NSW Coastal Environmental Water Requirements for Freshwater-Dependent Biota

June 2023

Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for Country and the waterways within.

Contents

Figures

Tables

1 Introduction

Coastal NSW has a range of freshwater ecosystems that support diverse biota including but not limited to birds, fish, macrophytes, amphibians, invertebrates, freshwater turtles, and platypus. In freshwater ecosystems, flow is the major driver of habitat, connectivity and ecosystem processes that determine the character and condition of the ecosystem (Poff & Zimmerman, 2010). However, as coastal NSW is one of the most populated regions of Australia, this has led to significant alterations of the natural flow regime of coastal river systems (Zhang et al., 2016). To avoid impacting ecosystems dependent on flow, NSW governmental agencies implement a range of management mechanisms including limits on water extraction volumes and provision of environmental flows.

The *Water Management Act 2000* (WMA) is the overarching legislation which regulates water resource use and management in NSW, with water sharing plans (WSPs) providing management arrangements for specific catchment areas or water resources. The WMA requires WSPs to commit water to the maintenance of ecosystem health or other specified environmental purposes (Clause 8 (1)(a)). This is achieved by defining a long-term average annual extraction limit (LTAAEL) on consumptive take and implementing access and licensing rules restricting extraction during various flow conditions within a WSP area, leaving a portion of water protected for environmental purposes. This water is provided through environmental flows which can include releases of water designed to maintain or enhance environmental values, or through cease to take access rules which protect water for basic rights and environmental purposes. Developing an understanding of the environmental water requirements (EWR) of an area and its water dependent flora and fauna, will help to inform the needs of environmental flows.

Environmental water requirements (EWRs) are used by natural resource managers in inland NSW to identify the flows required to sustain environmental values (e.g., NSW DPIE, 2020a). EWRs are defined as the flow or inundation regime that a species, biological community or defined group of species require to ensure survival, reproduction and persistence (NSW DPIE, 2020a). They do not refer to the watering requirements of ecosystems or habitats and their ecological functions. EWRs can provide a scientific basis which can inform water management mechanisms for the provision of environmental water. Phase 1 of the Innovative Coastal NSW Water Sharing Arrangements project undertaken by the Water Group in the NSW Department of Climate Change, Energy, the Environment and Water in 2022 identified EWRs in coastal NSW as an option to inform sustainable water management. Currently EWRs exist within long term water plans (LTWPs) for inland areas which were developed for the Murray Darling Basing Plan but have not been developed for coastal areas to date.

This project seeks to identify existing EWRs for freshwater-dependent biota and additional relevant information on these species that can contribute to sustainable water management in coastal NSW. It may contribute to setting ecologically sustainable LTAAELs, ensuring that WSPs fulfill the principles of the WMA and provide favourable environmental outcomes for coastal NSW. This project will also highlight gaps within the literature that may impede the use of EWRs in water management policy within coastal NSW. Sustainable water management faces considerable uncertainty and there is acknowledgement that our current understanding of EWRs will improve over time. This review of EWRs will help identify knowledge gaps which can be used to inform an ongoing cycle of improvement in coastal water management.

This technical report is the accompanying document to the Microsoft Excel file "Environmental Water Requirements (EWRs) for freshwater-dependent biota of coastal NSW - Information Spreadsheet" (EWR Spreadsheet) which presents a collation of existing information on the water requirements for freshwater dependent biota in coastal NSW, with an emphasis on threatened and endangered species that occupy coastal riverine systems. This report provides context and information relative to the interpretation of the Excel file.

2 Study region

The coastal draining rivers of NSW comprise those on the eastern side of the Great Dividing Range within the coloured catchments and management areas in Figure 1. Generally, these rivers are short, navigable in their lowest reaches and subject to flooding during high rainfall periods. The catchments cover an extensive area with over 2000 km of coastline over which the climate varies largely from the temperate south to the sub-tropical north. NSW coastal rivers typically receive between 800 and 1200mm of rainfall per annum, with the northern coastal regions (Lismore to Newcastle) receiving the most rainfall (1500 – 2000mm per annum). This variation in climate and rainfall contributes to the notable diversity in freshwater dependent species and community composition across the NSW coast.

Notably, the NSW coastline is one of the most populous areas in Australia with significant water use required in the area for residential, commercial, and agricultural purposes. This has led to a large amount of river regulation and water extraction along the coastline although only the Bega-Brogo River, Hunter River, Paterson River and the Richmond River are considered as regulated rivers in a planning and policy context.

