FINAL REPORT

Hawkesbury Nepean River System Physical and Ecological Processes Abridgement Report

December 2022

Developed as a part of:

Hawkesbury-Nepean River System (HNRS) Coastal Management Program (CMP) – Stage 2

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 Vicki Golding. This piece was commissioned by Alluvium and has told our story of water across Country, from catchment to coast, with people from all cultures learning, understanding, sharing stories, walking to and talking at the meeting places as one nation.

Document history

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Abstract

This report provides an overview of the state of knowledge of the physical and ecological processes that operate in and impact on the Hawkesbury Nepean River System estuary (the HNRS estuary). It recognises the importance of estuaries as semi-enclosed bodies of water connected to the ocean that serve as an interface between freshwater catchments and the open ocean and are characterised by tidal action and freshwater mixing. The geographical scope of the HNRS estuary has been defined to include the three distinct estuaries – Hawkesbury River, Brisbane Water and Pittwater – and their catchments.

A general overview of the dominant physical and ecological processes in estuaries has been provided as a general summary of the wider scientific literature with relevant examples and research from the HNRS system. Critical physical and ecological interactions with the surrounding terrestrial environment and wider catchment which influence the estuary have been discussed.

The key physical structure and processes considered include:

- geology
- hydrodynamics and hydraulics
- hydrology
- geomorphology
- catchment land use and development
- water quality

The key ecological structure and processes considered include:

- flora, fauna and protected species and communities
- primary and secondary productivity
- food-web structure
- nutrient dynamics and cycling
- decomposition processes
- ecological connectivity
- importance of flow variability

Threats and stressors that impact most heavily on the ecological function of the Hawkesbury River estuary system are explored in more detail. Stressors have been grouped as either related to climate change, or other direct anthropogenic impacts.

An ecosystem vulnerability assessment considering the sensitivity of key estuarine habitats to stressors, considering their scarcity and adaptive capacity, has been undertaken following an approach adapted from Astles et al. (2010). Discussion is provided on the vulnerability of key habitats including seagrass, saltmarsh and mangroves to the identified stressors.

Further analysis was undertaken to identify actions that can support the ongoing and integrated management of the HNRS estuary. Rehabilitation opportunities were explored based on established principles of estuarine rehabilitation. The existing management context of the system was reviewed, and previously identified management actions were assessed for their relevance in addressing threats and stressors. The role of strategic planning in system management was examined, and opportunities for using available planning mechanisms to promote positive ecological outcomes were identified. Key knowledge gaps and a strategy for addressing them through targeted research were outlined.

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1 Introduction

1.1 Purpose and context

The Hawkesbury-Nepean River System Ecological and Physical Processes Abridgement Report (hereafter called the "HNRS Abridgement Report") is designed to provide the Partner Councils of the Hawkesbury-Nepean River System (specifically the Hawkesbury City Council, The Hills Shire Council, Hornsby Shire Council, Central Coast Council, Ku-ring-gai Council, and Northern Beaches Council, hereafter called the "Partner Councils") with a concise overview of the state of knowledge of the ecological and physical processes that operate in and impact on the Hawkesbury-Nepean River system estuary (the HNRS estuary). Another aim of the report is to collate all physical and ecological processes in the HNRS independently of council's boundaries, looking at the river system as a holistic river system.

This report is written within the wider context of the NSW Coastal Management Framework and the Hawkesbury Nepean River Coastal Management Program (HNR CMP). The HNR CMP is being developed as a whole of system management tool that covers the distinct, yet interconnected waterbodies: the Hawkesbury River Estuary, Brisbane Water Estuary, Pittwater Estuary, and Broken Bay. The six Partner Councils have completed a whole-of-system Stage 1 Scoping Study for the HNRS estuary as part of the CMP process (Stage 1 scoping study – Water Technology, 2020). One of the major limitations outlined in the Stage 1 scoping study of the system is a lack of coordination across the river system between estuary councils, upper catchment councils, and state government agencies which can impede collaborative and coordinated efforts between councils and reduce the effectiveness of system wide management (Water Technology, 2020).

This Abridgement report represents an important component of the Stage 2 process of the HNR CMP, the development of an improved shared understanding of the ecological and physical processes of the HNRS estuary for the Partner Councils. This is a fundamental step toward the effective and collaborative management of the system and will help to ensure that the HNRS estuary remains a healthy ecosystem into the future.

In brief, this report is designed to provide the Partner Councils with a concise and up-to-date synthesis of current understanding of the physical and ecological processes that operate in the HNRS estuary. The information presented in this document will assist partner councils to identify management actions for consideration in the HNR CMP. It is intended to be easily understandable by the non-expert, while addressing important aspects relevant to a better understanding of the ecology and physical processes of the HNRS estuary and how it can be better managed. This shared understanding will support effective management of the system through a collaborative, cross-jurisdictional approach. By providing a singular reference point for the Partner Councils and their staff to refer to in managing the HNRS estuary this will allow better coordinated engagement with local and external stakeholders.

1.2 Report structure and approach

The abridgement report is presented in the following sections:

Section 1 – Introduction: establishes the context of the report and outlines the approach used to write it.

Section 2 – Hawkesbury-Nepean River system overview: provides a general overview of the HNRS estuary and a clear definition of the geographical scope and focus of the report.

Section 3 – Physical structure and processes: describes important physical processes and components including geological setting, geomorphology, land use, hydrology, and water quality.

Section 4 – Ecology structure and function: describes the ecological structure and function of the estuary including distribution and extent of different habitats, primary and secondary productivity, food-web structure, nutrient regeneration and cycling, decomposition processes, lateral and longitudinal connectivity.

Section 5 – Stressors, vulnerabilities and synthesis: examines prominent threats and stressors impacting the HNRS estuary, assesses the vulnerability of important ecosystems, and synthesises information into a series of conceptual diagrams.

Section 6 – Management to enhance estuarine values: discusses the current management context, reviews and identifies opportunities for improved and targeted future management and discusses key knowledge gaps and research areas.

Section 7 – Conclusions and recommendations: outlines how information from this report will be carried forward to the following stages of CMP development and be used for future HNRS estuary management.

1.3 Literature review and reference database

This abridgement report is based upon a comprehensive literature review, with the underlying information drawn from scientific journal databases (Web of Science, both Core Collection and All Databases), supplemented with additional references, often from the unpublished 'grey literature'. The compilation of these resources was assisted by Prof. Paul Boon, the author of "The Hawkesbury River: A Social and Natural History" (Boon, 2017). Collectively, these information sources were added to a reference database which supplements the extensive list of sources collected during the Stage 1 CMP scoping study. This database serves as both a reference list and repository for estuary managers and has been designed as a living reference that should be updated as new information and studies relevant to the HNRS estuary are published.

1.4 Mapping of the HNRS

Maps containing spatial information relating to various topics discussed serve as an important visual component of the abridgement report and are interspersed throughout it as figures. The maps have been produced with readily available spatial data from various resources such as the NSW Sharing and Enabling Environmental Data (SEED) database, DPI Fisheries Spatial Data Portal, and previous studies from which spatial data was available.

The maps included in this report highlight the connectivity of different processes and habitats within the system and their importance to its ecological function. They illustrate features of the catchment including land use characteristics, rivers and creeks, subcatchment boundaries, soils, dams, weirs and extraction points that link to important ecological processes or threatened habitats or ecological communities.

A web-based mapping tool has also been developed alongside this abridgment report. This interactive visual tool allows users to explore the HNRS estuary and select from a range of spatial data that illustrates key ecological and physical processes. This tool has been designed to support Partner Councils and stakeholders during subsequent CMP development stages and is able to be maintained and updated with new information such as any spatial information arising from concurrent HNR CMP Stage 2 studies.

The web-based mapping tool can be accessed here: HNCMP Web Map Application (arcgis.com)

2 Hawkesbury-Nepean River system overview

2.1 Geographical scope

The Hawkesbury-Nepean River system is one of the most significant coastal river systems in NSW. Being one of the most culturally and historically important natural landscapes of the NSW coast, the estuarine section of the HNRS provides significant environmental, social and economic value to the people of the Sydney Metropolitan and Central Coast regions. The Hawkesbury Nepean River system are part of the traditional lands and waters of several Aboriginal Peoples who have a continuous physical, spiritual and cultural connection to the area extending more than 40,000 years. The surrounding catchment includes some of the oldest and most utilised national parks in Australia. These protected areas support immense biodiversity value and provide many ecosystem services from the catchment and its estuary.

The geographical scope of the Hawkesbury Nepean River Coastal Management Program comprises the tidal waterways of the Hawkesbury-Nepean River system including the Brisbane Water Estuary, the Pittwater Estuary, the Hawkesbury River Estuary, and Broken Bay, as well as their contributing catchments (Water Technology, 2020).

While the NSW coastal management framework focuses on the coastal zone (as defined in the *Coastal Management Act 2016*, and *State Environmental Planning Policy (Resilience and Hazards) 2021* (formerly *SEPP (Coastal Management) 2018),* it is important to consider the broader system because estuarine health and successful estuarine management is impossible without consideration of the interconnected upstream processes. Therefore, this report examines processes throughout the entire estuarine system which includes the freshwater reaches beyond tidal influence as well as the contributing catchment. The geographic scope of this study is illustrated in (Figure 1), while the estuarine area that is the focus for the CMP and the corresponding management efforts is illustrated in (Figure 2).

2.1.1 Estuarine overview

Estuaries can be defined in numerous ways (Tagliapietra et al., 2009) with a distinguishing characteristic being their position at the interface of fresh and ocean water. For this report, an estuary is defined as semi-enclosed bodies of water connected to the ocean; an interface between freshwater catchments and the open ocean and are characterised by tidal action and freshwater mixing (Cameron and Pritchard, 1963; Fairbridge, 1980). They are highly valued for their ecological functions and biodiversity, remaining sites of great social, economic, and cultural value with many global population centres built around them (Pierson et al., 2002).

Using this definition allows for both the Pittwater and Brisbane Water to be considered as estuaries even though freshwater influence there is restricted to their most upstream limits, and freshwater inflows are minimal in comparison to that of the Hawkesbury. The critical terms within the definition applying to these estuaries are 'semi-enclosed' and 'tidal action', however freshwater inputs are the primary driver of estuarine processes. Therefore, there are three main estuaries that are considered in this report: The Hawkesbury, Brisbane Water, and Pittwater – which coalesce in the waters of Broken Bay. Six Local Government Areas (LGAs), (the HNR CMP Partner Councils) have frontages along the estuaries while an additional 18 LGAs lie either wholly or partially within the catchment. The CMP study area lies wholly within the wider *Broken Bay coastal sediment compartment*, which extends from Third Point to Barrenjoey Head – in between the *Sydney Northern Beaches* and *Central Coast* sediment compartments (Water Technology, 2020). Figure 2 illustrates the estuarine reach of the system and identifies the indicative location of the tidal limit of the Hawkesbury River Estuary.

Figure 1. *Overview of the Hawkesbury-Nepean River system including Brisbane Water and Pittwater.*

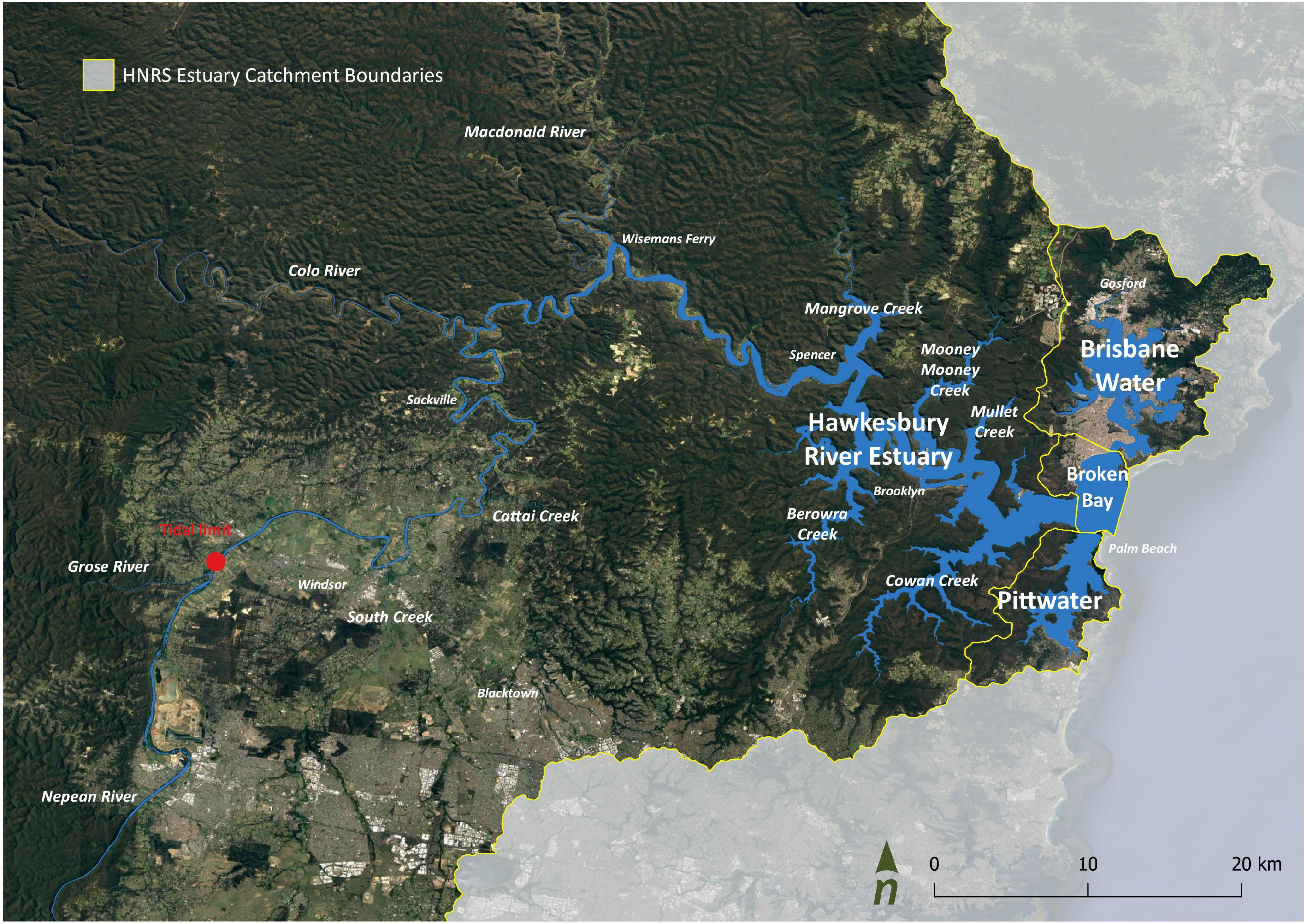


Figure 2. *Overview of Hawkesbury River, Pittwater and Brisbane Water estuaries*

2.1.2 Hawkesbury River estuary

The Hawkesbury River estuary is classified under the typology of Roy et al., (2001) as a tide-dominated drowned river valley estuary. The geographical extent of the Hawkesbury River, as well as the estuarine extent of the Hawkesbury-Nepean River system is generally considered to begin at the confluence of the Nepean and Grose Rivers at Yarramundi (Boon, 2017). This confluence represents an approximate location for the upper extent of tidal influence on the Hawkesbury River. Figure 1 provides an overview of the catchment of the Hawkesbury-Nepean River system, while Figure 2 focuses on the Hawkesbury River estuary.

The catchment of the Hawkesbury-Nepean River system covers approximately 21,400 km^2 and the riverine components include over 470 km of major waterways. The Nepean River system commences near the regional centre of Goulburn in the NSW southern highlands where it flows to meet the Grose River, thus becoming the Hawkesbury River which discharges into the Pacific Ocean at Broken Bay, north of Sydney.

There are three significant tributaries that flow into to the Hawkesbury River estuary—the Grose, Colo and Macdonald Rivers. The water is generally saline downstream from the confluence of the Hawkesbury River with the Colo River to the mouth—a length of 83 km, though saline water can penetrate upstream to Sackville during drought conditions (Markich and Brown, 1998).

Tributaries (listed from upstream down) of the Hawkesbury River include:

- Grose River
- Rickaby's Creek
- South Creek
- Cattai Creek
- Little Cattai Creek
- Colo River
- Webb's Creek
- MacDonald River
- Mangrove Creek
- Marramarra Creek
- Berowra Creek
- Mooney Mooney Creek
- Mullet Creek
- Cowan Creek

There are 21 islands in the Hawkesbury River estuary of varying sizes. These are significant in terms of habitat and biodiversity and many benefit from some sort of ecological protection status. The six largest in downstream order are:

- Bar Island
- Milson Island
- Peat Island
- Spectacle Island
- Long Island
- Dangar Island.

