetlands. Murray Hardyhead adults have a high salinity tolerance; however, extended periods of high salinity are detrimental to egg survival. Environmental water delivery is a key management tool to maintain and support breeding of Murray Hardyhead populations.

This project had two aims:

1. To determine whether salinity concentrations are being controlled appropriately using environmental water
2. To continue monitoring the persistence of Murray Hardyhead at Lake Elizabeth and Round Lake to assess whether spawning and recruitment has occurred.

From 2018 onwards, the watering regime for Lake Elizabeth and Round Lake has been modified in line with previous WetMAP recommendations, with environmental water being delivered in spring to support and maintain the Murray Hardyhead populations. Fish surveys have occurred in autumn each year from 2018 to 2024 (excluding 2023), and the species has consistently been recorded in both wetlands.

The regular surveys have provided clear insights regarding the effectiveness of the existing environmental water deliveries to maintain and support Murray Hardyhead, showing that the species persists and is recruiting in both Lake Elizabeth and Round Lake, with multiple size-classes being recorded.

4.2.1 Insights for environmental water management

This work has provided information to support managers planning environmental watering actions to benefit Murray Hardyhead through environmental water management. The following recommendations are provided to guide future work.

1. Continue environmental water delivery to Murray Hardyhead wetlands to achieve recommended salinity thresholds to maintain and support survival of the species.
2. Maintain salinity monitoring within the wetlands to ensure environmental water targets are being met, to ensure success for all life stages of Murray Hardyhead populations.
3. Establish populations elsewhere; undertake translocations to wetlands that receive environmental water to support genetic diversity.

4.2.2 Final reports

Cornell, G. and Russell, A. (2023). *WetMAP Murray Hardyhead monitoring 2022 Annual report.* Arthur Rylah Institute for Environmental Research. Unpublished report for DEECA Catchments and Communities. Arthur Rylah Institute for Environmental Research, Department of Energy, Environment and Climate Action, Heidelberg, Victoria.

Amtstaetter, F. and Russell, A. (2024). *WetMAP Murray Hardyhead monitoring 2024 Annual Report.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

Amtstaetter, F. and Cornell, G. (2024). *Connectivity between a river and floodplain wetlands through regulators enhances bidirectional migration of two species of small-bodied fish.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

4.2.3 Published paper

Amtstaetter, F. and Cornell, G. (2026). Connectivity between a river and floodplain wetlands through regulators enhances bidirectional migration of two species of small-bodied fish. *Freshwater Biology* **71** (1). doi:10.1111/fwb.70162.

4.3 Wetland fish theme overview

Two wetland fish projects were delivered under WetMAP Stage 4—one extended a previous study to increase its statistical power, while the other continued to track the benefits of environmental watering for the critically endangered Murray Hardyhead. This work demonstrated the importance of connecting wetlands to the Murray River at particular times of year, to enable adults to enter and juveniles to return to the river, and showed how environmental regulators can be operated to help restore wetland functions for fish and may contribute to riverine food webs (though further work is needed). Monitoring at two wetlands in northern Victoria demonstrated that environmental water can successfully be used to reduce salinity to levels that support Murray Hardyhead egg and larval survival, enabling population persistence. This information will guide the future management of highly saline lakes where Murray Hardyhead occur.

5. WetMAP vegetation projects

For the WetMAP vegetation theme, three projects were completed using literature reviews, long-term data analysis, and interviews and a targeted workshop with land managers. These approaches were used to assess specific questions related to the role of environmental flows in influencing the type, composition, growth and persistence of wetland vegetation under a range of hydrological regimes. The key results generated for each of the projects are as follows.

5.1 Updating knowledge on the ecology, distribution and physiology of Tall Marsh, including evaluation of the success of past Tall Marsh management

Tall Marsh is a freshwater Ecological Vegetation Class (EVC) commonly dominated by Common Reed (*Phragmites australis*), Cumbungi (*Typha* spp.) or Giant Rush (*Juncus ingens*). It is an important ecological component of wetlands, but in some situations it can become overabundant, commonly because of hydrological regimes. For example, environmental water is often used to support waterbird foraging and breeding habitat, by providing shallow water or damp conditions in late spring and summer, which aligns with the peak growing season for Tall Marsh, leading to its increased abundance, via widespread recruitment and/or rapid rhizomatous expansion. Many methods are used to control Tall Marsh (e.g. slashing, burning, herbicides and inundation), but the outcomes of these management efforts are often not well documented and/or evaluated. This project investigated the current knowledge of Tall Marsh and explored the effectiveness of management actions to reduce Tall Marsh in natural wetlands, including how environmental water can be used as a tool in management programs.