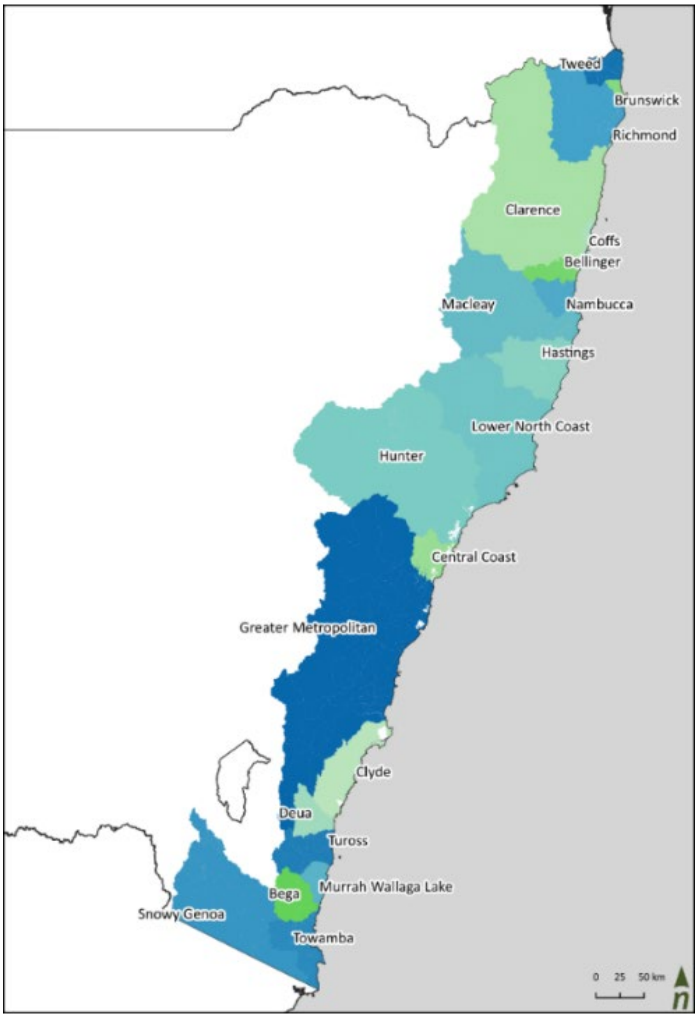

Figure 1. *Water sharing plan areas in coastal NSW.*

3 Study scope and considerations of review

This review is focused on the existing EWRs of freshwater-dependent biota in NSW coastal systems. The review was performed via desktop and encompassed existing EWR information in:

- peer reviewed scientific literature and books,
- government and research program websites and data bases (e.g., Frog ID and BioNet)
- government reports and policy documents (e.g., Long Term Watering Plans)
- internal government reports and manuscripts not yet published that were provided by the Water Group project team (including DPIRD documents).

The review did not include any fieldwork or new studies.

Information was considered relevant to the review if it informed the flow or habitat requirements of a species or its life history. Information developed outside of the NSW coastal area was included if it was developed in a similar context (e.g., information on the Australian Grayling was included although studies were conducted in coastal Victoria). A full list of references used in the review are available in Appendix A and the "References" sheet of the EWR spreadsheet.

A key source of information for providing examples of EWRs and their integration into water policy and management were the NSW Long Term Water Plans (LTWPs) (NSW DPIE 2020a). EWRs have been developed and implemented throughout the Murray-Darling Basin in LTWPs. These documents provide the language and definitions used in EWR policy documents and the potential mechanisms for relating EWRs to river flows and operation. This allowed for the project team to ensure relevant information was provided regarding EWRs in coastal systems. However, there are differences between coastal and inland river systems (e.g., size, discharge volume, geomorphology, seasonality, regulatory structures etc.) which must be considered in the potential application of EWRs to coastal NSW. Some preliminary considerations are outlined below.

1. Characteristics of coastal rivers

NSW Coastal rivers arise on the east face of the Great Dividing Range through a network of steep tributaries that merge into rivers in the mid-slopes where agricultural development and land clearing tend to begin within the catchment, before flowing through to the highly developed coastal plains with floodplains and wetlands before meeting the ocean. The changes in stream flow and morphology over hundreds of kilometres need to be considered in the selection of EWRs for riverine areas. For example, despite being relatively close in terms of distance and longitudinal connectivity, upland areas and headwaters have contrasting management challenges and EWRs.