2.1.3 Brisbane Water

The most downstream northern arm of the Hawkesbury-Nepean River system is the Brisbane Water estuary. This wave-dominated barrier estuary (Roy et al., 2001) has a catchment area of nearly 150 km^2 and contains over 90 km of foreshore habitat (Astles et al., 2010).The water body covers 27 km^2 and includes large areas of open-water habitat. There are five major waterways that make up the Brisbane Water estuary including:

- Entrance Reach between The Rip and Half Tide Rocks
- Woy Woy Reach, including Pelican Island, Riley's Island and St Hubert's Island
- Kincumber Broadwater
- Brisbane Water (upstream of Pelican Island)

- Woy Woy Bay and Woy Woy Inlet.

The tributaries of Brisbane Water are generally much smaller than those of the Hawkesbury. The main inflowing streams are:

- Ettalong Creek
- Kincumber Creek
- Woy Woy Creek
- Coorumbine Creek
- Upper and Lower Narrara Creek
- Erina Creek.

Important urban centres within the catchment include Gosford, Erina, Kincumber, Saratoga, Davistown, Empire Bay, Woy Woy, Ettalong and Umina.

There are three large islands in Brisbane Water along with numerous smaller islands. St. Huberts Island is a canal estate connected to the mainland via Helmsman Blvd. Pelican and Rileys Island are uninhabited and contain large and ecologically important estuarine wetland habitats. Figure 3 provides an overview of Brisbane Water.

2.1.4 Pittwater

The most downstream southern arm of the HNRS is the Pittwater estuary. This tide-dominated drowned river valley estuary (Roy et al., 2001) has a catchment area of approximately 60 km^2 bounded by approximately 52 km of foreshore (Astles et al., 2010). Extending from Newport in the south, the Pittwater estuary includes many secluded bays, beaches and headlands.

Large areas of this sub-catchment, especially to the west, are national park or other forms of protected area (e.g., Ku-ring-gai Chase National Park). In contrast, the eastern and southern areas of the catchment are highly urbanised with urban centres such as Palm Beach, Clareville, Newport, Bay View and Church Point.

The tributaries of Pittwater are also generally much smaller than those of the Hawkesbury. The main tributaries include:

- Careel Creek
- Salt Pan Creek
- Mona Vale Main Drain
- Cahill Creek
- McCarr's Creek
- Salvation Creek

Scotland Island is the lone major island in the Pittwater estuary, located in the southern estuary between Elvina Bay to the west and Clareville to the east. Scotland Island covers approximately 52.5 hectares. Although it is inhabited and serviced by four ferry wharfs, the majority of the island is covered by Spotted Gum forest, an Ecologically Endangered Community. Figure 4 provides and overview of Pittwater.

2.1.5 Broken Bay

The three aforementioned systems converge in Broken Bay, which links the river and most seaward northern and southern arms with the Pacific Ocean. Broken Bay is bounded by Box Head to the north and Barrenjoey Head to the south.

Broken Bay is classified as a semi–mature tide-dominated drowned valley estuary (Roy et al., 2001). Broken Bay is exposed to coastal processes as are the beaches and rocky foreshores in the northern portion of the Pittwater and Patonga, Pearl, Umina and Ocean Beaches.

Broken Bay contains a series of smaller coastal estuaries such as Patonga Creek, Pearl Beach Lagoon and Ettalong Creek which are each situated adjacent to coastal communities. Cowan Creek, which drains into Broken Bay, is a main arm of the estuary that contains the recreational boating hubs of Cottage Point and Bobbin Head.

Lion Island is situated in the middle of Broken Bay. It is a protected nature reserve with significant ecological and conservation value. It is important breeding grounds for migratory seabirds and Little Penguins (*Eudyptula novaehollandiae)* and is free of feral cats and foxes. Figure 5 provides an overview of Broken Bay.

Figure 3. *Overview of Brisbane Water*

Figure 4. *Overview of Pittwater*

Figure 5. *Overview of Broken Bay*

2.2 Functional zones

In addition to understanding the location of the main sections of the HNRS estuary, it is useful to understand the functional zones of the system. There are numerous ways to classify and subdivide estuaries to discuss the processes that occur within them; these classifications and definitions can often overlap (Tagliapietra et al., 2009). For the purposes of this report and to aid the Partner Councils in aligning with the work of other important stakeholder agencies, including Sydney Water and NSW DPE, the functional zone classifications used by NSW DPE have been used in this report to help steer reporting and communication of physical and ecological processes in the Hawkesbury (Figure 6; Table 1). These functional zones, listed from upstream to downstream, include:

- Contributing Catchments
- Freshwater Tidal Pools
- Upper Estuary
- Middle Estuary
- Lower Estuary

The functional zones are principally determined by their location on the freshwater to saltwater continuum. This is influenced by the distance (or proximity) to freshwater sources and the saline tidal inputs. This continuum exists in three dimensions: longitudinally up the mainstem of the Hawkesbury River (illustrated in Figure 6); laterally up the tributaries; and vertically within the water column due to stratification of fresh and saline water (see Section 3.2 for further discussion of this topic).

As such, there are also different functional zones within the different estuaries and tributaries although the scale of this zonation is significantly reduced compared to that of the main Hawkesbury River estuary. For example, although the entrance to Berowra and Cowan creeks are located in the 'Lower Estuary' functional zone of the mainstem of the Hawkesbury River, they would also contain areas of 'Upper Estuary' and 'Middle Estuary' functional zones when viewed at a local scale. The functional zones framework can also be applied to the Brisbane Water and Pittwater Estuaries, although again, these zones are less pronounced than for the Hawkesbury River Estuary due to the comparatively small freshwater inputs.

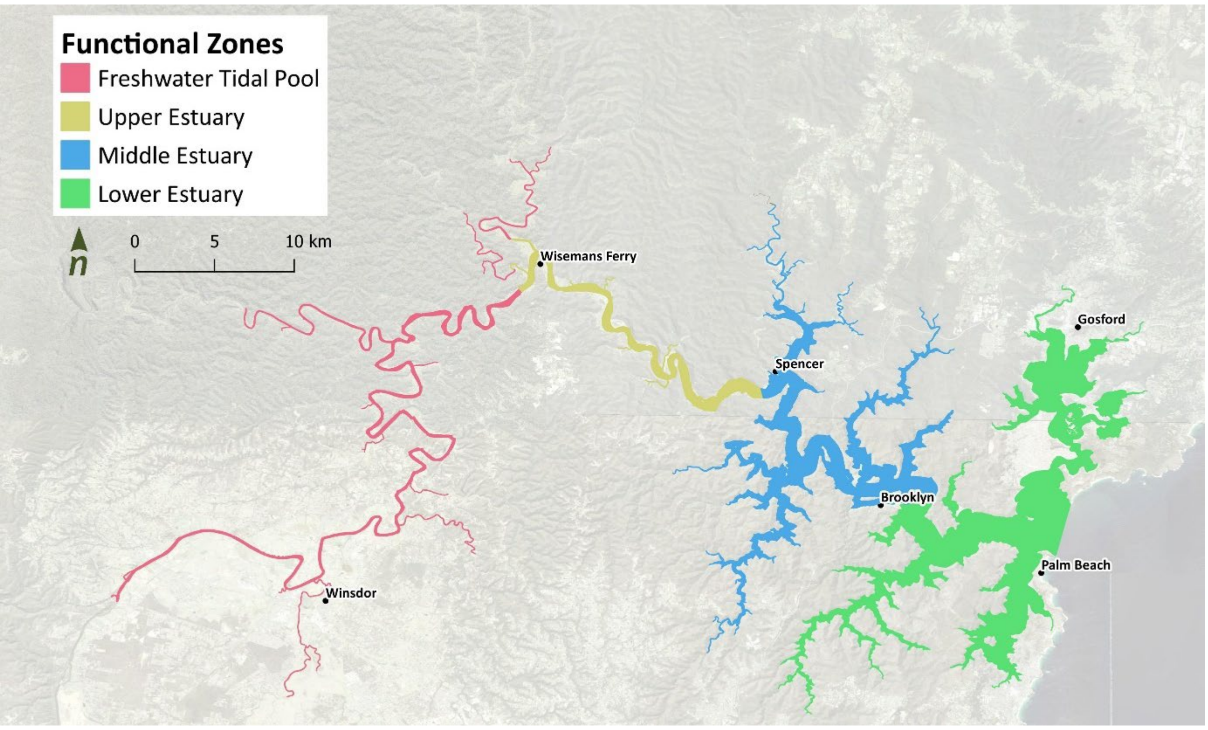


Figure 6. *Functional zones of the Hawkesbury-Nepean River System*

Table 1. Functional zones of the Hawkesbury-Nepean River Estuary

Functional zone	Description
Contributing catchments	The land area that drains to the tidal waters of the Hawkesbury-Nepean River system is inherently connected to the functions, processes and health of the estuaries and coastal zone. Land uses determine the characteristics of the catchment and influence physical and ecological processes. Overview of the 'Contributing Catchments' for the HNRS are provided above in Section 2.1.
Freshwater Tidal Pool	The 'Freshwater Tidal Pool' zone of the Hawkesbury extends from the tidal limit at Yarramundi approximately to Wisemans Ferry. This zone is characterised by freshwater and very low brackish salinities (though reaching up to 10-12 PSU at Wisemans Ferry) while still being tidally influenced (Loveless, 2011). This zone has high levels of sediment deposition, nutrient inputs and is at high risk of harmful algal blooms (HABs). Freshwater Tidal Pool zones of Brisbane Water and Pittwater are significantly less prominent due to their smaller volumes of freshwater inputs.
Upper Estuary	The 'Upper Estuary' zone of the Hawkesbury extends from Wisemans Ferry to just upstream of Spencer and Mangrove Creek. It is characterised by lower range brackish salinities (10 PSU - 20 PSU, 25 PSU during prolonged drought), tidal resuspension of sediments and benthic sources of nutrients (Ferguson and Scanes, 2021). Mangroves and saltmarsh are present throughout this section. There are similar 'Upper Estuary' functional zones, though less pronounced, in the Hawkesbury tributaries, Brisbane Water and Pittwater.
Middle Estuary	The 'Middle Estuary' zone of the Hawkesbury extends from Spencer to Brooklyn and has higher salinities (25 PSU and above) due to the stronger influence of marine exchange (Loveless, 2011). Tidal processes are stronger here than in the Upper Estuary, with sediments reworked, or mobilised, by tidal currents in this area. During flood events this area is a significant receiving zone for sediment deposition with substantial nutrient resources in the sediment. Berowra Creek and the upper sections of Brisbane Water have similar conditions to the Middle Estuary due to their shared position along the estuarine continuum. However, due to their reduced freshwater inflows relative to the main stem of the Hawkesbury they can suffer from thermal, oxygen and nutrient stratification which lends to its increased risk of algal blooms relative to the Upper and Middle estuarine zones of the Hawkesbury (Larsson et al., 2017).
Lower Estuary	The 'Lower Estuary' zone (inclusive of Broken Bay and most of Pittwater, Cowan Creek and Brisbane Water) is the marine dominated extent of the system. Marine exchange ensures high salinities and generally good water quality throughout this reach (Ferguson and Scanes, 2021). There is substantial wave and tidal energy here which plays a role in reworking, or mobilising sediments.

3 Physical structure and processes

This section outlines the physical structure and processes that are responsible for shaping and creating the estuarine environment of the Hawkesbury-Nepean River system. This is designed to help managers understand general physical principles and aid them in effectively understanding the HNRS estuary. This section provides a general overview of the dominant physical processes in estuaries including a summary of the wider scientific literature and relevant examples and research from the HNRS system. The aim is to increase localised understanding of these processes and inform future management decisions.

While this section is focused on the physical processes occurring within the estuary, it will also address interactions with the surrounding terrestrial environment and wider contributing catchment which influence the estuary. This is a necessary step in understanding and managing coastal waterways and estuaries holistically, with the surrounding terrestrial environment and contributing catchment playing a large role in defining estuarine function.

The components of physical structure and processes that are crucial to estuaries explored in this section include:

- Geology
- Hydrodynamics and hydraulics
- Hydrology
- Geomorphology
- Catchment land use and development
- Water quality

3.1 Geology

The geology of an estuarine catchment plays an important role in shaping the character of estuaries governing:

- the topography of the catchment,
- the way water flows into the estuary and
- the materials carried into the estuary by inflows e.g., nutrients and sediments.

Furthermore, catchment geology often determines patterns of land use and development with geological features such as arable soil, water availability and accessibility of terrain playing a large role.

The Hawkesbury estuary and its catchment are situated within the much larger Sydney Basin which extends up as far as Mudgee in the NW and past Goulburn and Nowra in the S and SW (Figure 7). Subaerial erosion of Permian and Triassic sedimentary strata has resulted in the current topography of the Sydney and Hawkesbury regions. The HNRS catchment is geologically defined by the Hawkesbury Sandstone group, overlayed on the lowland river floodplain and along ridge-tops by Wianamatta Shale (Branagan et al., 1976). Large areas of the catchment in the Blue Mountains are underlain by the Narrabeen Sandstones group, which are slightly older than the Hawkesbury group. The alluvial soils of the Cumberland Plain atop the Wianamatta Shale are a recent Holocene addition to the area and have played an important role in the pattern of settlement of the Sydney metropolitan region into arable and easy-to-develop areas, while the steep and rugged sandstone cliffs of Hawkesbury Sandstone have resulted in a lack of expansion into areas north east of the Hawkesbury River. This has resulted in large areas of native vegetation retention to the north and north west of the estuary (Haworth, 2003), much of which is now protected within national parks and other protected areas. There are also examples of volcanic diatremes which are important for local spots of rainforest due to their fertile soils and sheltered aspects.

Soil types are derived from the underlying geology which determines the erosion potential, nutrient, mineral, and water content. This contributes to key physical processes such as sediment and nutrient transport and determines the suitability for certain land uses such as agriculture. Soils derived from Hawkesbury Sandstone are characteristically shallow, sandy and nutrient-poor, while those derived from Wianamatta Shale are more nutrient-rich and clayey which are able to absorb water and better support agriculture, although still relatively nutrient poor from a global perspective. An assessment and mapping of the land and soil capacity within the Hawkesbury-Nepean River system, including Brisbane Water illustrates the distribution of these different soil types (OEH, 2012). These are a critical factor in shaping settlement patterns, which over time have altered the landscape of the system and created conditions that have led to associated threats and pressures, which will be discussed further in Section 6.

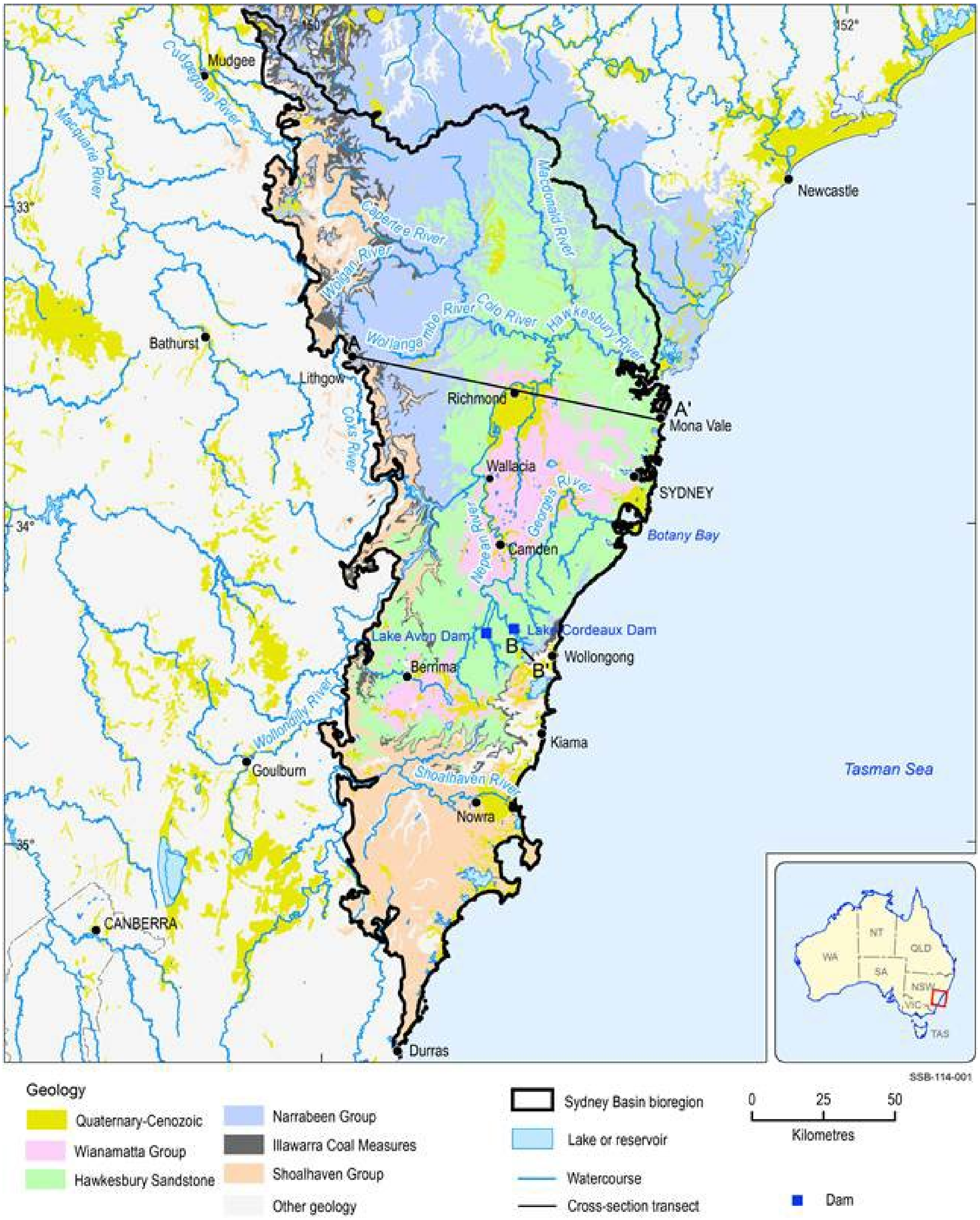


Figure 7. *Underlying geology of the Sydney Basin. (Bioregional Assessments, 2018)*

An example of the difficult to cultivate Hawkesbury Sandstone country typical of the lower Hawkesbury River and its northern and north western catchment can be seen in Figure 8, with the more arable alluvial plains of the Cumberland Plain shown in Figure 9.