This project had four aims:

1. To review the ecology, distribution and physiology of the key Tall Marsh taxa, particularly aspects directly relevant to Tall Marsh in Victorian wetlands that can receive environmental water
2. To collate and share data, knowledge and lessons learned (successes and failures) from Tall Marsh management programs, particularly programs that use environmental water
3. To identify priority remaining knowledge gaps and/or gaps in approaches to Tall Marsh management
4. To apply updated knowledge to identify how environmental water can be used in wetlands to most effectively manage Tall Marsh.

A key objective of this work was to determine whether Tall Marsh management is still required at certain wetlands, given the overall declines in this vegetation community since European settlement. In the case of individual expansion events, the key drivers (e.g. hydrology and/or other factors) should be investigated and addressed. Selection of appropriate control methods should consider management goals; characteristics of the existing Tall Marsh population; potential consequences to other susceptible ecological values; prioritisation of sites; logistics; and stakeholder engagement. Monitoring should be an integral part of any Tall Marsh control program, along with documentation of actions taken (including timing and antecedent seasonal conditions) and lessons learnt.

Environmental water management (or any hydrological manipulation) alone is unlikely to reduce the extent of Tall Marsh but can slow or halt expansion. In combination with other control methods, environmental water can drown young plants and the rhizomes of established plants—effective techniques for reducing the vigor of the target taxa.

5.1.1 Insights for environmental water management

This work has provided information to support management decisions related to the delivery of environmental water to slow, halt or reverse the expansion of Tall Marsh vegetation in natural wetlands, or promote it, if that is the desired goal. The following recommendations are provided to guide future work.

1. Consider the underlying cause of Tall Marsh expansion (commonly hydrological) in any management planning.

2. Avoid shallow water persistence in wetlands during the peak growth of Tall Marsh species (late spring to early autumn, and especially over summer) to slow/halt the expansion (if possible—see point 5 below).
3. Deliver environmental water in conjunction with at least one other control method (e.g. cutting, burning, or herbicide application) to reduce the extent of existing Tall Marsh stands.
4. Target effective control using a combination of cutting in autumn, herbicide application (painting stems as they are cut or spraying new regrowth 2–4 weeks after cutting), then prolonged inundation within 2–4 weeks of the herbicide application, to drown rhizomes.
5. Consider options to balance competing goals for environmental water (e.g. providing shallow water environments in late spring and summer to support the foraging and breeding of waterbirds coincides with the prime growth season for Tall Marsh).

5.1.2 Final report

Sutton, F., Vivian, L. and Kulich, H. (2024). *Updating knowledge on the ecology and management of Tall Marsh.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

5.2 Evaluating the effect of timing of inundation on aquatic plant composition and growth

Wetland vegetation composition, structure and dynamics are primarily determined by the flood or inundation regime (i.e. pattern and seasonality). Decisions about the seasonal timing of environmental water delivery consider likely historical seasonality of the pre-regulation regime, the hydrological and ecological needs of the wetland biota, and the logistical and physical constraints of water delivery. In Victoria, environmental watering often occurs during autumn, but how well this aligns with historical seasonality or recommended watering regimes is unclear. This project sought to determine the effects of timing of environmental water delivery (autumn versus late winter/early spring) on wetland vegetation composition and growth, which is a key knowledge gap.

This project had five aims:

1. To review and summarise the current watering objectives related to seasonality in Victorian wetlands, including within EWMPs
3. To summarise the wetlands in which autumn watering has occurred
4. To review the evidence base for autumn watering (via a workshop)
5. To develop a conceptual model outlining hypothesised responses to autumn watering
6. To identify knowledge gaps for further research.

A key finding was that EWMPs rarely contain objectives for watering specifically in autumn. They may include objectives that cover this period (e.g. autumn to spring watering), but justification for autumn watering is rarely provided. However, autumn watering has occurred in almost half of the watered wetlands in Victoria since records began in 2011. In any one year, approximately a quarter to a third of all environmental watering events has occurred in autumn.