2. Focus on base flow and low flow requirements

Unlike coastal river systems, inland river systems are generally large, extensively regulated and can have sizeable volumes of water released from large upstream storages to fulfill environmental water needs, for example, to establish controlled floodplain connectivity. In coastal rivers there is limited capacity to influence larger flows. This is true both in terms of:

- reducing large flow peaks, due to smaller dams being unable to hold large amounts of water in wetter years and limited regulation of coastal rivers, and
- in increasing flow peaks, due to the unregulated nature of most coastal rivers as well as large amounts of constraining assets (e.g., houses, business).

Therefore, this review is focussed on the range of EWRs that pertain to base flows, low flows and cease to flow conditions as these are the types of flows that can be most easily influenced by WSP policy settings in coastal NSW. However, where relevant and available additional information on EWRs relating to other flow components, such as freshes and floods, has been included in the review.

3. Estuarine systems

There is broad scientific evidence on the importance of longitudinal linkages between freshwater catchments and estuaries in terms of physical and ecological processes (e.g., maintenance of salinity gradients, provision of food and nutrient resources, larval and egg dispersal). However, this review is focussed on freshwater systems extending to the tidal limit of river systems and does not encompass saline estuarine waters. As such, many estuarine species which may have a relationship to, but not a dependence on freshwater flows or habitats have not been included (e.g., estuarine generalists like yellow fin bream, or mulloway where high flow events can promote spawning (Taylor et al., 2014)). However, diadromous species which require freshwater habitats to complete their life cycles, which may also access estuaries and marine areas have been included (e.g., Australian bass, eels, common galaxias).

It is worth noting that increased freshwater flows to estuaries have been shown to vary the community structure and increase the abundance of estuarine and near shore coastal fisheries (Gillson et al., 2012). This can improve the yield of both commercial and recreational fishing for some species.

4. Unintended bias toward socially valued species

As with inland studies it was found that more information is available regarding socially valued species (e.g., fish caught commercially and recreationally, larger native faunal species). However, these larger and socially valued species are only a small part of the wider ecosystem and food web. There are inherent biases in setting EWRs for a broader region based on the available information for a few socially valued species and discounting the requirements and importance of other species. Increasingly, there is a recognition of the importance of understanding the EWR of whole ecosystems, habitats and key ecosystem functions, however, this is another area of considerable uncertainty. A high-level review of ecosystem function EWRs has also been included as part of this report.

4 Reporting structure, rationale and terms

4.1 Spreadsheet structure

This section refers to the EWR Spreadsheet ("Environmental Water Requirements (EWRs) for freshwater-dependent biota of coastal NSW - Information Spreadsheet") that was developed as part of this project, providing details on its structure and how to use and interpret it. This resource was developed to help inform water policy makers, planners and natural resource managers of the requirements of freshwater dependent species to enhance the provision of environmental water through water sharing rules and management mechanisms in NSW coastal rivers. The primary outputs of this review are the EWR Spreadsheet which contains a list of environmental water requirements for freshwater dependent biota in coastal NSW and the maintenance of ecological functions in coastal river systems.

The species specific EWRs ("Species EWRs" sheet) are based upon habitat, connectivity (e.g., movement) or process (e.g. productivity, recruitment) requirements for flora and fauna and how they are dependent on patterns of discharge, including timing, duration and frequency. These requirements were developed, sourced from and based upon on a review of available scientific and government agency literature and are summarised into an EWR statement for each species.

The review of ecological function EWRs ("Ecological Functions" sheet) presents high-level information indicating the flow requirements and components that must be considered to maintain ecological functions in riverine and aquatic systems. It also presents information regarding:

- the importance of these functions for ecosystem continuation,
- the relevant water quality zones (e.g., NSW Water Sharing Plan Risk Assessments, NSW DPIE 2020b),
- habitat types where these processes are most important,
- life histories that flows and associated processes support,
- examples interactions between flows, and habitats and species.

Additional sheets within the excel workbook identify rivers where specific information on species is present (the "Specific River Requirements" sheet) and water dependent species for which there is limited or no environmental flow information (the "Species with Limited EWR Info" sheet).