Figure 8. *Typical sandstone dominated gorge country of the Hawkesbury River Region. Berowra Creek as viewed from Naa Badu lookout near Berowra. Photograph by P.I. Boon 2016.*

Figure 9. *Agricultural use of the alluvial plains near Pitt Town Bottoms, atop the Wianamatta Shale deposits. Photograph by P.I. Boon 2016.*

3.2 Hydrodynamics and hydraulics

Hydraulics and hydrodynamics describe the forces exerted by and movement of water through aquatic systems (e.g., estuaries) by inflows, currents, tides, waves, groundwater exchange and wind action. The way that water moves through an estuary is an important element shaping its physical and ecological processes.

In estuaries, one of the most important physical processes is the mixing and circulation of freshwater and saline water across varying spatial and temporal scales by hydraulic and hydrodynamic forces. This mixing of fresh water from riverine inputs and saline water from the ocean results in an estuarine salinity gradient, the defining feature of estuarine environments. Figure 10 provides a conceptual overview of how hydrodynamic processes operate in the HNRS estuary. These include:

- Catchment inputs – Freshwater inflows enter the catchment from rain-fed upstream sources e.g., rivers and catchment tributaries and from groundwater. Freshwater inputs are important in regulating estuarine salinity, flushing estuaries of pollutants and transporting resources such as nutrients and sediments to the system. These topics are explored in more detail in Section 3.3 – Hydrology, Section 3.5 – Catchment land use and development, and Section 3.6 – Water quality.
- Riverine flow – The volume of freshwater that flows from the Hawkesbury River plays a crucial role in determining the estuary's character. Variability in flows due to factors such as rainfall, land use practices, and changes to the river's natural flow patterns from dams and urbanization can have significant impacts.
- Floodplain connectivity – During high discharge periods the estuary can become hydrologically connected to the floodplain. When flood waters recede organic matter and nutrients are transported to the main channel of the estuary. This process is highly influential on certain ecological processes and is explored in more detail in Section 4.4 – Lateral and longitudinal connectivity.
- Inflow into Upper Estuary - Riverine flow into the Upper Estuary begins to mix with low salinity estuarine water in the Middle and subsequently Lower Estuary zones. During high discharge periods, the estuary will be mostly fresh in salinity, well flushed and have large inputs of terrestrial nutrients and sediments. If flows are reduced substantially, the Upper Estuary can increase in salinity and nutrients and pollutants can remain in the Upper Estuary. This process is highly influential for certain ecological processes and is explored in more detail in Section 4.5 – Freshwater inflows and flow variability.
- Tidal mixing – Tidal processes increase the mixing of fresh and marine waters with high tides bringing more saline water higher into the estuary. Especially during periods with larger freshwater inflows, these saline waters can enter the estuary as a salt wedge, with denser salt water penetrating the estuary along the bottom of the estuary in a wedge. This can happen during high discharge periods when the velocity of freshwater is increased. Salt wedges can remain stratified if there is inadequate mixing of fresh and salt waters. The high tide also inundates intertidal environments such as mangroves, and on the highest of tides (e.g. HAT) also saltmarshes.
- Stratification – Stratification of fresh and salt water occurs in the Hawkesbury both longitudinally, laterally and vertically. In the mainstem of the Hawkesbury, longitudinal stratification is mainly driven by the interaction of freshwater inflows and tidal influx. In the Upper to Middle functional zones vertical stratification occurs when there is minimal freshwater to mix fresh and saline waters, and results in the formation of the salt wedge discussed earlier. Tidal currents and water turbulence through wind actions can accelerate mixing both longitudinally along the river and vertically through the water column.
- Brackish export – Brackish water is exported from the estuary due to riverine forces pushing brackish water out into the ocean. The relative salinity of the water and volume being exported is dependent on the amount of freshwater being discharged into the estuary by the river.
- Marine exchange – Marine exchange occurs through the open mouth of the estuary. The relative volume of seawater exchange at any time is determined by the volume of freshwater flowing into the system (pushing ocean water out), tidal cycles (pushing ocean water in) and the relative level of the ocean (controlled largely by weather systems such as low-pressure cells, pushing ocean water into the estuary to various degrees).

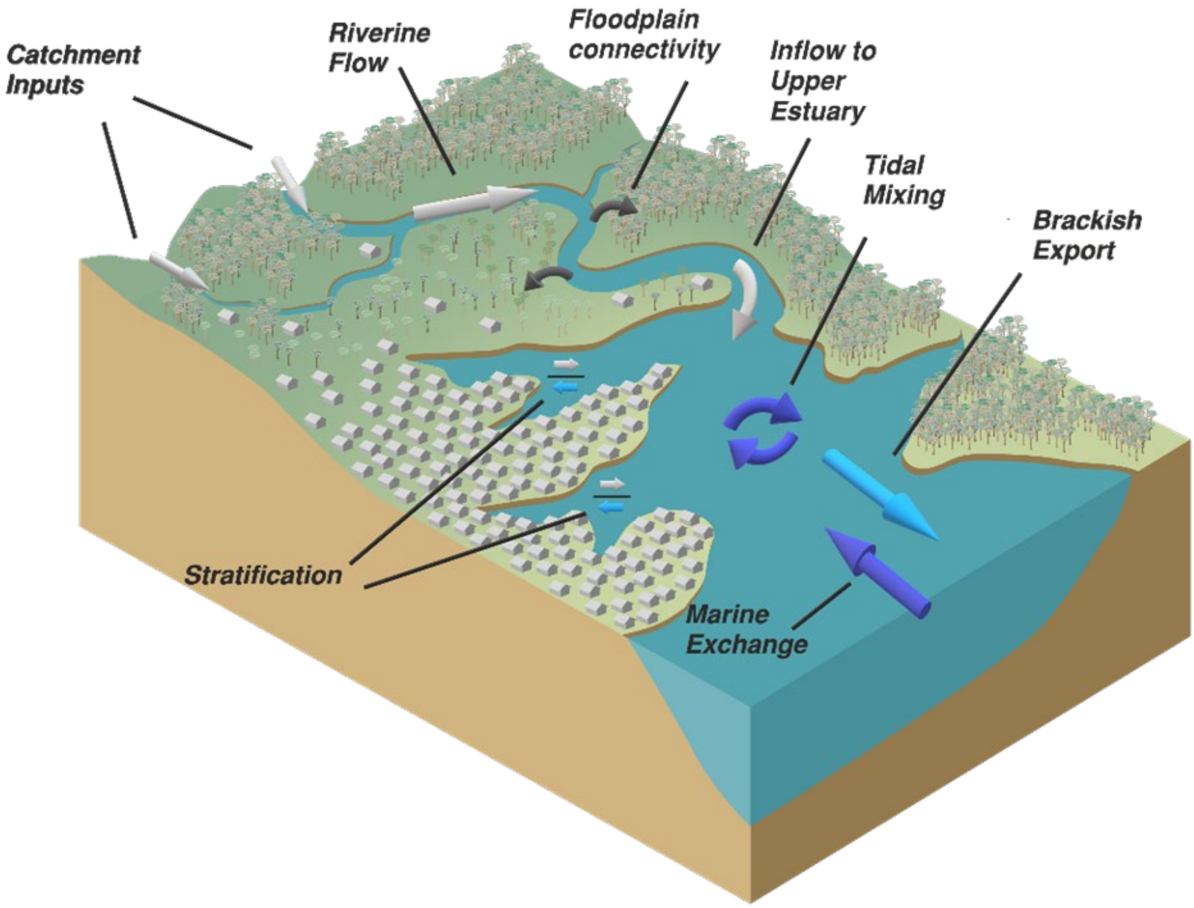


Figure 10. *Hydrodynamic processes within the HNRS*

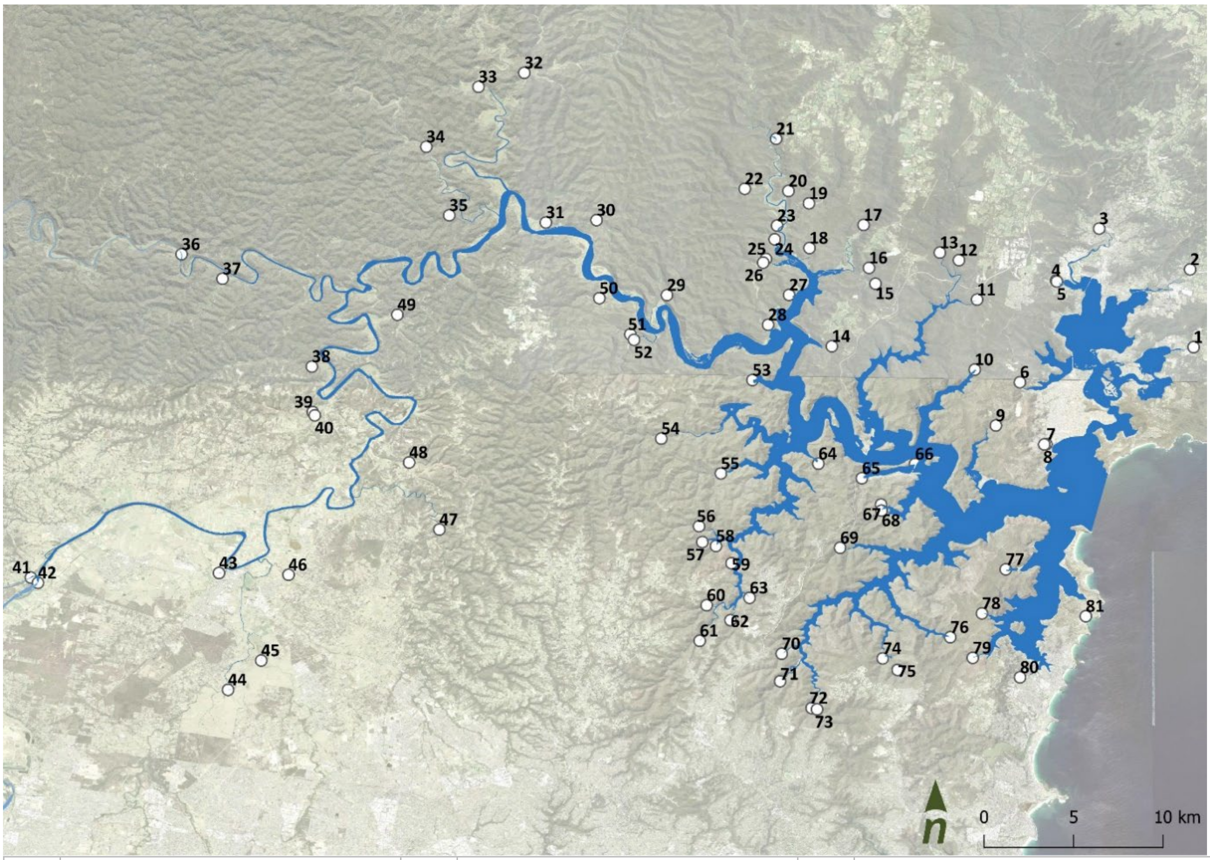
Throughout the different functional zones of the system, different hydrodynamic processes are more important to the physical and ecological character of the estuary (Table 2). The relative strength of these processes is dependent on the force of the riverine, tidal and wave processes occurring at any given time in the system. The strength of these forces can also fluctuate due to local weather systems, regional weather patterns (e.g., East Coast Lows) or seasonal dynamics.

Table 2. Dominant hydrodynamic processes in different functional zones of the estuary

Location	Hydrodynamic processes	Forces
Freshwater Tidal Pool	Freshwater inflow, weak tidal fluctuation	Riverine, tidal (weak)
Upper Estuary	Freshwater inflow, tidal inundation	Riverine, tidal
Middle Estuary	Tidal mixing, inundation and sediment resuspension Freshwater inflow (Flooding only)	Tidal and riverine (floods), wave (weak)
Lower Estuary	Tidal fluctuation, wave energy	Tidal and wave processes

3.2.1 Tidal influence

The longitudinal extent of an estuarine environment can be defined by the tidal limit, the furthest point of tidal influence and saline water penetration upstream from the estuarine mouth (Kim et al., 2017). For the Hawkesbury, this point is approximately the confluence of the Grose and Nepean Rivers at Yarramundi. The approximate location of tidal limits throughout the HNRS are presented in Figure 11.



#	Location	#	Location	#	Location
1	Kincumber Creek	28	Breakfast Creek	55	Coba Creek
2	Erina Creek	29	Gunderman Creek	56	Calabash Creek
3	Narara Creek	30	Mill Creek	57	Banks Creek
4	Coorumbine Creek (North)	31	Roses Creek	58	Fosters Creek
5	Coorumbine Creek (South)	32	Wrights Creek	59	Crossland Creek
6	Woy Woy Creek	33	Macdonald River	60	Still Creek
7	Ettalong Creek	34	Webbs Creek	61	Berowra Creek
8	Kahibah Creek	35	Doyles Creek	62	Lyrebird Gully
9	Patonga Creek	36	Colo River	63	Sams Creek
10	Mullet Creek	37	Wheeny Creek	64	Mougamarra Creek
11	Piles Creek	38	Roberts Creek	65	Seymours Creek
12	Floods Creek	39	Howes Creek	66	Sandbrook Inlet
13	Mooney Mooney Creek	40	Currency Creek	67	Porto Gully
14	Marlows Gully	41	Grose River	68	Campbells Creek
15	Kellys Creek	42	Nepean River	69	Yatala Creek
16	Cabbage Tree Creek	43	Rickabys Creek	70	Apple Tree Creek
17	Popran Creek	44	South Creek	71	Cockle Creek
18	Hominy Creek	45	Eastern Creek	72	Cowan Creek
19	Ironbark Creek	46	McKenzies Creek	73	Kierans Creek
20	Bedlam Creek	47	Cattai Creek	74	Smiths Creek (South)
21	Mangrove Creek	48	Little Cattai Creek	75	Smiths Creek (East)
22	Sugee Bag Creek	49	Doyles Swamp	76	Coal and Candle Creek
23	Birdseye Creek	50	Dalgetys Creek	77	The Basin
24	Screech Owl Creek	51	Ashdale Creek	78	Salvation Creek
25	Dinner Creek (North)	52	Layburys Creek	79	McCarrs Creek
26	Dinner Creek (South)	53	Pumpkin Point Creek	80	Cahill Creek
27	Scotchmans Creek	54	Marramarra Creek	81	Careel Creek

Figure 11. *Tidal limits of the HNRS* (Manly Hydraulics Laboratory, 2006)

Tidal processes play a significant role in the HNRS from the Freshwater Tidal Pool zone through to the Lower Estuary, mobilising sediments and providing lateral connections with the intertidal habitat. Even though water is nominally fresh in the Freshwater Tidal Pool and riverine processes play a significant role in shaping the physical and ecological conditions of the estuary here, tidal cycles do occur within a small range, 0.2-0.5 m. This range increases to as much as 2 m of tidal fluctuation throughout the Lower Estuary from Gunderman to Broken Bay (Hughes et al., 1998).