Workshop discussions, collated information from EWMPs and other documents, and follow-up discussions with wetland ecologists indicate that autumn watering is often delivered as a priming event. A priming event is the delivery of a relatively small volume of water in autumn, resulting in shallow inundation, followed by a larger ‘top-up’ the following spring, resulting in a deeper and larger inundation. The two main reasons for delivering an autumn priming event are as follows: (1) it improves the ability to deliver water given the constraints and risks of watering if left till spring, and (2) it results in a more effective specific ecological or hydrological process (e.g. promotes the early germination of aquatic plants in autumn prior to winter flooding or watering).

Investigations found that watering in autumn only (no follow-up spring watering required) was only done if there was a specific ecological reason.

5.2.2 Insights for environmental water management

This work confirms that autumn watering is a common strategy for environmental watering in Victorian wetlands, despite limited understanding of how this affects the long-term outcomes for wetland plants and communities. Justifications for the practice are also not clearly articulated in EMWPs.The following recommendations are provided to guide future work.

1. Further consultations with catchment management authorities and the Victorian Environmental Water Holder to identify whether knowledge gaps around autumn watering and the seasonality of environmental watering more broadly remain high priorities are recommended.
2. Consider undertaking analysis of long-term monitoring datasets to improve knowledge of the effects of watering seasonality (and the effects of cumulative watering) on wetland vegetation.
3. Consider carrying out field and nursery experiments to improve our understanding of the effect of timing of environmental water delivery (autumn versus late winter/early spring) on wetland vegetation composition and growth.

5.2.3 Final report

Vivian, L, Kulich, H. and Sparrow, A. (2024). *Effect of seasonal timing of inundation on wetland vegetation in Victoria: synthesis of current knowledge and implications for watering in autumn. Component 1: Short Summary Report.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

5.3 Investigation of long-term vegetation survey data from wetlands that receive environmental water in the Goulburn Broken Catchment Management Authority region

Monitoring is a critical part of evaluating the outcomes of environmental water delivery. Planning for wetland vegetation monitoring needs to consider timing in relation to a flood or environmental watering event, as wetland plant communities can change rapidly in response to hydrological conditions.

Flood events result in a sequence of different types of wetland plant species, but it is unclear how quickly these changes occur, and whether the speed of these changes is predictable between flood events. Rapid changes in species richness and cover are most likely for short-lived herbaceous wetland species that persist during dry periods as a seed or bud bank and appear above-ground for a short period during and/or after a flood event. They can grow rapidly in response to flooding and/or exposure of the soil to the air. A flood triggers their germination from the seed bank or resprouting from rootstock, which is followed by growth, flowering, seed production, and finally plant dieback and death. Therefore, vegetation surveys conducted at different times, particularly in relation to flooding, may detect different plant species and different abundances, as plants grow and then die back.

The project used Goulburn Broken Catchment Management Authority (GBCMA) long-term vegetation survey data (2005–2020) from nine environmentally watered wetlands to quantify how vegetation changed over the course of a single inundation event.

There were three main aims:

1. To compile and explore the GBCMA dataset and hydrological states to identify potential sequences of monitoring regarding the timing of flooding
2. To quantify the variation in the cover and richness of wetland plant functional groups over time as the surface water recedes
3. To use the outcomes to inform environmental water monitoring plans/objectives, including specifying the optimal timing of wetland monitoring surveys.

Key findings included the results that vegetation surveys soon after drawdown are likely to capture the presence of most wetland plant functional groups. The drawback with such early surveys, however, may be that they are potentially too early to record the maximum cover of amphibious plant groups. The collection of hydrological data (especially water depth and the time since commencement of inundation) at the survey-plot level will help establish how the recorded richness and cover of plants relate to the specific inundation event being monitored. Insufficient records of aquatic species in the dataset mean insights into the timing of monitoring these species could not be provided.

5.3.1 Insights for environmental water management

This work has provided information to support managers planning environmental water delivery to benefit wetland plants, with the following recommendations to guide future work.

1. Develop clear management objectives that specify which wetland species or functional groups are the target of the environmental watering. This will determine the most appropriate timing and monitoring approach for wetland plant surveys.
2. Account for survey timing and consider contextual data, particularly related to time since inundation and water depth, in the interpretation of the vegetation monitoring results.