The 6 separate sheets within the file are:

- "Read Me" – an introductory sheet that presents information necessary to the interpretation and use of the spreadsheet.
- "Species EWRs" - A sheet of all species with environmental water requirements or useful information found in the review.
- "Ecological Functions" - A sheet highlighting the flow requirements to maintain ecological functions in coastal systems.
- "Specific River Requirements" - A short list of species Environmental Water Requirements that refer or pertain to a specific system river.
- "Species with limited EWR information" - A list of additional freshwater dependent species on the NSW coast that have limited or no environmental water requirement information.
- "References" - A sheet of reference used to inform the review.

The definitions of column headings for each sheet can be found in the "Read Me" sheet of the excel file.

4.2 EWR summary statements

Using information from this review, EWR summary statements have been developed for each species. These statements collate available information (e.g., discharge volumes, depths, habitat preferences, life history requirements etc.) into an interpretable statement for species or species groups/guilds. This will allow consideration of the corresponding and conflicting environmental flow requirements for different species when working to provide environmental flows for coastal rivers. EWR statements for this project have been developed to align with the language used in inland NSW LTWP EWR descriptions. The recognised components of flow that contribute to EWRs in long term water plans are shown in Table 1.

Table 1. Recognised flow components and descriptions used in NSW LTWPs (reproduced from NSW Border Rivers Long Term Water Plan Part A – Draft for exhibition).

Flow Component	Description
Overbank / Wetland inundation flow (OB / WL)	Broad scale lateral connectivity with floodplain and wetlands. Supports nutrient, carbon and sediment cycling between floodplain and channel. Promotes large-scale productivity.
Bankfull flow (BK)	Inundates all in-channel habitats and connects many low-lying wetlands. Partial or full longitudinal connectivity. Drown out of most small in-channel barriers (e.g., small weirs).
Large fresh (pulse) (LF)	Inundates benches, snags, and inundation-tolerant vegetation higher in the channel. Supports productivity and transfer of nutrients, carbon, and sediment. Provides fast-flowing habitat. May connect wetlands and anabranches with low commence-to-flow thresholds.
Small fresh (pulse) (SF)	Improves longitudinal connectivity. Inundates lower banks, bars, snags, and in-channel vegetation. Trigger for aquatic animal movement and breeding. Flushes pools. May stimulate productivity/food webs.
Baseflow (BF)	Provides connectivity between pools and riffles and along channels. Provides sufficient depth for fish movement along reaches.
Very low flow (VF)	Minimum flow in a channel that prevents a cease-to-flow. Provides connectivity between some pools.
Cease-to-flow (CF)	Partial or total drying of the channel. Stream contracts to a series of disconnected pools. No surface flows.

Within LTWPs, EWRs are developed based on knowledge of a species needs from a biological and ecological perspective and aligned with ecological or environmental objectives. EWRs can be designed based upon volumes of water required for species, generalised descriptions of flow components and may include information on timings, durations and interflow periods as well as additional information like water temperature or connectivity requirements. The LTWP process for determining appropriate flows recognises that a combination of EWRs may be required for freshwater-dependent biota with the combination of these flows representing and ideal flow regime for a species or community.

Examples of EWR summary statements developed for species as part of this project that align with LTWP language are:

- **Blue-Billed Duck**: Overbank flows required for lateral connection and creation of vegetated deep-water habitat.
- **Eastern Freshwater Cod**: Baseflows deeper than 0.9m required near nesting sites in spring when temperatures increase over 16°C. Avoid freshes and higher flows during nesting to reduce displacement of larvae.
- **Bellinger River Snapping Turtle**: Requires perennial rivers with pools, baseflows to be maintained. Floods and overbank events act as a disturbance.
- **Barrington Tops Tree Frog**: Very-low flow to base flows required year-round to maintain adult habitats. Stream permanence is critical.

EWR summary statements are found in Column D of the "Species EWR" sheet in the EWR spreadsheet.

4.3 Water dependence rating

Water dependence ratings were provided for all species reviewed in the "Species EWR" sheet. The water dependence rating provides a rapid indication of a species sensitivity to a lack of water, and how important water is to completing its life cycle and reproducing effectively. A higher number means a higher dependence on water bodies e.g., Australian bass has a water dependence rating of 3 as it is unable to survive outside a waterbody, whereas casuarina or river oaks have a rating of 1 as they can withstand periods of time without water. The criteria for assigning weightings varies between flora and fauna and is provided below (Table 2). These criteria have been adapted from the NSW Long Term Watering Plans process for this project (NSW DPIE 2023).