The Pittwater tidal range (difference between high and low tide) is similar to that in Broken Bay, though Brisbane Water has a tidal range, reduced by about 15% due to the tidal delta at Ettalong and Woy Woy, which attenuates the tidal range in the Upper Estuary and limits exchanges of water to Broken Bay (CLT, 2008).

Broken Bay, and the Lower Estuary including Pittwater are the marine-dominated end of the HNRS and are more heavily influenced by tidal and wave forces as well as wind action, which drive mixing and circulate estuarine water. Modal offshore significant wave heights are in the range of 0.5-2.0 metres with spectral peak periods predominantly in the range 7-12 seconds, and a predominantly S – SE swell direction (Kulmar et al., 2013). This makes Broken Bay a high-energy zone with coarse, shelly sands where wave energy drives sediment inshore and creates barrier systems such as Patonga, Pearl and Ocean beaches. Ocean swell can also refract into Pittwater, and as far upstream as Dangar Island with wave energy contributing to sediment dynamics of the flood tide delta and sandy shorelines.

3.2.2 Stratification

One of the management risks that comes with reduced freshwater inputs to estuaries is salinity-based vertical stratification of the water column. This can result in vertical stratification of salinity, temperature, dissolved oxygen and nutrients. As the Hawkesbury estuary is generally well mixed, vertical salinity and temperature stratification is not often present in the main channel of the system. However, a shallow salt wedge is apparent in the Upper and Middle Estuary during low flow conditions (Figure 12). Base flow freshwater inputs keep salinities low, between 0 and 5 psu, in the Freshwater Tidal Pool between Windsor and the Colo River confluence but during larger inflows, freshwater flows over the top of marine waters, reaching as far down as the confluence with the MacDonald River at Wisemans Ferry. This phenomenon also occurs in the Upper Estuary zone of Berowra Creek. During these larger inflow periods, heavier salt water can become stratified underneath freshwater inflows and there is little mixing between the two layers (Collis, 2014a; Fugate and Jose, 2019).

Manly Hydraulics Laboratory maintain a real-time monitoring program in Calabash Bay in the Berowra Creek tributary that collects data at both 1 m and 5 m depths to better capture the stratification. The variables measured include water and air Temperature, salinity, chlorophyll-a, Photosynthetically Active Radiation (PAR) and thermistor chain (every 1 m from surface to maximum depth 15 m). The site has a depth of approximately 15 m which is unusually deep compared to the rest of Berowra Creek and is subject to regular stratification. This deep hole has been identified as a likely origin site for algal blooms. The data can be accessed with the following link - https://www.mhlfit.net/users/HornsbyShireCouncil-Site-BeroCR8.

Stratification of oxygen and nutrients are more often confined to the upper reaches of the lower estuarine tributaries where freshwater input is minimal (notably Berowra and Cowan Creek and Pittwater) and are discussed in a later section on water quality (Section 3.6).

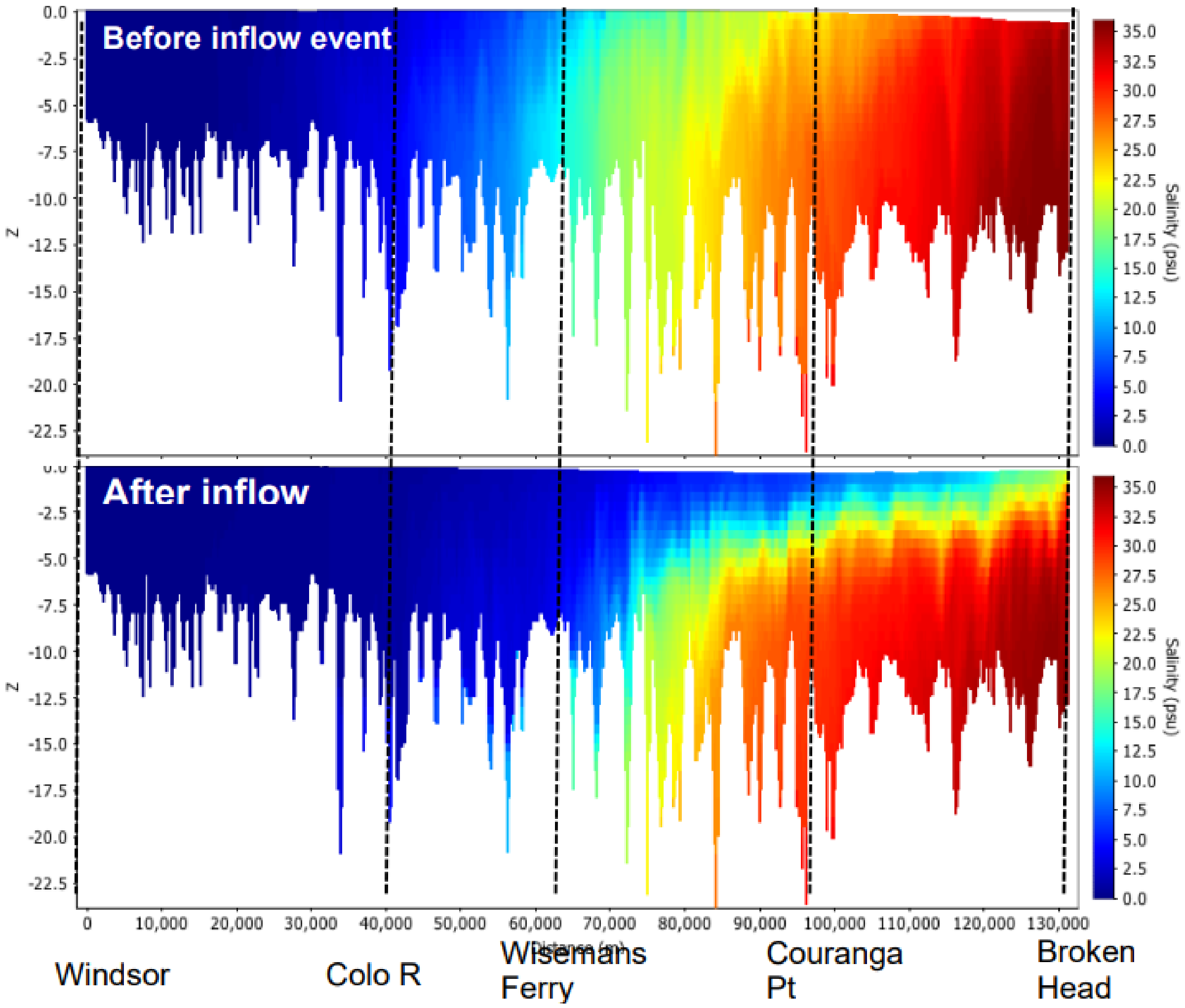


Figure 12. *Estuary salinity (PSU) gradients at water column depth (Z). Top panel: Modelled salinity from Windsor to Broken Head on Sept 1, 2008, after minimal freshwater discharges; Bottom panel: Modelled salinity along same thalweg on Sept 9, 2008, after freshwater flow event (Loveless, 2011).*

3.3 Hydrology

The hydrology of estuarine systems refers to the patterns of freshwater discharge from rivers and catchment runoff to estuaries, although other sources of water inputs such as groundwater may also contribute. These patterns influence the water availability, quality and changes to geomorphology within the estuary. The spatial and temporal distribution of rainfall is the principal driver of catchment hydrology changing how freshwater is discharged to estuaries. Higher intensities and durations of rainfall result in large freshwater inflows to estuaries and lower rainfall results in reduced freshwater inflow. The antecedent conditions of the catchment also influence what proportion of rainfall is generated into runoff, with lower runoff generated when the catchment is dry. The pattern of inflows from tributary creeks and rivers to estuaries can be characterised using the following classifications:

- Cease to flow – a period of no flow (does not occur in perennial rivers like the Hawkesbury-Nepean)
- Low or base flows – the general base level of freshwater discharge to maintain continuous discharge
- Freshes – periods of increased freshwater discharge
- High flows/Bank full flows – pronounced increases in freshwater discharge that fill rivers to their banks and wet benches
- Overbank flows – freshwater discharge periods that spill onto the floodplain.

The classification of each of these flow types is relative to the size of the river or estuarine system to which they are being applied. An example of how these various flow categories may appear on a hydrograph is shown in Figure 13, a hydrograph of Eastern Creek (a tributary of the Hawkesbury) between May 2020 and August 2021. The natural variation between these flow types, also known as the natural flow regime, is an important element in maintaining riverine and estuarine health and must be considered when managing aquatic systems (Poff and Zimmerman, 2010).

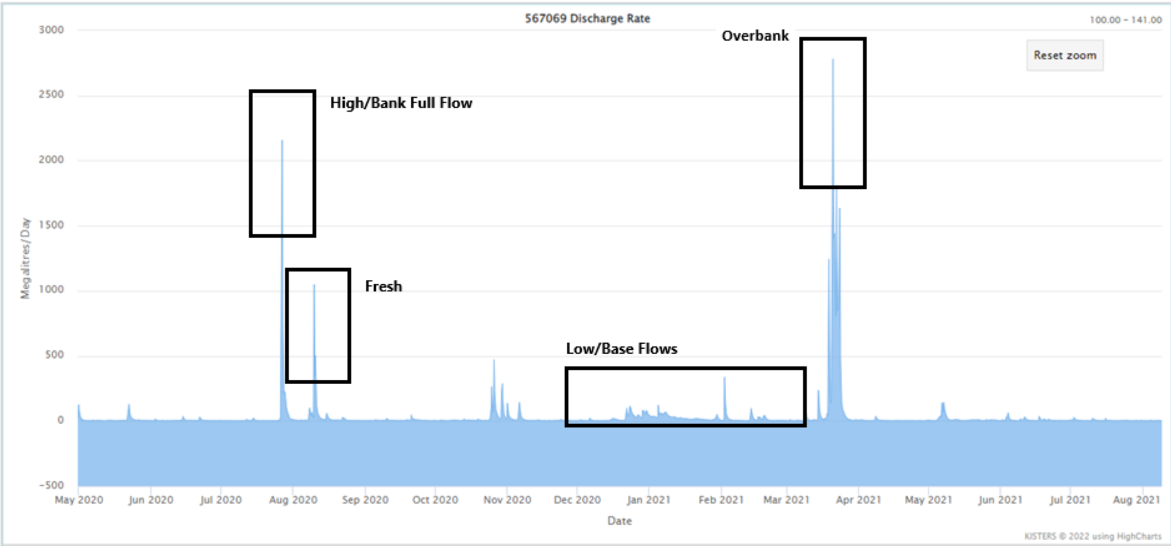


Figure 13. *Discharge (ML/Day) from Eastern Creek (WaterNSW gauge ID 567069).*

There are four main rivers that discharge freshwater into the Hawkesbury estuary: the Nepean River, the Grose River, the Colo River, and the MacDonald River. Each of these rivers has a variable natural flow regime, characteristic of most NSW coastal rivers. Their flow regimes do not have a strong seasonal pattern like streams and rivers with glacial and snowmelt events or those with monsoonal seasons. Instead, discharge is determined by:

- localised weather events,
- larger scale climatic patterns of rainfall like Australian East Coast Lows, which develop with warmer sea surface temperatures,
- the El Niño and La Niña Southern Oscillation (Simpson et al., 1993; Piechota et al., 1998)
- multi-decadal drought and flood regimes (Warner, 2014).

Despite the large catchment size of the Hawkesbury estuary (~20,000 km^2), freshwater inflows are relatively small on a global scale (McMahon et al., 1992) with the estuary experiencing extended periods of low flows, and short but intensive and large rainfall and related inflow events (Roper et al., 2011).

As river discharge is directly related to rainfall falling on the catchment, it is important to understand rainfall patterns in the Hawkesbury-Nepean catchment. The average annual rainfall for the wider Hawkesbury Nepean catchment is about 900 mm, but this is a potentially misleading average as it can vary from 500 mm on the Cumberland Plain to 1500 mm in the Blue Mountains (Figure 14). There is some seasonality, as most of the rainfall for the Hawkesbury and surrounding catchments falls between February and May (Figure 15), resulting in higher discharge during these periods (Callaghan and Power, 2014; Hajani and Rahman, 2014).

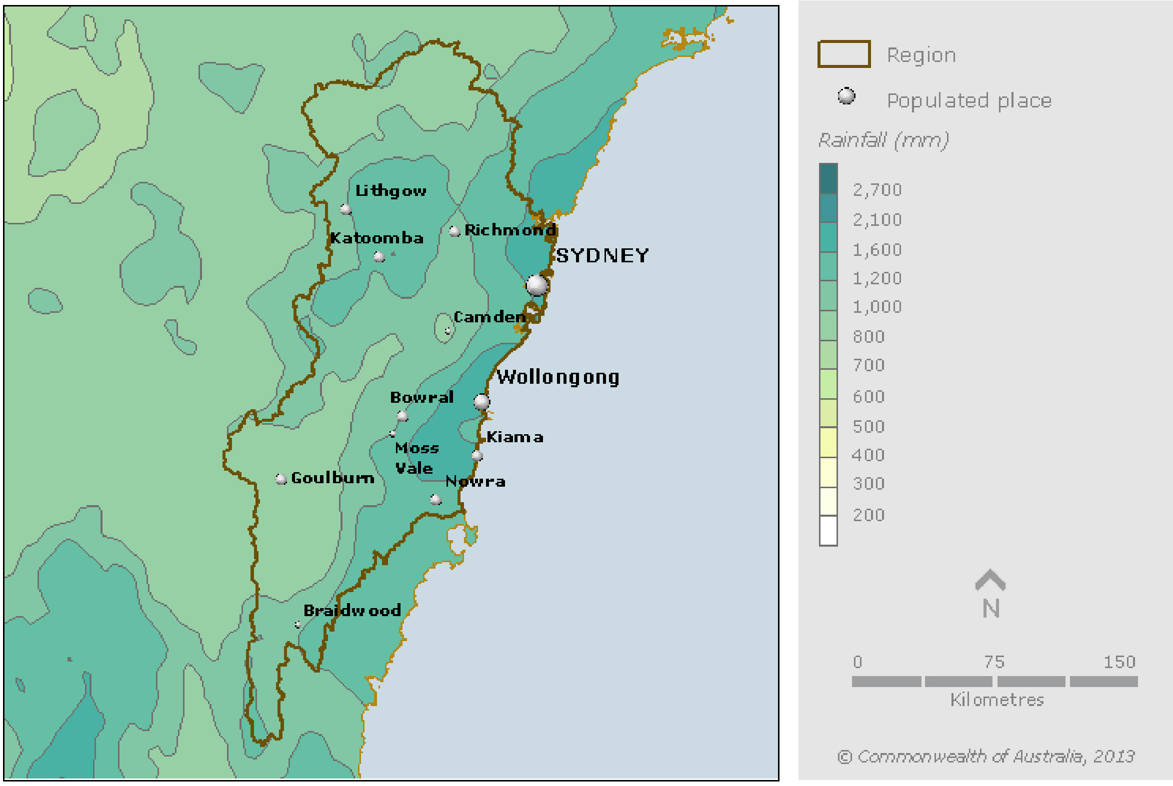


Figure 14. *Average annual rainfall distribution across the Hawkesbury Nepean catchment* (Bureau of Meteorology, 2013)

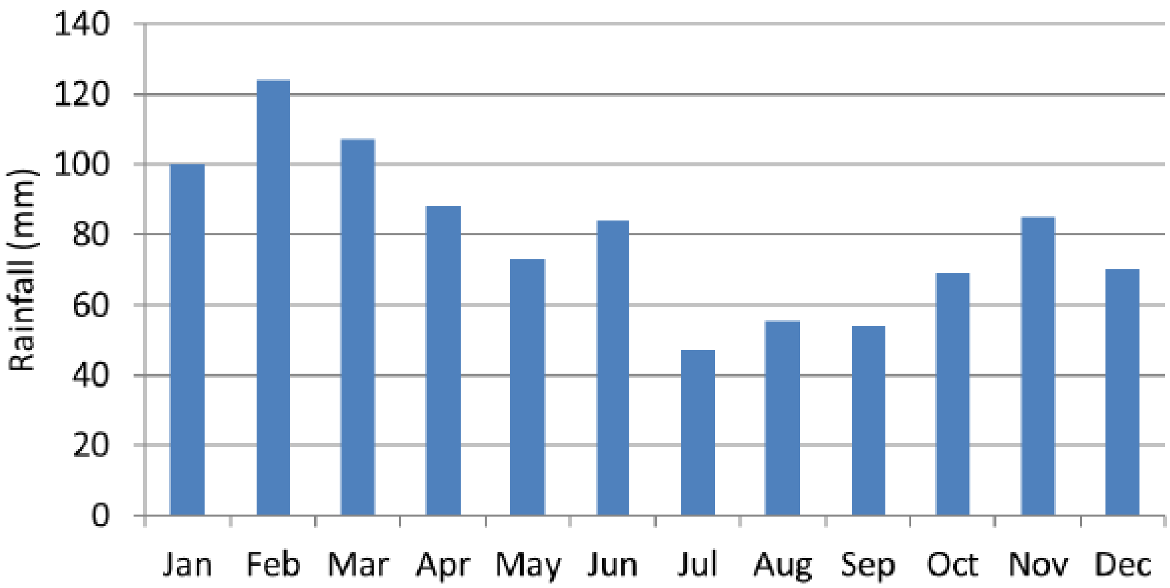


Figure 15. *Average monthly rainfall showing moderate seasonality with wetter summer/autumn and drier winter/spring (Hajani and Rahman, 2014).*

3.3.1 Drought and flood regimes

While the flow variability to the Hawkesbury estuary has been described as highly variable due to variable rainfall patterns in the catchment, it is also subject to longer term cycles (Warner, 2014) described as:

- Flood Dominated Regime (FDR) – periods of increased rainfall and freshwater inflows
- Drought Dominated Regime (DDR) – periods of decreased rainfall and freshwater inflows

FDRs can be characterised by flows with discharge rates up to three orders of magnitude larger than the mean (Hughes et al., 1998). During a large flood, freshwater inputs of more than 1,000,000 ML/day may be discharged to the estuary (BMT WBM, 2008). During large floods, freshwater flows can entirely flush the estuary, changing environmental conditions and reducing salinity substantially throughout the lower estuary. Conversely, DDRs lead to low runoff from the catchment, low freshwater inflows, higher salinity levels with saltwater mixing further upstream and, reduced flushing and sediment supply to the estuary.