5.3.2 Final report

Vivian, L., Kulich, H., Jones, C. and Sparrow, A. (2024). *Investigation of long-term Goulburn–Broken CMA vegetation monitoring data.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

5.4 Wetland Vegetation Theme Overview

The WetMAP Stage 4 vegetation theme advanced our understanding of how wetland vegetation responds to inundation. While environmental water is well understood to support increases in native wetland vegetation cover and richness in the short term, WetMAP Stage 4 further investigated the complexity and variability of these responses.

Our exploration of trends in wetland vegetation responses using long-term monitoring data quantified this variability over time and at different wetlands across the state. Long-term monitoring of wetland vegetation is critical for capturing the cyclical but variable nature of wetland vegetation responses. Vegetation responses are not always immediate and can differ significantly between wetlands and across events, suggesting caution when interpreting results from a single survey or a few surveys, or without understanding the hydrological context, particularly in terms of survey timing in relation to inundation.

The persistent challenge of Tall Marsh control was explored. While short-term actions were found to reduce Tall Marsh biomass, long-term success—including reduction of Tall Marsh extent and restoration of diverse ecological values—requires addressing the drivers of expansion, which is often difficult to achieve. Monitoring of outcomes has been generally lacking but is essential for evaluating management success and for learning which methods of control are most effective. Collectively, these findings reinforce the importance of understanding the hydrological, landscape and disturbance contexts when evaluating the impact that environmental water may have on wetland vegetation outcomes.

6. WetMAP Waterbird projects

Within the WetMAP waterbird theme, three projects were completed, investigating waterbird seasonal movements and structural habitat associations, with a focus on applications for environmental water management. The key results generated for each of the projects are as follows.

6.1 Analysing seasonality of waterbird breeding, occurrence and abundance to inform environmental water management

Environmental water is often used to provide benefits to waterbirds in wetlands. However, there is little collated quantitative data on the timing of waterbird breeding, occurrence and abundance in wetlands. Improving our ability to predict waterbird occurrence and abundance in Victoria can help managers deliver water effectively, while enabling the design of appropriate monitoring programs. This project involved the desktop collation and analysis of existing large waterbird datasets in Victoria (held by DEECA, Birdlife Australia and Melbourne Water) and the development of statistical models to describe seasonality patterns for waterbirds in Victoria.

The project had one broad aim: to analyse Victorian waterbird data to determine seasonality for breeding, occurrence and abundance to inform environmental water management. Analysis was used to coarsely assign each of 72 Victorian waterbird species into one of nine seasonality categories (e.g. breeding residents, summer-visiting international migrants, autumn/winter visiting partial migrants).

The results showed that almost all Victorian waterbird species are seasonal in their timing of breeding, the time of year at which they are most likely to be encountered (occurrence) and/or the time of year at which they are most numerous (abundance). For most species, breeding peaked in spring and early summer, occurrence peaked in the warmer months (September to April), and abundance peaked mid-summer to mid-autumn. Patterns were generally consistent across the state. For most species, year-to-year variation in the timing of peaks of occurrence and abundance was evident, a likely response to rainfall patterns and wetland availability; however, the underlying seasonal pattern remained clear.

This provides guidance on optimal timing for waterbird surveys to maximise detection. Surveys targeting priority species, such as the cryptic and endangered Australasian Bittern (*Botaurus poiciloptilus*), may require specialised methods and specific timing.

6.1.1 Insights for environmental water management

This work has provided important insights into how environmental water can be managed effectively to benefit waterbirds. The following recommendations are provided to guide future work.

1. Inundate wetlands from September to March to match the time when breeding is most likely, and when there is peak occurrence of most waterbirds.
2. Consider there may be some species that have different timing for breeding and peak occurrence to that outlined above—environmental water delivery will need to be adapted for any species, habitat or wetland that is a target of management objectives.

6.1.2 Final report

Rogers, D.I., Fanson, B., Loyn, R., Menkhorst, P., Purnell, C., Steele, W. and Khwaja, N. (2024). *Waterbird seasonality in Victoria: timing of occurrence and breeding and implications for waterbird monitoring and wetland management.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

6.2 Tracking threatened waterbirds to improve understanding of breeding requirements, landscape movements, and implications for water management

Data analysis from the WetMAP Stage 3 waterbird monitoring found that the relationship between wetland inundation events and waterbird breeding was a key knowledge gap. Observed waterbird breeding in watered wetlands was found to be too low to be able to sustain waterbird populations. Tracking of key species was recommended, to determine whether waterbirds feed, rest and roost in wetlands that receive environmental water but breed at other locations.