Table 2. Water dependence weighting scores for freshwater-dependent biota in coastal NSW.

Weighting score	Criteria Fauna	Criteria Flora
1 - Low water dependence	Dependent on a water-dependent ecosystem	Requires infrequent or non-seasonal inundation
2 - Medium water dependence	Requires access to a temporary waterbody or temporary access to a permanent waterboy	Requires frequent inundation or specific inundation periods.
3 - High water dependence	Requires permanent access to a permanent waterbody	Requires a waterbody or immersion in water for growth

4.4 Confidence score and rationale

Accompanying the EWR summary statement and water dependence ratings for each species in the "Species EWR" sheet is a confidence score and rationale. This provides a relative value between 1 and 6 indicating how confident the project team is in the EWR summary statement for each species, with a higher number indicating higher confidence, and a rationale for this score.

To provide a confidence score we used a scoring method derived from that of the Intergovernmental Panel for Climate Change (IPCC) which uses two criteria to rank confidence in their findings; agreement and strength of evidence (Bradley et al., 2017). *Agreement* refers to whether sources have a general agreement or alignment in the information presented by them. Within our assessment of confidence, high scores were provided when there were multiple sources of information that presented similar findings and low scores were given when there was a disagreement between sources or only a single source (Table 3). *Strength of evidence* refers to the type of sources information was sourced from. For our confidence scoring system, anecdotal evidence or unreferenced websites received low scores while peer reviewed scientific articles received high scores (Table 3).

An addition of the scores for agreement and strength of evidence for each species provides the confidence score within our assessment (Table 4). This final score is accompanied by a rationale statement outlining the relative strength or agreement of sources used.

In terms of the body of evidence reviewed, for most species there were limited sources of information, often only a single source. In light of this, the focus was on the type and quality of information available. The Australian Education Research Organisation has developed rubrics for the quality of information, based on whether evidence provides (AERO 2021):

- Evidence of why you would expect a to cause b
- A correlation between a and b
- Evidence of causation between a and b
- Causation is supported by corroborating evidence.

Most of the information reviewed fit into one of the first two categories. It was felt that this would not provide discrimination among sources and so the project team applied rubrics based on the source's strength of evidence (e.g., refereed scientific paper, website). In some instances, there was enough information (including references within articles) to determine whether there was agreement, and this was then rated as low, medium or high.

Table 3. Confidence score rating system for each confidence category

Confidence Category	Confidence score and indicative statements
Agreement	1 – A single source, or multiple sources that do not agree 2 – < 3 sources in broad agreement 3 – > 3 sources in agreement
Strength of evidence	1 – Anecdotal evidence or websites with no references 2 – Governmental reporting or agency websites with references 3 – Peer reviewed literature for specific species or related species groups

Table 4. Matrix for evaluating confidence in EWR summary statements based on the strength of evidence and the agreement between sources for a species. Numerical scores are given in column T of the "Species EWR" sheet.

Agreement	Quality (Limited)	Quality (Medium)	Quality (High)
High	High-Limited (3)	High-Medium (5)	High-High (6)
Medium	Medium-Limited (2)	Medium-Medium (4)	Medium-High (5)
Low	Low-Limited (1)	Low-Medium (2)	Low-High (3)

5 Outcomes of review

The review of existing EWRs for freshwater dependent species in coastal NSW encountered significant limitation and variation in available data between species, revealing large gaps in the understanding of species EWRs in coastal NSW.

5.1 Summary of identified species findings

The review encompassed 123 freshwater-dependent species along the NSW coast including fish, turtles, frogs, birds, mammals, invertebrates and vegetation. Throughout the EWR review process it was evident that there is limited scientific research on the flow requirements for freshwater biota in coastal NSW, particularly in terms of required flow volume, velocity, seasonality and discharge. Several socially valued species have had significant research committed to them resulting in quantitative understandings of their flow requirements (e.g., velocities at nesting habitat or volumes for upstream migration in a specific river) which may allow a detailed extrapolation to other river systems or species (e.g., Australian Bass, Short-finned Eel, Eastern Freshwater Cod). However, for most species EWR summary statements in this project have been extrapolated from qualitative descriptions of flow habitat, seasonality and breeding requirements, general habitat preferences (e.g., temperature and depth), migratory processes and information or studies from outside NSW.