Figure 16 shows the approximate time periods of the FDR and DDR periods from 1900 to 2020. The FDR from 1949 to 1991 was followed by a DDR. Recent floods in the system (February 2020, March 2021, March 2022) potentially indicate the beginning of a new FDR.

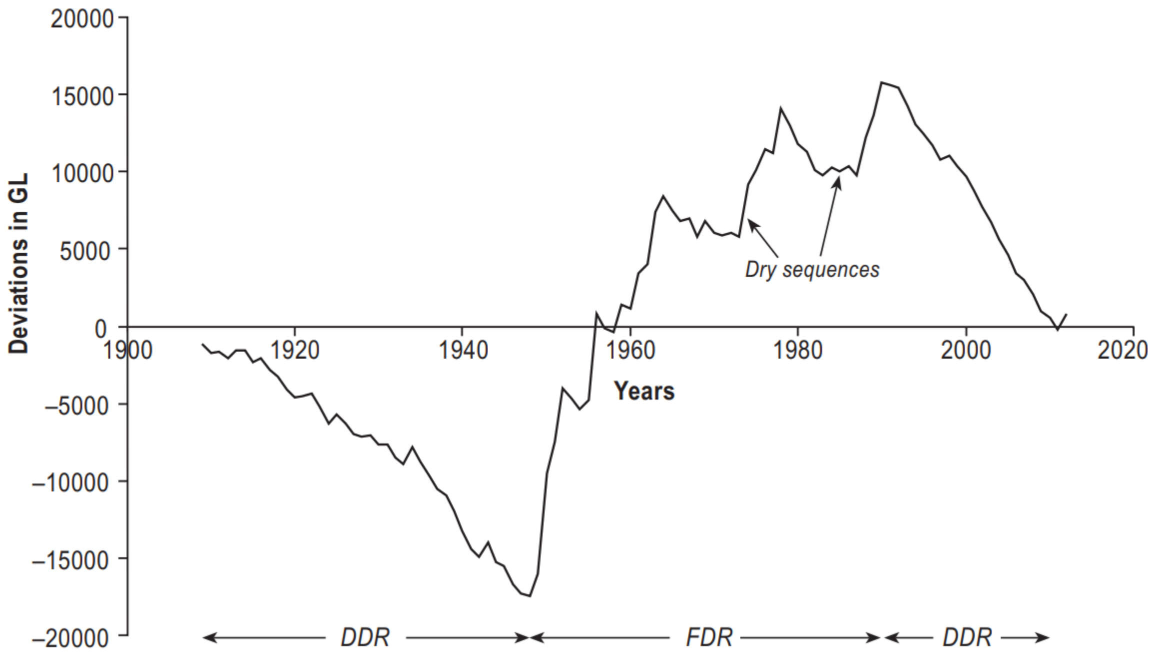


Figure 16. *Cumulative deviation of Nepean and Warragamba inflows from the long-term mean of 1367 GL/y* (Warner, 2014)

The first European explorers and colonists of the Hawkesbury, in the late 18th century, recognised the flood-prone nature of the Hawkesbury River and detailed records have been taken of its flood history since the early 1800s (Boon, 2017a). Table 3 presents a flood history of the Hawkesbury River in terms of annual exceedance probabilities (AEPs).

The table indicates the anticipated river height at Windsor for a range of AEPs, as well as examples of years where flow records have indicated the heights. AEP is the chance of a particular river height being exceeded in any one year. The AEP threshold river heights were developed based on a flood frequency analysis using data up to 2014 (Boon, 2017a). The column in Table 3 with the number of flood occurrences within each band indicates the lowest AEP threshold that each flood height reached at Windsor bridge. Therefore, the floods in the less likely AEP bands are not counted multiple times in higher likelihood bands, although it is noted that, for example, a 1% event would also inherently mean a 2% (or any higher AEP) threshold had been exceeded.

It should be noted that in 2020, 2021 and 2022 river heights entered the range of these design events. These floods have been listed in the examples of flood years; however, they were not used in the flood frequency analysis and as such were not included in the calculation of AEP.

Table 3. Flood history of the Hawkesbury River in terms of Annual Exceedance Probability (AEP), number and year of occurrences for river heights at Windsor (Boon, 2017a).

AEP	River height at Windsor (m)	Number of flood occurrences within this band	Examples of flood years
20%	11.1	17	1952, 1956, 1975, 1986, 1992, 2020
10%	12.3	Unknown	1988, 1990, 2021, 2022
3.33%	13.3-14.5	16	8 times between 1806 and 1819, 1956, 1964, 1978, 1990
2.5%	15.1-15.3	2	1799, 1961
2%	15.7	0	No Record
1%	17.2	0	No Record – common residential floor standard
0.5%	18.6	1	1867
0.2%	20.3	Unknown	At least once prior to 1788

The number and intensity of floods experienced across the east coast of Australia is expected to increase with a changing climate (Head et al., 2014; Johnson et al., 2016). These extreme events are likely to alter typical physical and biogeochemical patterns in estuarine systems and pose greater risk to settlements in flood prone areas.

Floods are difficult to monitor as they are unpredictable and physical measurement can be hazardous. However, evidence suggests that the rising limb of floodwaters can typically carry high loads of fine sediment, nutrients, heavy metals, pathogens (from sewage) and other particles (Chrastny et al., 2006; Burkholder et al., 2007; Smith et al., 2008) to waterways exacerbated by land clearing and increased urban development in the catchment (Goonetilleke and Lampard, 2019). Sedimentation and nutrient recycling tend to occur as water flow slows down when the floods recede. With large quantities of freshwater entering an estuary during a flood, a freshwater layer tends to form over the saltier estuarine water resulting in increased stratification within the water column limiting nutrient and phytoplankton mixing.

Since 2004 Hornsby Shire Council has deployed 'smart' instrumentation along the Lower Hawkesbury estuary. These water quality monitoring probes are positioned at six locations to capture real-time information including salinity, temperature, chlorophyll-a and turbidity. The probes were active during the March 2021 flood event and provided valuable data recorded at an interval of 15-30 minutes. A summary of the changes in water quality observed throughout the one in 100-year flood event is provided on the website - https://www.mhlfit.net/users/HornsbyShireCouncil-Floods.

As shown below in Figure 17, a series of satellite images represent the spatial extent of flood waters moving seawards before, during and following the March 2021 event. These images highlight the physical extent of the flooded waters impacting flood prone areas and visualise the sediment transport occurring within the river system including the extensive plume leaving the estuary into the Pacific Ocean.

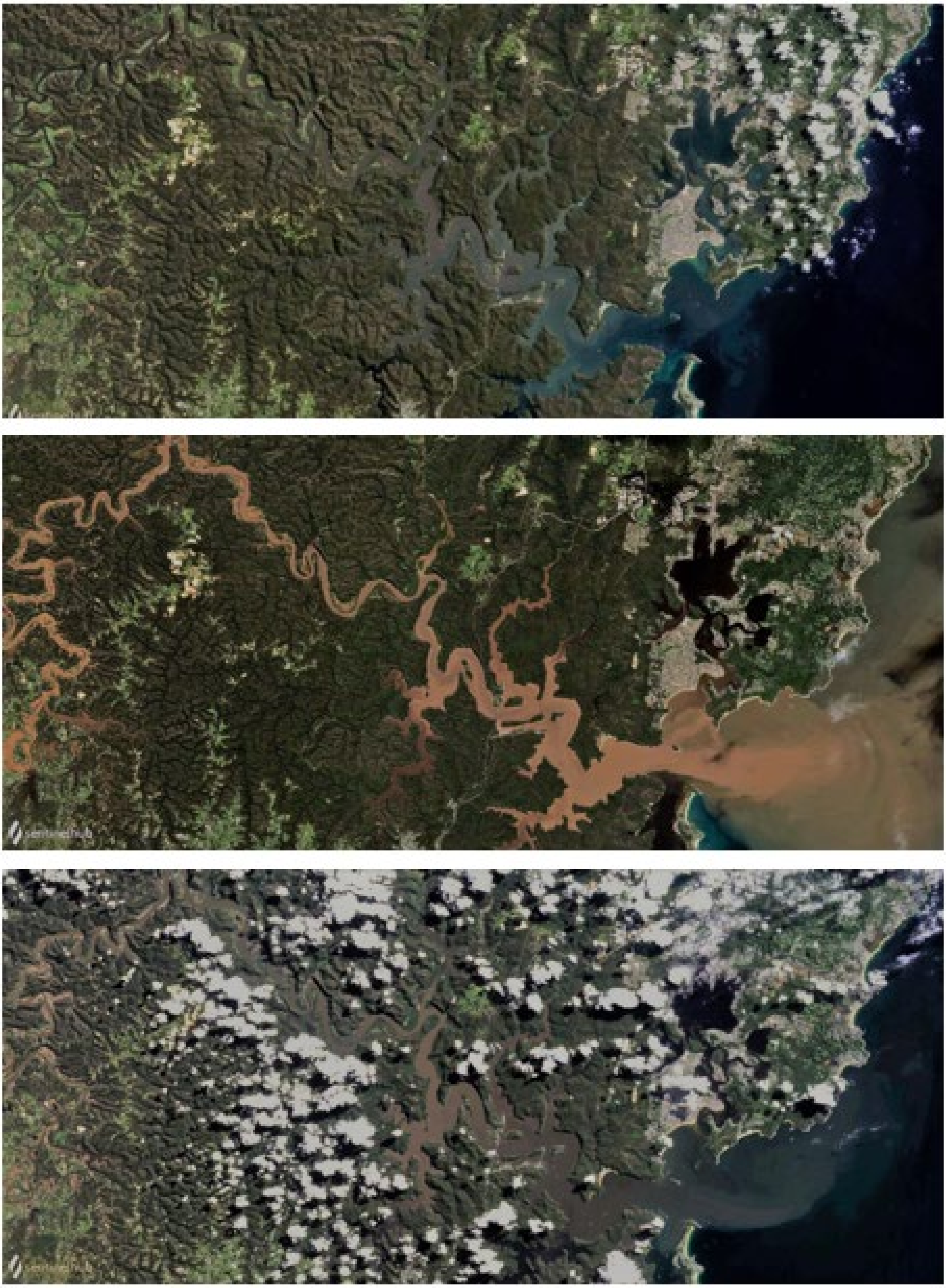


Figure 17. *Satellite images showing the spatial extent of flood waters from the March 2021 flood event. Top - pre-flood, Middle - during flood, Bottom - post-flood (Manly Hydraulics Lab, 2021)* *https://www.mhlfit.net/users/HornsbyShireCouncil-Floods*

3.3.2 Contributions of sub catchments and alterations to natural flow regime

Literature regarding the relative contributions of the subcatchments of the Hawkesbury Nepean to freshwater discharge into the estuary is limited. A very high-level estimate of the relative contributions of the subcatchments can be achieved through comparison of the area occupied by each subcatchment. This estimate does not consider several important aspects of hydrology such as the spatial distribution of rainfall and runoff, however, it does provide an indicative view of the relative magnitude of each subcatchments contribution. Table 4 presents the percentage of the total catchment area occupied by each of the major tributary subcatchments.

Table 4. Area (ha) and percentage of the major subcatchments within the Upper Hawkesbury Nepean River catchment

Subcatchment name	Area (ha)	Percentage (%)
Warragamba and Nepean	1,140,026	52
Colo	462,598	21
Macdonald	227,361	10
Grose	66,841	3
Total Hawkesbury Estuary Catchment area	**2,198,259**	

The table shows that the Nepean River (inclusive of its Warragamba subcatchment) covers 52% of the upstream catchment and would be the dominant freshwater tributary to the Hawkesbury estuary if it were not heavily extracted for Sydney metropolitan water use. The Colo River subcatchment covers 21% of the total catchment area, the MacDonald 10% and the Grose 3%, each likely to be the source of smaller relative contributions of freshwater to the estuarine system under unregulated conditions. However, the Nepean and Warragamba rivers have large dams which divert a great proportion of freshwater (approximately 80%) which would otherwise flow to the estuary (Kimmerikong, 2005). This suggests that the natural hydrology of the estuary has been substantially altered. The physical and ecological impacts of this flow reduction present significant management difficulties within the estuary and are discussed in more depth in later sections of this report.

Other minor subcatchments include those draining directly into the Middle and Lower Estuary zones. Although these contribute substantially less freshwater, by volume, freshwater inputs from sub catchments do have local impact. Additional consideration of the difference in average rainfall over the various catchments relates to their contribution of freshwater to the greater system.

3.3.3 Effect of upstream regulation and extraction

While the hydrology of upstream catchments of estuaries are fundamental to their ongoing physical processes and health, reductions in freshwater inflows to estuaries are common due to river regulation by dams and weirs which harvest freshwater for human needs (Arthington et al., 2018). River regulation through dams, weirs and water extraction changes the natural flow patterns of freshwater to estuaries by reducing freshwater inflows. This can lead to significant impacts on the estuary including increased salinity in the upper reaches of estuaries, reduced sediment transport and reduced channel complexity and connectivity of branches, channels and benches (Florsheim et al., 2008; Simmons et al., 2016).

Freshwater inflows to the Upper Hawkesbury estuary are heavily regulated by a network of dams, weirs and extraction points throughout the upper parts of catchment (e.g. on the Nepean River and its tributaries). Of the streams that flow directly into the Middle Estuary, only the dam on Mangrove Creek is a significant structure (the weir on Mooney Mooney Creek is very small). A list of the main structures and a brief description is provided in Table 5, and a map is provided in Figure 18.

It has been estimated that approximately 80% of water that would naturally flow to the Hawkesbury estuary from the Nepean catchment is extracted for metropolitan water use as part of the Sydney Water Supply

Scheme, approximately 2.6 million ML a year (Kimmerikong, 2005) This extraction of water that would otherwise flow to the estuary on this scale has had a noticeable impact on the physical and ecological processes of the Hawkesbury estuary (Warner, 2014).