The project had three aims:

1. To track waterbirds to identify wetlands chosen for breeding, their use of structural habitat, and the inundation conditions present
2. To identify any differences between the structural habitats and inundation conditions found in wetlands where breeding occurs, and those found in watered wetlands
3. To collate further information on landscape-scale movements derived from tracking data, to provide recommendations to support species using environmental water.

This project involved fitting remote tracking devices onto three species of waterbirds to track their movements: Brolga (*Grus rubicunda*), Australasian Shoveler (*Spatula rhynchotis*) and Sharp-tailed Sandpiper (*Calidris acuminata*). Selection was based on the preferences of environmental water managers and the feasibility and appropriateness of tracking (e.g. size, catchability, threatened status, cost, and management implications).

6.2.1 Brolga

Brolgas (listed as endangered in Victoria under the FFG Act) depend on wetlands for breeding, roosting and feeding, while there are specific ecological objectives related to them in EWMPs for several wetlands in northern Victoria. Tracking of three adult birds revealed two nesting sites in spring 2024: one at Gaynor Swamp (which hatched two young) and a previously unknown breeding site at Murphy Swamp. The real-time information provided by the remote tracking enabled adaptive watering decisions to be made at a wetland where a Brolga nest was identified. Adaptive management at nest sites based on tracking information will continue to be a valuable tool to support this species in northern Victoria.

6.2.2 Australasian Shoveler

Australasian Shovelers (listed as vulnerable in Victoria under the FFG Act) have undergone population declines in recent years for reasons that are not fully known. Six Australasian Shovelers were fitted with remote tracking devices at the Western Treatment Plant, Port Phillip Bay. Tracking showed widespread movements across southern Victoria in spring 2024, with four of the six individuals moving east to spend time in Gippsland, including one that subsequently crossed Bass Strait to northern Tasmania. The tracked Australasian Shovelers visited dozens of wetlands, including two wetland complexes (Lower Barwon and Lower Latrobe wetlands) managed using environmental water, and many wetlands not previously known to support the species.

6.2.3 Sharp-tailed Sandpiper

Sharp-tailed Sandpipers [listed as vulnerable in Australia under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act)] are migratory shorebirds that breed in Siberia and spend the austral summer in Australasia. Populations have undergone recent declines. Thirty-five captured Sharp-tailed Sandpipers were fitted with remote tracking devices: 14 at Sparrovale wetlands in the Lower Barwon complex, and 21 at the Western Treatment Plant on Port Phillip Bay. Analyses focused on the Lower Barwon wetland complex and migratory stopovers in the Murray–Darling Basin, because these systems are relevant to environmental water management.

6.2.4 Insights for environmental water management

This work provides novel and valuable insights into the use of wetlands by three threatened species that are a high priority for water managers. The following findings are relevant to environmental water management.

1. Environmentally watered wetlands make an important contribution to breeding opportunities for the small Brolga population in northern Victoria.
2. Shallow water with emergent vegetation is the critical structural habitat requirement for Brolga, particularly in temporary freshwater wetlands.
3. Support of Australasian Shoveler breeding may be a realistic and valuable target for watered wetlands in southern Victoria and, more specifically, in the Gippsland area.
4. Environmental water management benefits the Sharp-tailed Sandpiper from January until early March in southern Victoria, and from February until mid-March in the Murray–Darling Basin.
5. Optimum conditions for the Sharp-tailed Sandpiper are provided by very shallow water and bare wet substrate, indicating that inflow to wetlands should be avoided during the time periods provided above.

6.2.5 Final report

Rogers, D.I., Amos, N., Veltheim, I. and Khwaja, N. (2025). *GPS tracking of Brolga, Australasian Shoveler and Sharp-tailed Sandpiper in Victorian wetlands.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

6.3 Understanding the habitat requirements of waterbirds and the water regimes needed to support this habitat

Enhancing the availability of suitable habitat for waterbirds is a common objective of environmental flow management in many Victorian wetlands. Many waterbird species respond rapidly and positively to the delivery of environmental water in wetlands, often resulting in increased abundance and species richness. However, to date there has not been a quantitative assessment of the specific relationships between waterbird presence and structural habitat characteristics at watered wetlands in Victoria. Furthermore, the role of water regimes in determining vegetation structure, and the potential contribution of environmental water to this process, has also been unclear.