5.2 Summary of key ecosystem functions

The summary of EWRs for the maintenance of ecosystem functions ("Ecological Functions" sheet) was developed from scientific literature relating to riverine, catchment and estuarine scale ecology concepts. It identifies 19 ecosystem functions of aquatic environments related to connectivity, habitat, food webs and ecosystem services. This information provides a high-level resource for readers unfamiliar with river ecology concepts and ecosystem functions to understand the importance of flows in catchment ecology. Where possible these ecosystem functions and the roles of flows in maintaining them have been aligned with habitat types where they may be most important or species who may rely on them. This information can be used to inform the refinement and implementation of EWRs in water management in coastal NSW.

5.3 Gaps

The major gap identified in this review is the paucity of consistent information for freshwater-dependent species flow requirements. While the review sought information with a preference for existing EWRs as flow volumes and discharge percentiles or flow component descriptions (baseflows, freshes etc.) this information was difficult to find for the majority of species. These values are important in delivering environmental water as they aid in setting objectives and watering regimes.

However, there are a number of other types of information that were found in the review which can be related to EWRs, although again, there was a lack of consistency in the literature. For example, depth information was present for a number of species but not all (both flora and fauna) while duration of flows/inundation was only present for some vegetation or fish. This type of information can be used to design EWRs e.g., depth requirements can be complemented with knowledge of specific river geomorphology and bathymetry to provide a greater understanding of species flow needs (Reinfelds et al., 2020). Additionally, habitat information, though generally descriptive in nature, can provide an indication of species requirements for vegetation, substrate or structure (e.g., large woody debris) with some preferred flow velocities described qualitatively (e.g., slow, still or fast flows). While integrating these varied and often qualitative descriptions into reliable EWRs remains challenging, this information provides some guidance on the habitat that needs to be created in riverine systems by water managers for species to thrive.

It is also worth noting the contextual gaps in the literature due to the review being for coastal species. For example, there was very little information on the ability of species to survive without water through dry and cease to flow spells. While this may be due to the lack of information generally for coastal species EWRs, it may also be related to the higher rainfall of the coast compared to inland areas and the perennial (rather than ephemeral) nature of the majority of waterways on the NSW coast to which species are adapted.

6 A complement to EWR

The environmental watering requirements of individual species and biotic communities are uncertain due to limits to, or the absence of, information on their habitat and life cycle needs, and the way ecosystems ensure these needs are met. For environmental flow planning to be as effective as possible it must address this uncertainty. Over time, adaptive management can reduce uncertainty, however, the information takes time to accumulate, and it is unlikely that the risks associated with uncertainty will be eliminated.

There are several measures that water managers and policy makers can adopt to deal with this uncertainty. The most common is to identify an appropriate indicator of community or ecosystem condition. Examples include using the EWR of keystone or umbrella species to represent a community or ecosystem. This approach carries risks as indicators are often selected on the basis of their value to local communities of people or how much we know about them rather than the correlation between their condition and the condition of the ecosystem of which they are part.

A further measure that managers can take in dealing with uncertainty is to identify complementary lines of evidence that can inform planning decisions. Bunn and Arthington (2002) published four principles that encompass the way in which flow regimes influence aquatic biodiversity. The principles are:

1. Habitat – the physical and chemical conditions required to survive.
2. Connectivity – Population viability is dependent on patterns of lateral and longitudinal connectivity.
3. Life History – Species have evolved to breeding, recruitment and survival in response to natural flow regimes.
4. Invasions - Success of invasive species is facilitated by the alteration of flow.

In many instances, while details of the EWR for individual species may be uncertain, consideration of what is known of the life history of species and associated habitat and connectivity needs can be used to complement detailed EWR in planning environmental flows (Espinoza et al., 2021). As such, these details for species identified in coastal NSW have been included in the attached spreadsheet.

To complement the approach taken, of identifying the EWR of individual species, the complementary life history considerations approach starts with general perspectives and seeks to get as specific as it can given available information. For example, the following questions could be posed when initiating this approach:

1. What type of ecosystem is it or what are its known characteristics?
   From a flow perspective, this means considering patterns of variability and predictability.