Table 5. Major water storage structures within the HNRS

Storage (manager)	Description
Nepean Dam (WaterNSW)	**Height** – 82 m **Capacity** – 67.73 GL **Size of lake (catchment)** – 3.3 km^2 (320 km^2) Created by damming the Nepean River, Nepean Dam's main role today is to supply water to the nearby towns of Bargo, Thirlmere, Picton and The Oaks, as well as the Macarthur and Prospect water filtration plants. It also receives water transferred from the Shoalhaven River and Kangaroo River when the Shoalhaven Scheme is in operation to top up our dams. Together, the Nepean, Avon, Cataract and Cordeaux dams also provide an additional supply of water for Sydney, via Pheasants Nest Weir, Broughtons Pass Weir and the Upper Canal.
Avon Dam (WaterNSW)	**Height** – 72 m **Capacity** – 146.7 GL **Size of lake (catchment)** – 10.5 km^2 (142 km^2) Created by damming the Avon River and completed in 1927, Avon Dam's main role today is to supply water to the Illawarra region. It is Sydney's second largest dam after Warragamba but has a small catchment. Water from Nepean Dam and water transferred via Nepean Dam from the Shoalhaven can be sent to Avon to secure water for the Illawarra. Together, the Nepean, Avon, Cataract and Cordeaux dams also provide an additional supply of water for Sydney, via Pheasants Nest Weir, Broughtons Pass Weir and the Upper Canal.
Cordeaux Dam (WaterNSW)	**Height** – 57 m **Capacity** – 93.64 GL **Size of lake (catchment)** – 7.8 km^2 (91 km^2) Created by damming the Cordeaux River, construction started in 1918 and was completed in 1926. Together with Cataract Dam, Cordeaux's main role today is to supply water to Camden, Campbelltown and Wollondilly council areas via the Macarthur water filtration plant. Together, the Nepean, Avon, Cataract and Cordeaux dams also provide an additional supply of water for Sydney, via Pheasants Nest Weir, Broughtons Pass Weir and the Upper Canal.
Cataract Dam (WaterNSW)	**Height** – 56 m **Capacity** – 97.19 GL **Size of lake (catchment)** – 8.5 km^2 (130 km^2) Cataract was the first of the four dams constructed to collect water from the Illawarra Plateau. Created by damming the Cataract River, construction started in 1902 and was completed in 1907. Together with Cordeaux Dam, Cataract's main role today is to supply water to Camden, Campbelltown and Wollondilly council areas via the Macarthur water filtration plant. Together, the Nepean, Avon, Cataract and Cordeaux dams also provide an additional supply of water for Sydney, via Pheasants Nest Weir, Broughtons Pass Weir and the Upper Canal.
Warragamba Dam (WaterNSW)	**Height** – 142 m **Capacity** – 2,027 GL **Size of lake (catchment)** – 75km^2 (9,051 km^2) Created by damming Warragamba River and flooding the Burragorang Valley, the storage lake is four times the size of Sydney Harbour and stores around 80 percent of Sydney's water.

	Warragamba Dam supplies water to more than 5 million people living in Sydney and the lower Blue Mountains.
Mangrove Creek Dam (Central Coast Water Corporation)	**Height** – 80 m **Capacity** – 190 GL **Size of lake (catchment)** – 7 km² (101 km²) The dam was constructed between 1978 and 1982, formed by impounding the headwaters of Mangrove Creek. The Mardi-Mangrove Link transfers water from Wyong River for storage in Mangrove Creek Dam. It supplies approximately 93 per cent of water to 300,000 residents in Central Coast Council.
Mooney Mooney Dam (Central Coast Water Corporation)	**Height** – 28 m **Capacity** – 4.6 GL **Size of lake (catchment)** – (39 km²) The dam was constructed in 1961 to provide water supply to the Central Coast region and was Created by damming Mooney Mooney Creek. Water is pumped to Somersby Water Treatment Plant and then to residents.

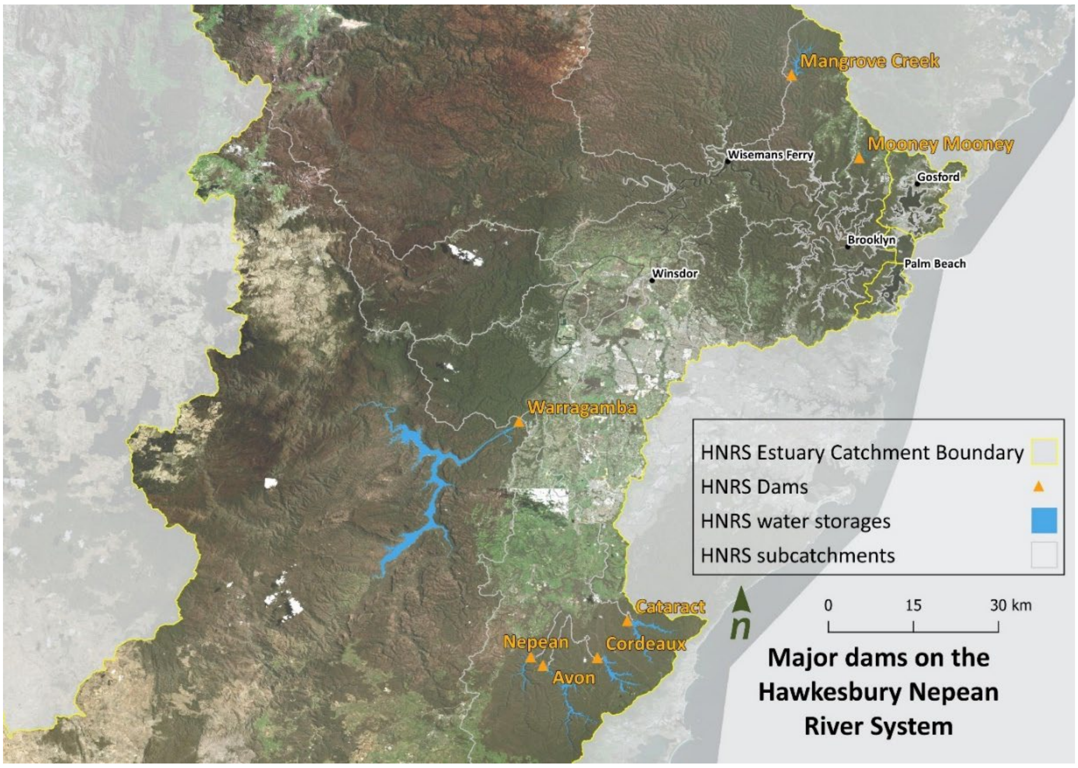


Figure 18. *Map showing the location of major water storages in the HNRS.*

There are several smaller weirs on the Nepean River which disrupt longitudinal connectivity including (from most downstream):

- Penrith Weir
- Wallacia Weir
- Brownlow Hill Weir
- Mount Hunter Weir
- Cobbitty Weir
- Sharpe's Weir
- Camden Weir
- Thurns Weir
- Bergin's Weir
- Menangle Weir
- Douglas Park Weir
- Maldon Weir

3.3.4 Environmental flows

As river regulation and water extraction can negatively impact downstream environments such as estuaries, predetermined releases of freshwater for environmental restoration are often used as a management tool to alleviate some impacts. These are known as environmental flows or, in short, e-flows.

Due to observed environmental impacts of river regulation and reduced inflows on the Hawkesbury estuary, e-flow requirements and legislation were introduced to help alleviate the impacts of reduced freshwater inflow. The impacts that e-flows are used to address include increased residence time of water and pollutants in the estuary, as well as stratification of brackish water in the upper reaches of the system.

Given the size of the Hawkesbury River estuary, complete flushing of the estuary by freshwater inflows was already an infrequent occurrence occurring approximately 1-in-100 years and was an unrealistic target for e-flows. However, short intense flow peaks were used to try and mitigate for the low flow conditions being imposed upstream by river regulation (Markich and Brown, 1998), particularly Warragamba Dam, the largest of the regulatory structures. However, a review by (Warner, 2014) found that due to river regulation approximately 3.6% of the natural regime was flowing to the Hawkesbury estuary, in comparison to the 80% recommended to sustain river and estuarine systems (Arthington and Pusey, 2003).

Currently there are minimal environmental flows releases from Warragamba Dam, with a consistent 5 ML/day to flush discharges from the Wallacia wastewater treatment plant and an additional 17 ML/day in winter and 25 ML/day in summer to provide additional drinking water supply for extraction at North Richmond. Daily variable flows are used for other storages in the catchment, with all inflows to dams during low flow periods being released up to a specified limit for each dam (Table 6). At times of higher flow an additional 20% of inflows to each storage is released downstream, and during floods, overflows can reach up to 8,000 ML/day. New environmental flow releases are proposed from Warragamba Dam, but these have been delayed due to delays associated with the proposed dam wall raising for flood management purposes (WaterNSW, 2022).

Table 6. Environmental flow volume limits of major dams on the Hawkesbury-Nepean (WaterNSW, 2022)

Storage	Upper limit of daily releases at low flow conditions (ML)
Nepean Dam	20.1
Avon Dam	6.8
Cordeaux Dam	4.5
Cataract Dam	14.5
Pheasants Nest Weir	4.4
Broughtons Pass Weir	4.5

3.3.5 Groundwater

While hydrodynamics and hydraulics in estuarine catchments are generally determined by the previously discussed hydrodynamic forces, groundwater return flows can also be an important factor. Groundwater flow occurs when water is able to penetrate the catchment topsoil and subsoils and flow through the water table back to the stream or river channel (Figure 19).

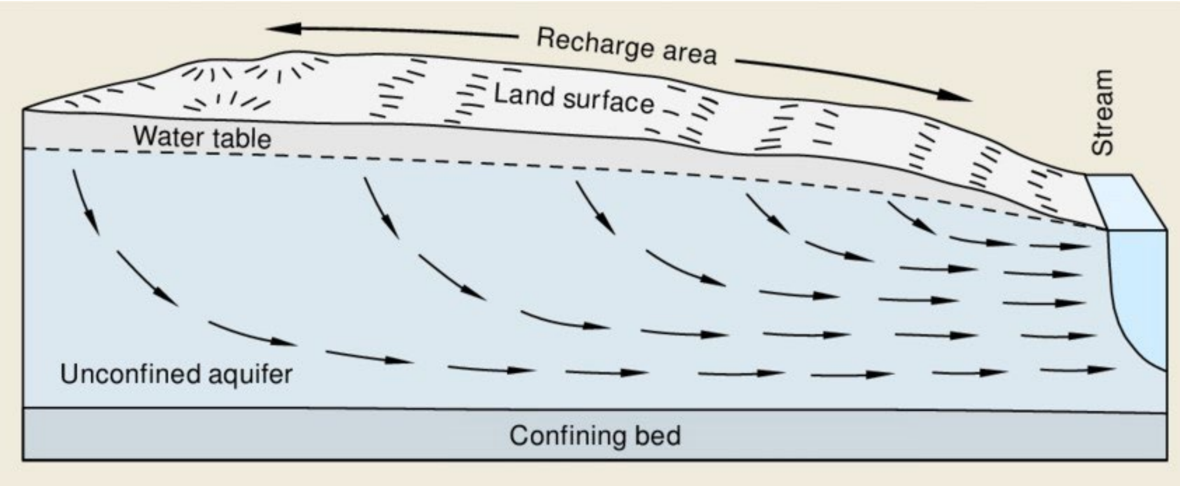


Figure 19. G*round water – stream interactions* (Reid et al., 2009).

Within the Hawkesbury–Nepean region there are alluvial, coastal sands, fractured rock and porous rock aquifer province groundwater management areas (GWMAs). Sandstone aquifer systems are the main aquifer type in the Hawkesbury–Nepean region. The Sydney Basin–Mangrove Mountain GWMA is used for bottled drinking water and is important for supplying water (baseflow) to the river systems in the area. A study of the area has also identified groundwater dependent ecosystems (GDEs). The fractured rock aquifer systems in the region are the Goulburn Fractured Rock and Coxs River Fractured Rock. These aquifers are mainly used for domestic and stock water supplies, and industrial and commercial purposes. The various GWMAs within the Hawkesbury Nepean catchment are mapped in Figure 20.

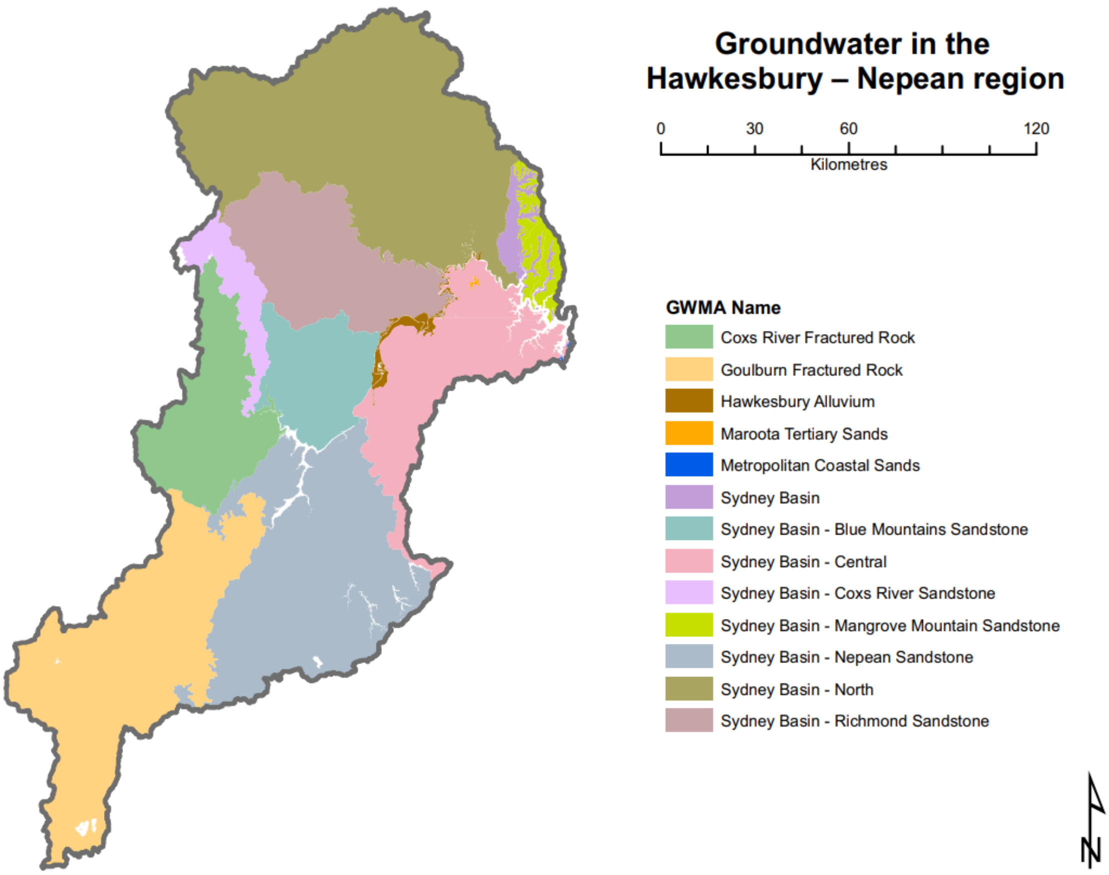


Figure 20. *Hawkesbury–Nepean region groundwater management areas* (Department of Environment, Climate Change and Water NSW, 2010)

Increased sedimentation can lead to a breakdown of connectivity between riverine waters and groundwater processes (Brunke and Gonser, 1997). Groundwater recharge is an important aspect of freshwater inflow to estuaries and clogging of the porous interface between groundwater systems and rivers by sediment can reduce the exchange that maintains this connectivity. While groundwater may enter the estuary from the Hawkesbury sandstone aquifer, information on these processes is relatively scarce and is not considered to impact on the estuary significantly (BMT WBM, 2008). Further investigation into the effect of changing sediment dynamics in groundwater exchange may be required though this is unlikely to be a priority.

3.4 Geomorphology

Geomorphology is study of the development and evolution of landforms and is critical in understanding the present and future formation of estuaries. Much of the geomorphology of an estuary relates to its hydrodynamics and hydraulics. Estuarine channel shape and size, floodplain features, substrate conditions (e.g., bedrock or sand) and the general shape of the river are all shaped by geomorphological processes relating to hydrodynamics (e.g., sediment deposition and fluvial erosion), as well as additional processes like waves, ocean swell, wind weathering and mass movements (rock falls).

The major geomorphological process at play in estuaries is sediment transport and deposition. Sediment deposition patterns can be used to classify estuaries (Roy et al., 1980; Roy et al., 2001) with immature estuaries having less sediment deposited within them. The Hawkesbury, which is still filling with sediment, compared with mature estuaries (e.g., the Nile and Mississippi) which have filled with sediment and now have large estuarine deltas outside their old headlands. The input of sediments into the estuary by fluvial (riverine forces) is critical to the productivity of an estuary through resource provision and habitat formation (Prosser et al., 2001). The estuary classification for the three waterways of the HNRS is provided in Table 7.

Table 7. Estuary classifications (Roy et al., 2001)

Estuary	Estuary Group	Estuary Type	Evolution Stage
Brisbane Water	Wave dominated	Barrier estuary	Youthful
Hawkesbury River	Tide dominated	Drowned valley estuary	Semi-mature
Pittwater	Tide dominated	Drowned valley estuary	Youthful

The Hawkesbury is geomorphologically classified as a tide dominated, drowned river valley (Roy et al., 1980; Roy et al., 2001). Post-glacial sea-level rise beginning approximately 16,000 years ago and stabilising approximately 6,000 years ago drowned the existing deeply incised river valleys and gorges which had been carved into the Triassic Hawkesbury Sandstone throughout the upper and middle Hawkesbury estuary prior to sea level rise (Roy et al., 1980; Roy et al., 2001). In the lower Hawkesbury estuary, two ancient river valleys carved into the bedrock, one, the main channel of the Hawkesbury River and the other at Brisbane Water have filled with as much as 125 m of sediment in the last 11,000 years. A reduction in the quantity of freshwater inflows due to the changing climate 11,000 years ago, combined with sea level rises and deposition of oceanic material led to the formation of river mouth sand bars that limited the freshwater outflow of Brisbane Water and Pittwater. Freshwater flows from the larger catchment of the Hawkesbury, aided by tidal currents, maintained its mouth relatively free of sand bars (Albani and Johnson, 1974; Thom and Roy, 1985; Roy, 1994) resulting in the shape of the estuary at Broken Bay today.