This project had three aims:

1. To identify the suitable structural habitat types that support the key life functions of waterbirds, including feeding, resting and nesting (habitat definition)
2. To determine the appropriate environmental watering regimes needed to sustain the structural elements of habitat essential for waterbird life functions (habitat provision)
3. To assess the extent to which waterbirds are utilising available structural habitat elements for key life functions (habitat use).

Information on suitable structural habitat associations was compiled for 78 waterbird species that occur in environmentally watered wetlands across Victoria. A comprehensive analysis was conducted using WetMAP waterbird count data in conjunction with structural habitat extent data (from field surveys in northern Victoria) to identify statistically significant relationships between species abundance and specific structural habitat types. This analysis was further supported by a literature review, expert elicitation, and field-based observational records.

Statistical models were developed for 39 of the more commonly recorded waterbird species, and expert elicitation was used to provide data for all 78 species, which found both positive and negative associations with a suite of specific habitat types. Additionally, analysis of hydrology and vegetation cover showed that structural habitat types, especially those with live vegetation, were influenced by water regime history, wetland type, and flood duration, with freshwater and frequently inundated wetlands supporting the highest vegetation cover.

6.3.1 Insights for environmental water management

This work provided structural habitat information for the 78 waterbird species that are likely to occur in Victorian freshwater wetlands, including wetlands that receive environmental water. The information enables targeted provision (hydrological and structural) of specific habitats at specific times of the year for the greatest likelihood of positive outcomes for waterbird species or groups of interest. The following recommendations were provided to guide future work.

1. A combination of deep open water, shallow open water, bare wet substrate, shallow water with emergent vegetation, and Tall Marsh provides suitable habitat for almost all waterbirds in Victorian freshwater wetlands.
2. Wetlands with extensive woody vegetation (lignum and live eucalypts) are probably important for waterbird breeding, although they tend to be less associated with abundance.
3. Open habitats devoid of structural vegetation are associated with flood durations exceeding 3 years, and/or saline wetlands. Conversely, cover of most vegetation types is greatest in freshwater wetlands that had temporary water regimes in the late 20th century, and currently have an average flood duration of less than 3 years. Cover of Tall Marsh is greatest at wetlands that had permanent water regimes in the late 20th century and are inundated frequently.

6.3.2 Final report

Khwaja, N., Kulich, H.V.J., Wootton, H., Amos, J.N. and Rogers, D.I. (2025). *Waterbird structural habitats in Victorian wetlands: definition, provision and use.* Arthur Rylah Institute for Environmental Research unpublished report for Catchments and Communities, Department of Energy, Environment and Climate Action (DEECA). DEECA, Heidelberg, Victoria.

6.4 Waterbird theme overview

The WetMAP bird theme research projects have improved our understanding of how birds respond to environmental water management in Victorian wetlands. We have described the structural habitat associations and seasonality for all waterbird species that are likely to occur in environmentally watered wetlands. These descriptions will assist managers to better target wetland watering regimes, and to provide suitable habitat for many of these species. By summarising patterns across species, we have also been able to provide watering recommendations in relation to the general waterbird objectives specified for many wetlands, and identified species and situations for which such generic actions may be insufficient or inappropriate. More detailed objectives will be required in some cases to meet broader needs. This complements information on other factors that influence the responses of various waterbird species to environmental water, such as lag times following water delivery and responsiveness to inundation elsewhere in the Australian landscape, which was investigated in WetMAP Stage 3 and elsewhere in the literature.

In addition, we used remote telemetry to gain new insights into how three threatened species can be supported through environmental water management, including Australasian Shoveller, Brolga and Sharp-tailed Sandpipers. GPS tracking has provided information that would have been impossible to gain from observations alone.

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Appendix 1. Basin Plan Matter 8 final reports

Monitoring was undertaken to support DEECA's management and reporting obligations as required under the Murray–Darling Basin Plan (including Schedule 12, Matter 8). Summaries of this work are not provided in this report. References to the final reports are listed below.

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