2. What species are critically dependent on the ecosystem?
   From a life history perspective, which species would be most vulnerable to ecosystem degradation?

3. What do we know of the identified species' life history?
   While the specifics may be uncertain, there may be enough general information about the family or order to identify broad needs. Relevant issues would be the life span, breeding strategy, role in the food web.

4. From what has been found, how does flow, through effects on habitat and connectivity, meet the species' needs?

Examination of flows and their influence on habitat was central to the early study of environmental flows as a restorative approach for waterways due the importance of the physical habitat in the survival of fauna and flora (Richter et al., 2006; Figure 3). There are multiple dimensions to habitat including its physical and chemical (water quality) characteristics which may encompass disturbance and refuge depending on flows as well as the biotic components and interactions (e.g., trees as shelter, structures or food resources). However, the physical dimensions e.g., soils, water availability and flow, and chemistry will determine the biotic dimensions of habitat. To complicate matters, consideration needs to be given to the need for habitat complexity with many species requiring various habitat to complete individual life cycles, and in some cases changes in flow to accommodate these requirements (e.g., higher flows may help facilitate migration for spawning of fish which require deeper or faster flowing water to move more easily). Despite these complexities, there is some available information on lifecycle and habitat requirements that may help inform environmental flow planning. Some of which has been included in this review. However, greater understanding between freshwater flow, geomorphology and habitat will need to be developed for effective implementation (Pardo-Loaiza et al., 2022).

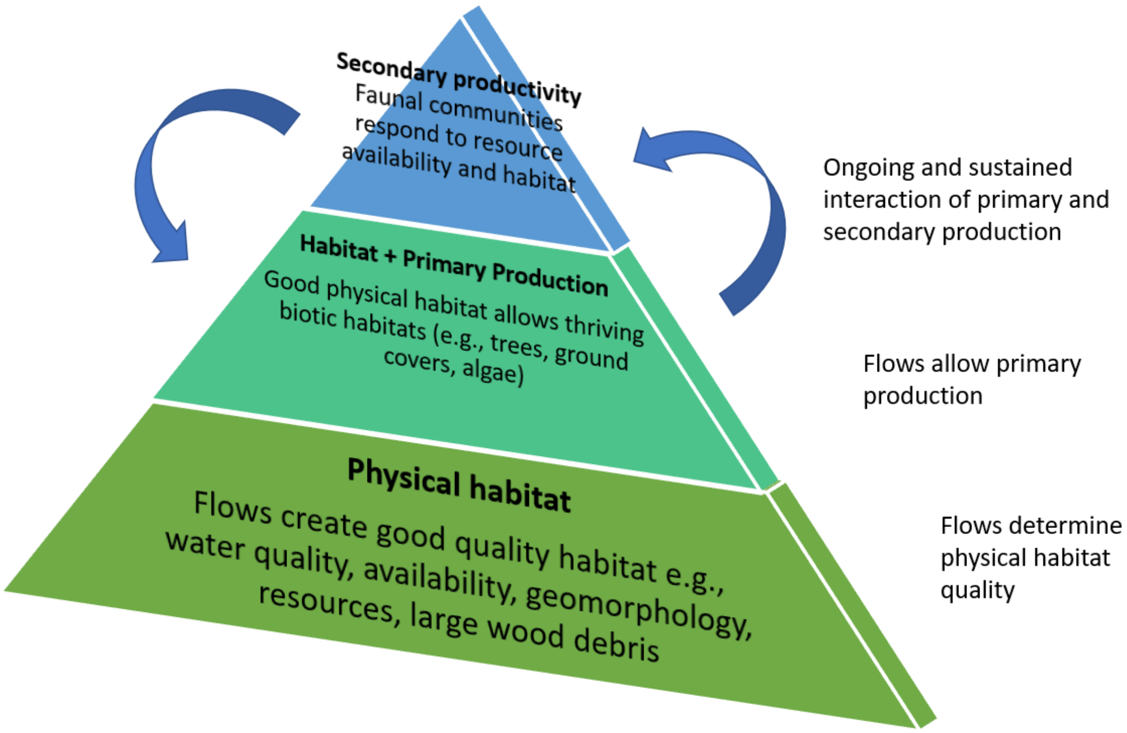

Figure 2. *Conceptual model of the relationship between flows, physical habitats and primary and secondary productivity.*

In many ways, this complementary approach reflects the logic of the natural flow paradigm (Poff et al., 1997), where the absence of an appropriate benchmark and uncertainty around EWR meant that the natural flow regime represented a reliable source of information because it was clear that species had been sustained over millennia. Here, the suggestion is that general information about what is known of species life histories and habitat requirements provides a better foundation than no information at all. Importantly when dealing with complex systems, this complementary approach may provide an important contrary view than that derived from specific information about a very small number of popular species. If nothing else, this complement will clarify areas of uncertainty and risk.