Previous work has characterised the Hawkesbury estuary into three broad sedimentary zones, differentiating the sediment types and processes (Nichol et al., 1997). These zones are summarised in Table 8. It is noted that similar zones exist for Brisbane Water and Pittwater, although at different scales.

Table 8. Sedimentary zones of the Hawkesbury River estuary (Nichol et al., 1997)

Sedimentary Zone	Functional zone	Character
Outer marine dominated zone	Lower Estuary	Intertidal/subtidal, sand-dominated flood-tidal delta. Sediment is generally sourced from the ocean. Ocean wave energy is partially dissipated by this flood-tidal delta, so that tidal level fluctuations are the predominant marine mechanism operating further landward.
Central Basin	Middle Estuary	Deposition of finer grained sediments derived from the river catchment. This is essentially a low-energy environment characterised by sub-tidal and intertidal muds and muddy sands. The central mud basin also extends into the Lower Estuary.
Hawkesbury River	Upper Estuary and Freshwater Tidal Pool	River-dominated comprising distributary channels, levees, and overbank floodplain deposits of mixed lithologies. The upper reaches of the zone occupy deeply incised bedrock valleys. Upstream channel morphology is mostly of a fluvial nature and shaped by infrequent flood events rather than by the tides (Hubble and Harris, 1994).

Today, changing sediment deposition patterns are occurring in the HNRS due to increased sediment inputs from the catchment through changed land use and reduced flushing of sediments from the estuary due to reduced freshwater inputs. Sedimentation rates and patterns are variable for different tributaries and arms of the HNRS. Sedimentation rates are determined by catchment characteristics and can be modelled by considering land use, soil type and hydrology. A fluvial delta volume is related to the catchment area and catchment denudation rate (Coastal & Marine Geosciences Geological and Environmental Consultants, 1998). Events or development patterns in the catchments, such as bridge construction, and urbanisation can increase sediment delivery (WBM, 2003).

Sediment delivery to the Lower Estuary is largely restricted to larger magnitude inflows which bring sediments from the catchment and are deposited mainly at the salt intrusion limit (Hughes et al., 1998). Research suggests that sediment delivery patterns in the estuary are changing due to increased sediment inputs during low flow conditions, and reduced inflows contributing to sediment build up through reduced flushing (Collis, 2014). Increased sediment inputs have been attributed to changing land use patterns such as urbanisation, agriculture, etc. and increased catchment runoff contributing to erosion of catchment substrates and river banks (Rustomji and Pietsch, 2007).

Increased sediment deposition, usually coupled with low discharge or drought periods, can lead to issues of depleted dissolved oxygen at depth due to microbial processing. Instances of stratification can occur during very low flow periods in the upper Hawkesbury estuary (Collis, 2014), however, decreased dissolved oxygen at depth and stratification in the mainstem of the Hawkesbury River is unlikely due to the tidal forces keeping the water column generally well mixed (Jones, 1987).

Brisbane Water is classified as a wave-dominated barrier estuary (Roy et al., 2001). Both wind waves and ocean swell are important in different regions of Brisbane Water estuary. Local wind waves occur throughout the estuary, being most important in the wide expanse of the Gosford Broadwater. On a minor scale, local wind waves are important in the region north-east of St Hubert's Island to the Cockle Channel. Swell wave conditions typically affect coastal areas and locations near Ettalong. Swell energy does not propagate past The Rip (CLT, 2008).

Severe ocean-storm swell is important at Ettalong, especially at high tide when larger waves can propagate over the Ettalong Point shoal. Beach and tidal delta sands have been identified in Brisbane Water estuary as far up estuary as Pelican Island. The deltaic formation to the north of Pelican Island is thought to represent the limit of infilling of Brisbane Water by marine sand driven by waves and tides. Upstream of The Rip, fluvial sediments are more prevalent (CLT, 2008).

Pittwater Estuary is classified as a tide-dominated drowned valley estuary (Roy et al., 2001). Pittwater is classified as being in a 'youthful' stage of development due to the limited extent of fluvial reclamation and its extensive and deep mud basin. As Pittwater matures, the entrance tidal delta and fluvial sediments will progressively fill the mud basin. This is a process that will occur over thousands of years (Roy et al., 1980).

The flood tide delta at the entrance to Pittwater is slowly prograding into the waterway. Sediment from the delta is moving onshore to the western foreshores and is then transported south along the foreshore to accumulate on the barrier at the entrance to The Basin. Ocean waves, which impact the entrance to Pittwater most profoundly when the predominant swell direction is from the East and North East, can agitate bed sediments, suspending them in the water column and making them available for transport by the flood tide currents present in the entrance channel (Lawson & Treloar, 2003).

A large number of the natural fluvial deltas around the southern shores of Pittwater have been dredged to improve navigability and deep water frontages, resulting in the significant loss of wetlands. Given the incised nature of the estuary, wetlands can only form on low-lying fluvial deltas. It is expected that there has been a significant increase in the sediment load delivered to the estuary due to urbanisation of the catchment. However, significant progradation of fluvial delta fronts has not been observed during contemporary times. Nonetheless, fine sediments would be accumulating in the deeper parts of the estuary, as well as within areas that have been artificially deepened (Lawson & Treloar, 2003).

Figure 21 demonstrates the current sediment dynamics occurring in the HNRS. These include:

- Catchment inputs – catchment sediments are carried to tributaries and rivers by catchment runoff during rainfall events and erosion of landscapes and river banks. Sediment inputs have increased due to changing land use increasing erosion throughout the upper catchment.

- **Sediment transport –** Sediments are transported to the estuary by flowing waters. The faster water flows the further downstream particles will be transported. Coarser sediments like gravel and rocks will also fall to the bed of the river channel and estuaries before finer sediments like muds.
- **Floodplain deposition –** Sediments can be transported onto the floodplain during large floods and provide important nutrient and organic matter resources to these environments. This sediment forms the basis of the good farming soil found on floodplains.
- **Channel deposition and reworking –** When finer sediments reach the estuary they react with the saline water, cling together and fall to the bed of the channel creating the muddy floor that covers much of the Hawkesbury. These fine sediments and muds hold lots of organic matter and nutrients and can be resuspended and reworked by the tides.
- **Tidal deposition –** Sediments can also be deposited into intertidal areas like mangroves and saltmarsh by the tides. Tidal action can also erode estuarine river banks with additional sediments entering the system through this mechanism.
- **Marine inputs –** marine sand is transported by ocean swell and tidal currents forming flood tide and ebb tide deltas. Prominent tidal deltas in the HNRS are located in Pittwater, Brisbane Water, and Broken Bay.
- **Wave energy –** locally generated wind waves and longer period ocean swell interact with sediments in shallow water transporting them alongshore or across shore.
- **Export –** During high flow periods and floods large amounts of sediment can be exported to the coastal zone. This includes newly washed in sediments and old sediments that have been scoured from the bed of the estuary.

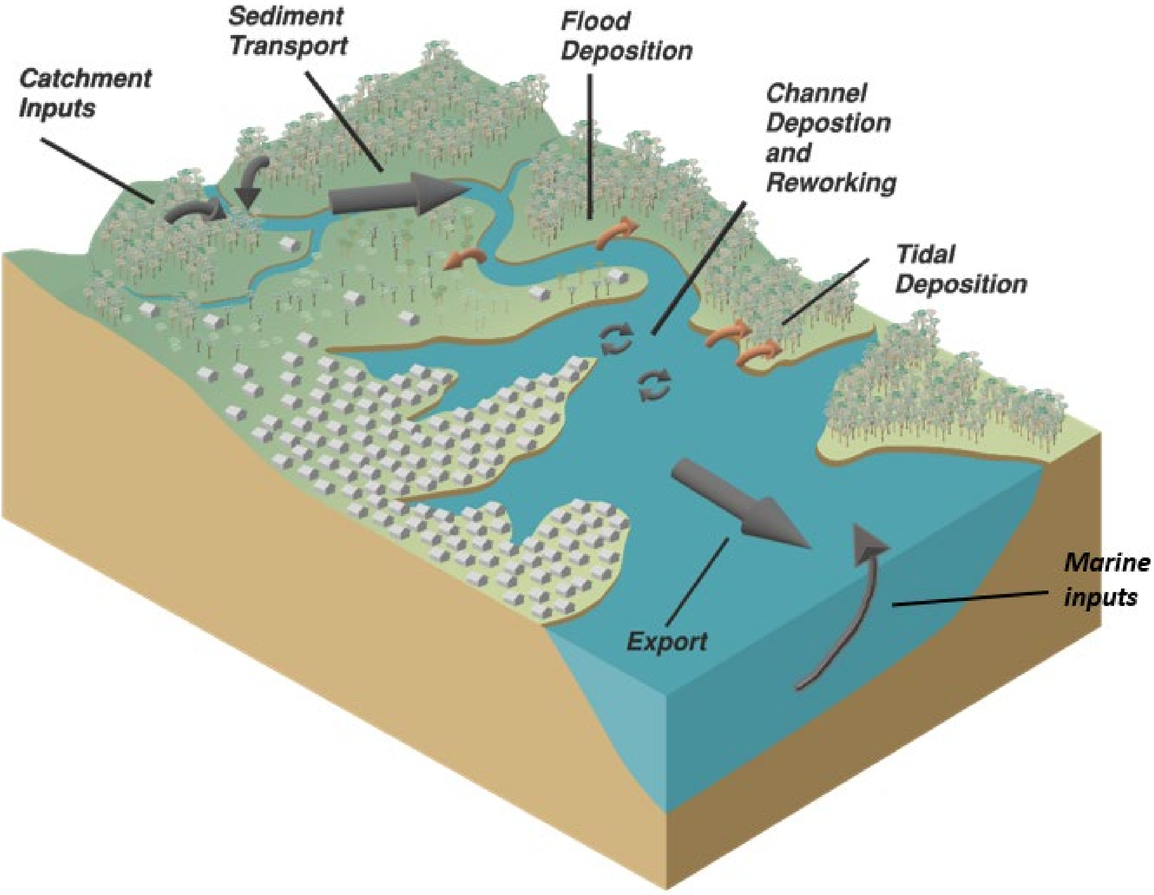


Figure 21. *Conceptual model of sediment dynamics*

3.5 Catchment land use and development

Estuaries are the most downstream receiving systems of rivers and catchment runoff. Therefore, the nature of the Contributing Catchment functional zone plays a fundamental role in shaping the characteristics of the estuarine environment. Catchment land use, is therefore an important determinant in quantity, quality and timing of freshwater inputs to estuaries, heavily influencing estuarine water quality.

Broadly speaking, in naturally forested Contributing Catchments, runoff is filtered and slowed by vegetation with flows downstream carrying little sediment or nutrients to tributaries and estuaries. However, in urbanised or agricultural catchments, a lack of natural vegetation and hard, impervious surfaces cause higher volumes of fast-moving catchment run off. This can trigger erosive events, transporting greater amounts of sediments downstream compared to forested catchments, as well as carrying high nutrient loads and pollutants from industrial, agricultural and urban areas (Rustomji and Pietsch, 2007).

Differences in catchment land use can also change the speed and duration of flows as they return to tributaries, streams and estuaries, accelerating or slowing flows. For example, a highly forested catchment, where rainfall can penetrate the soil will have a lower stream flow peak with a longer duration in comparison to an urban catchment with hard impervious surfaces (Melbourne Water, 2017). In the urban catchment the inability of water to penetrate the subsoil results in large amounts of catchment runoff which flow quickly across the catchment surface and can result in impacts such as flash flooding. These differences are illustrated in Figure 22.

As a result of the Hawkesbury's proximity to the city of Sydney and the urban centres of the Central Coast, large portions of the estuarine catchment and its shoreline have been developed for agricultural and urban purposes and are subject to pressures arising from this peri-urban setting.

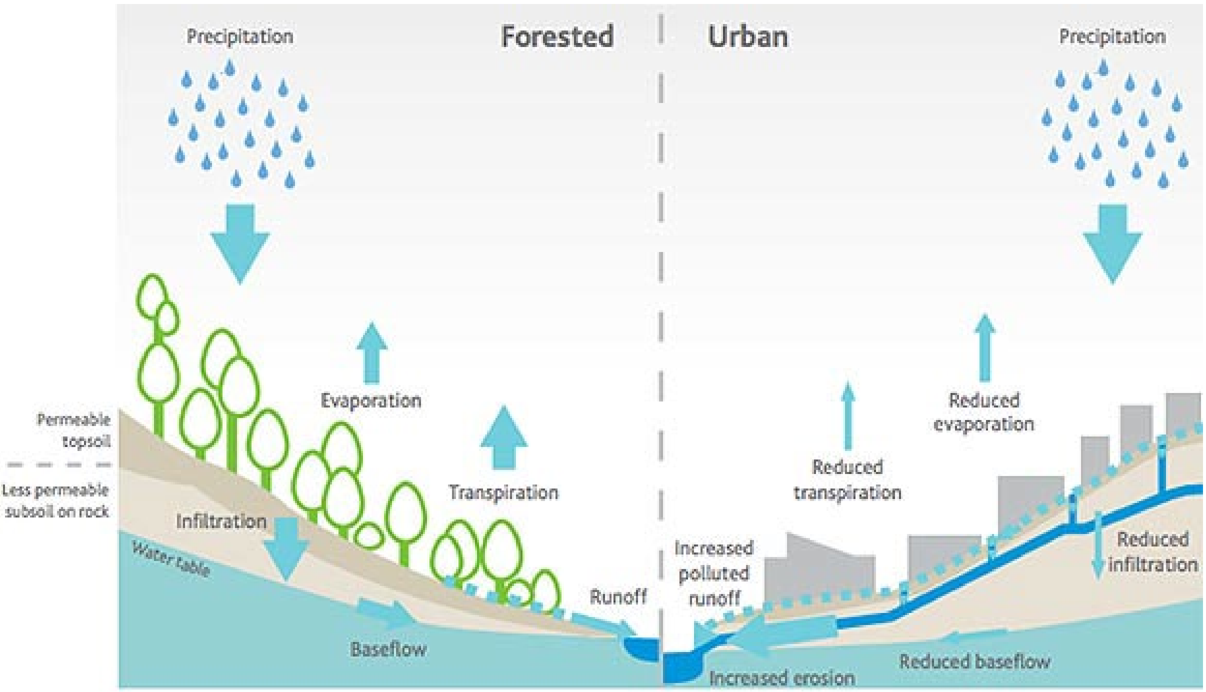


Figure 22. *Comparison of run off patterns in a forested and urban catchment* (Melbourne Water, 2017).

Historically, extensive land clearing of the native vegetation in the Hawkesbury, inclusive of woodland and riparian areas, began in the early 1800s and was carried out by colonial parties throughout the Cumberland Plain and the sub catchments of South and Eastern Creek. Figures vary on the extent of remaining Cumberland Plain Woodland in the Sydney Basin, from 3% (Howell et al., 1994a) to 8.8% (Tozer, 2003). These changes in the catchment led to increased erosion and slumping of riverbanks and sedimentation of waterways. From the 1850s the growth of the agricultural industry led to further land clearing, soil and rock disturbance and increased sediment inputs to the estuary (Melbourne Water, 2017)

The impacts of land clearing were recognised as early as the 1890s, with large vessels no longer able to navigate the increasingly shallow water at Windsor due to sediment build up in the upper estuary. Excavation of sand and gravel from the surrounding catchments between 1952-1981 as part of the Penrith Lakes Scheme led to further stream instability and sedimentary inputs into the estuary (Simmons et al., 2016).

Currently, the Hawkesbury-Nepean catchment is mostly natural areas classified as conservation areas (59%) or grazing and forestry and native vegetation (16%). Urban and industrial land use accounts for roughly 10% of the entire catchment, but in some subcatchments such as South Creek, this proportion is as high as 62% (NSW DPIE, 2017).

Of the three major estuary catchments, Brisbane Water has the highest proportion of urban land use, with significant light-industrial land use in places (NSW DPIE, 2017). Nevertheless, large areas of the sub-catchment remain naturally protected areas (e.g., Brisbane Water National Park). Table 9 provides an overview of land use in the main subcatchments of the HNRS.