7 Practical and operational considerations

One of the core elements of planning and associated adaptive management processes for freshwater systems is forecasting the expected outcomes of different options. Within the context of planning, forecasting enables evaluation of different management options to navigate trade-offs and increase the likelihood that objectives or targets will be met. In complex systems such as the economy, climate or an ecosystem it is difficult to forecast outcomes due to the number of factors that influence the response, chance and uncertainty around the system's components and processes.

Regarding the implementation of EWRs in sustainable water management practices there are several practical and operational elements that can be considered that may improve the forecasting of outcomes.

1. **The scope, role and purpose of species specific EWRs in NSW coastal systems**

As detailed in the previous section, species specific EWRs provide one line of evidence to design environmental flows or protections. Recognising the shortcomings in this process is imperative to designing complementary approaches with the integration of EWRs for multiple species in a river or reach being the first step toward holistically designed flow regimes or protections for coastal rivers. However, flow requirements of other riverine aspects such as geomorphology and resource transport remain out of scope. Integrating the flow requirements of physical aspects may aid in refining EWRs across river systems.

Furthermore, incorporating species specific EWRs into, and implementing, environmental flow regimes and protections presents a challenge in NSW coastal rivers, due to their relative lack of infrastructure and operational regulation compared to inland rivers, where EWRs have been previously used.

2. Timescales of change in response to flow adjustments

In the integration of EWRs in sustainable water management practices and design of management and evaluation processes it must be noted that changes in habitat, ecology and species may take longer than expected. For example, there were no short-term responses to environmental flows by fish following experimental water releases in the Hunter River system (Rolls et al., 2011). Furthermore, even species with short life-cycles may take time to fully recover in disturbed ecosystems with macroinvertebrate communities taking up to 15 years to fully recover in the Snowy River after the reinstatement of flows downstream of Jindabyne Dam (Brooks and Coleman 2020).

3. Importance of connectivity and influence of barriers

Through this review there has been a focus on the importance of longitudinal and lateral connectivity for river systems and freshwater dependent biota. While restoring flows will help to alleviate pressures of reduced connectivity for some species (e.g., Australian bass, Reinfelds 2020) physical structures may still impede movement and dispersal, despite ameliorating measures. As an extreme example, the fish lift installed at Tallowa Dam on the Shoalhaven has not overcome the impediment that the dam poses to the migration of fish through this system in combination with environmental flow protections, particularly for species moving upstream (Walsh et al., 2014). Similar river regulation structures including weirs, levees, roads and channels that may, or are designed to, reduce longitudinal and lateral connectivity must be considered as they may influence the benefits of any environmental flows or protections which EWRs are integrated in.

4. Impacts of climate change on riverine habitats and ecology

Climate change is expected to alter the rainfall patterns and temperatures of the NSW coastline (Murphy et al., 2008). While changing rainfall patterns will influence the natural hydrology of riverine systems (Zhang et al., 2019), combined with temperature shifts it may also influence the range and distribution of species capable of migration and increase pressures on those unable to relocate (Poff et al., 2012). The implementation of EWRs into sustainable management practices must therefore take into account the role that climate change will play not only in altering flow regimes but in redistributing species home ranges. Maintaining baseline flow requirements in response to a shifting climate and rainfall patterns will first require the determination of a baseline but also will require adaptive management practices, adjusting requirements in line with climate shifts.

5. Incorporation of Traditional Owner and Indigenous Knowledges into planning.

Incorporation of Traditional Owner and Indigenous Knowledge into water management practices is increasing within NSW and Australia (Moggridge et al., 2021). Several programs are underway across the state to enable this integration across the Water Group and Department of Primary Industries and Regional Development (DPIRD). Future work in designing EWRs and developing sustainable water management practices may consider the benefits of Traditional Owner and Indigenous Knowledges can bring to this work.

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Appendix A

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