Figure 23 provides a map of land use in the HNRS catchment. One of the important features of the Hawkesbury-Nepean Region that contributes to the ongoing ecological health of the river system and its estuary is the natural state of the surrounding catchment (Harris, 2001) to the north and west of the estuary (Howell et al., 1994b). Large expanses of the catchment surrounding the Hawkesbury estuary are protected areas and national parks (e.g., Blue Mountains NP, Wollemi NP, Yengo NP, Ku-ring-gai Chase NP). Two of the tributaries (the Colo and the Grose River) to the estuary are listed as Wild Rivers, those relatively unmodified by catchment land use and water regulation since European arrival, under the 2008 NSW DECC assessments (Department of Environment and Climate Change, 2008a; Department of Environment and Climate Change, 2008b). . Maintaining these areas and their naturally vegetated state into the future will be fundamental in the continued ecological health and social amenity of the catchment area and the estuary.

Adjacent to the Freshwater Tidal Pools functional zone, low density urban development and semi-rural lots are present with some higher density development around Windsor and Richmond. Downstream of this area are low density riverside developments, and the lower Hawkesbury bushland areas interspersed with agriculture in the form of high value food trees, nurseries, market gardens, poultry, and low-density grazing (DLWC, 1997). There is a small amount of light industrial development (WBM, 2003). Larger urban centres exist near the coast, especially the Gosford area and Pittwater.

Table 9. Summary of catchment land use - total area and proportion of major subcatchments (NSW DPIE, 2017)

Subcatchment	Total area (ha)		Cropping & forestry	Grazing & forestry - Native Vegetation	Irrigated agriculture	Nature conservation & other minimal use	Urban & industrial	Water & wetlands
Brisbane Water	17,870	ha	97	770	-	6,181	7,938	2,884
		%	1%	4%	0%	35%	44%	16%
Broken Bay	1,134	ha	-	16	-	721	381	16
		%	0%	1%	0%	64%	34%	1%
Cattai Creek	28,635	ha	693	193	350	12,674	14,173	552
		%	2%	1%	1%	44%	49%	2%
Colo	462,521	ha	19,295	58,238	373	376,190	6,287	2,137
		%	4%	13%	0%	81%	1%	0%
Cowan and Berowra Creek	46,338	ha	62	33	411	31,920	11,060	2,852
		%	0%	0%	1%	69%	24%	6%
Grose	66,843	ha	124	1,279	154	59,283	5,803	200
		%	0%	2%	0%	89%	9%	0%
Hawkesbury and minor tribs	66,788	ha	2,930	1,019	3,889	32,647	21,386	4,918
		%	4%	2%	6%	49%	32%	7%
MacDonald	227,126	ha	441	28,551	71	196,109	1,149	805
		%	0%	13%	0%	86%	1%	0%
Mangrove Creek	43,712	ha	2,601	8,883	0	28,631	2,011	1,586
		%	6%	20%	0%	65%	5%	4%
Mooney Mooney	13,801	ha	1,392	1,398	-	8,577	1,682	751
		%	10%	10%	0%	62%	12%	5%
Mullet and Patonga Creek	4,303	ha	-	33	-	4,028	203	39
		%	0%	1%	0%	94%	5%	1%
Nepean	236,551	ha	30,093	19,490	1,869	133,565	43,683	7,851
		%	13%	8%	1%	56%	18%	3%
Pittwater	6,860	ha	3	3	-	3,066	1,973	1,816
		%	0%	0%	0%	45%	29%	26%
South Creek	62,867	ha	11,842	1,870	1,608	6,991	39,278	1,278
		%	19%	3%	3%	11%	62%	2%
Warragamba	903,962	ha	213,377	221,218	699	395,572	53,769	19,327
		%	24%	24%	0%	44%	6%	2%
Grand Total	**2,189,311**	ha	**282,951**	**342,994**	**9,424**	**1,296,154**	**210,777**	**47,012**
		%	**12.9%**	**15.7%**	**0.4%**	**59.2%**	**9.6%**	**2.1%**

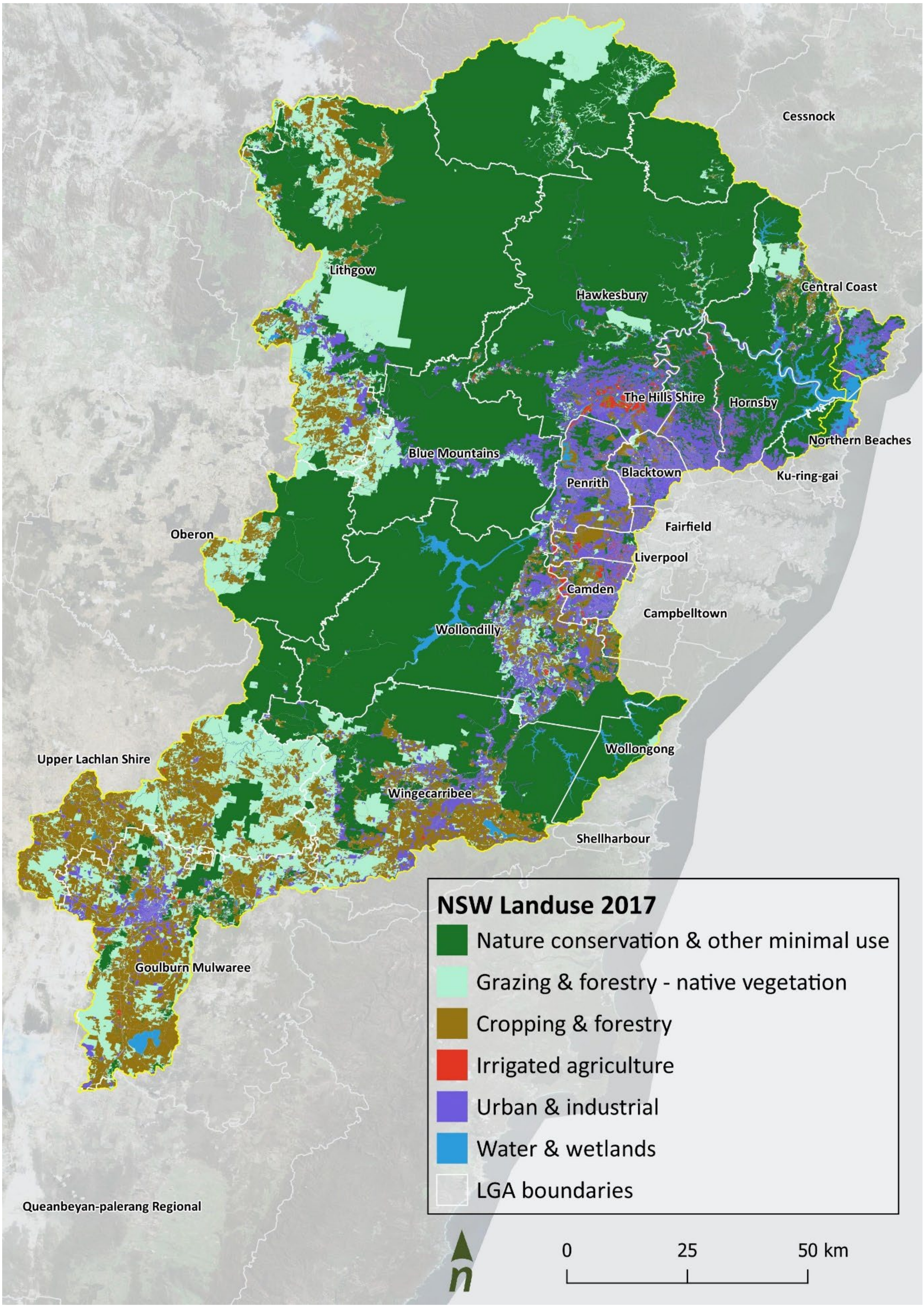


Figure 23. *Simplified land use map of the HNRS catchment* (NSW DPIE, 2017)

Population projections and estimates of future land use change indicate that significant pressure will be placed on the HNRS through the further development of its catchment. Population expansion in the Hawkesbury catchment has largely been limited by topographical constraints (e.g., rugged sandstone country unsuitable for housing development and agriculture) and legislative provisions (e.g., National Parks and development regulations regarding floodplain safety) (Harris, 2001). However, significant population growth and land use intensification is expected in the Western City, with the focal area being the Western Sydney Airport – Badgerys Creek Aerotropolis. The Western City District Plan predicts an additional 184,500 dwellings for this area in greenfield land release areas and through urban renewal. Development codes also allow for existing dwellings to be expanded, with granny flats and other lot and strata subdivisions. This will significantly increase the urban nature of the Eastern and South Creek sub catchments and put further pressure on the Hawkesbury estuary through catchment modification and subsequent changes to inflow patterns and quality.

3.5.1 Foreshore and estuarine development

Like the terrestrial catchment surrounding it, the estuary has also undergone significant physical development. In the lower Hawkesbury Estuary there is 32 km of foreshore with artificial rock walls and another 15 km of foreshore with a mix of artificial rock wall and natural surfaces (Astles et al., 2010).

In the Lower Hawkesbury alone, there are 20 boat ramps, almost 4,500 moorings and nearly 250 in-stream navigational aids, with the majority of these located in Pittwater (Astles et al., 2010). Numerous oyster leases are also located through the middle estuary region of the Hawkesbury though the industry and the State Government have made a concerted effort to remove structures from abandoned leases since 2004. Similar foreshore development patterns are present in Brisbane Water and Pittwater. In urban areas, foreshores are often engineered to prevent erosion and inundation and formalise access.

3.6 Water quality

Water quality is a subjective standard applied to the chemical, physical and biological properties of water to denote those conditions that are desirable for human consumption, to ensure safety for human contact, and to protect key ecosystem functions and attributes (Odume, 2017). In estuaries, water quality is determined by the geological setting and geomorphology of the system, hydrodynamic processes, resource inputs from the catchment, sediment processes and the responses of biological organisms.

Maintaining good water quality in estuarine systems is fundamental to their health and function. Good water quality is critical for the Hawkesbury-Nepean River system, the ecosystems and human use it supports, e.g., water extraction from the system for human consumption and extensive use of the system for recreational swimming, boating, commercial fishing and oyster farming (Kuruppu and Rahman, 2015).

Common estuarine water quality variables used to determine water quality are show in Table 10, with explanations of their potential influence in estuaries also given.

Table 10. Physical, chemical, and biological water quality measures and their function and importance to estuaries. (Ozbay et al., 2017)

Water Quality Type	Water Quality Variable	What it measures and its importance to estuaries
Physical	Temperature	Can influence the productivity and growth of estuarine organisms and the timing of seasonal events e.g., spawning. It can influence growth rates of estuarine organisms.
	Turbidity/suspended solids	The cloudiness of the water – important for underwater light regimes and photosynthesis. Turbidity may also influence predator-prey interactions e.g., high turbidity can impact visual-hunting predators such as fish (Lunt and Smee 2020).
	Colour	Not the same as turbidity, which refers to water cloudiness created by suspended solids and other material that scatters light. Colour is caused by

		dissolved polyphenolic compounds, commonly derived from plants. Together with turbidity, controls water clarity.
	Salinity	Salinity varies from fresh to marine along the estuary due to the mixing of fresh and seawater. Salinity fluctuation can either exclude species or extend their habitat access depending on the species, salinity is also important in the sedimentation process, aiding suspended particles in falling out of the water column. Electrical conductivity is often used as a surrogate for salinity.
Chemical	pH	The acidity or alkalinity of the water, generally between 7 and 8 pH units due to the mixing of fresh and seawater in the estuary
	Nutrients (mainly nitrogen and phosphorus, silica in some situations eg for diatoms)	Nutrients are essential to the production of photosynthetic organisms like algae, seagrasses and mangroves. When nutrients are too high in concentration a system can become eutrophic and prone to algal blooms.
	Dissolved oxygen (DO) concentration or % saturation	Determines oxygen availability for organisms like fish. Low dissolved oxygen can lead to increased mortality of estuarine organisms
	Heavy metal (e.g., lead, mercury and copper)	High concentrations of heavy metals in the water column and in the sediments of estuaries can disrupt the life cycles of flora and fauna.
	Organic pollutants (toxicants)	High concentrations of industrial pollutants such as pesticides in the water column and in the sediments of estuaries can disrupt the life cycles of flora and fauna.
Biological	Chlorophyll *a*	An indicator of photosynthetic/algal productivity.
	Bacterial (e.g., enterococci)	High concentrations can indicate bad water quality or sewerage inputs. This can impact safe primary contact associated with recreational activities and also can cause contamination of shellfish (eg oysters)
	Phytoplankton (water column algae)	Phytoplankton are microscopic plants that serve as the base of food webs. There are a variety of key groups: including diatoms, blue green algae, and dinoflagellates Chlorophyll a (a plant pigment) is often used as a surrogate for total phytoplankton biomass
	Harmful algae	Some phytoplankton can be harmful to humans. High concentrations of phytoplankton can indicate algal blooms, however a harmful bloom can also occur at low concentration as some toxic algae do not need high densities to become a hazard.
	Benthic diatoms	Used in surface water monitoring and are particularly successful in detecting eutrophication, organic pollution and acidification, but are also used as a key component of report health cards.
	Macroinvertebrates	Abundance and type of macroinvertebrates can indicate good or bad water quality and overall creek health depending on which species are present.
	Macrophytes	The depth, density, diversity and types of macrophytes present in a system are indicators of waterbody health. Where submerged aquatic macrophytes are abundant, they can have a heavy influence on habitat structure, fishability, recreational use and nutrient dynamics.

As the most downstream receiving system of rivers, estuarine water quality is influenced by the inputs of the entire catchment. Inputs to estuaries that can come from numerous sources in the catchment.

External sources:

- Point-source discharges – identifiable and specific discharge points, e.g., sewage-treatment plants discharging into upstream rivers or into the estuary itself. These are often regulated by pollution licenses that are issued by the Environmental Protection Authority (EPA).
- Diffuse sources – inputs derived from catchment runoff, e.g., overland flow from agricultural areas, urban stormwater from impervious surfaces.

- **Atmospheric deposition** – e.g., nutrients associated with dust, and nutrients dissolved in rain that enter the system.
- **Groundwater discharges** – resources carried in with groundwater recharge. This is very poorly understood but demonstrably important for algal blooms in some estuarine systems.

Internal sources:

- **Sediment-water fluxes** – resuspension of nutrient rich sediments. Also referred to as the 'internal load'. Examples include phosphorus liberated from anoxic sediments. Often enhanced by bioturbation from burrowing animals
- **Nitrogen fixation** – fixation of inorganic nitrogen by phytoplankton or algae attached to sediments (e.g., mud flats) or the leaves of submerged plants (e.g., seagrasses)
- **Animal metabolism –** release of bioavailable forms of nitrogen (e.g., excretion of $NH4+$ as a waste product by fish or invertebrates).

Nutrients and pollutants that enter estuaries can thereafter experience multiple fates including:

- Suspension in the water column of the estuary
- Flushing and export to coastal zones
- Deposition into sediments – nutrients and pollutant are often bound to sediments and carried by them through aquatic systems
- Assimilation into biota – uptake by photosynthetic organisms and indirect consumption by fauna, generally benthic feeders ingesting sediments.

Through our modification of the catchment and its land use, humans have significantly impacted on the water quality of the HNRS estuary (Markich and Brown, 1998). This has come about through a mixture of:

- **Contaminated runoff** – (including sediments) from impervious urban surfaces such as roads, driveways, and roofs, and from industry and agriculture carrying excess nutrients, pesticides and chemical pollutants
- **Wastewater and waste** – e.g., sewage that contributes excess nutrients, pathogens, hormones and heavy metals
- **Diverting flows** –reducing the flushing capacity of the estuary leading to pollutants remaining in the estuary longer (BMT WBM 2013)
- **Sand and gravel mining** – which increases turbidity and alters the hydrological flow regime of the system.
- **Recreational activities** – waterways use, particularly boating, is often associated with rubbish and pollution from boats including fuel, heavy metals and anti-fouling chemicals. Boating activity can also disturb stratified waters and contribute to algal blooms

3.6.1 Water quality monitoring and trends

As noted in the Stage 1 Scoping Study (Water Technology, 2020) important estuary condition indicators are currently monitored by a range of local and State government organisations at over 50 locations throughout the estuarine reach of the study area. These are depicted in Figure 24 and include:

- 9 sites across Brisbane Water (by Central Coast Council)
- 5 sites across Pittwater (by Northern Beaches Council)
- 24 sites across the Lower Hawkesbury and Broken Bay (including 8 by Central Coast Council, 14 by Hornsby Council and 2 by Sydney Water); and

- 15 sites across the Upper Hawkesbury from Wisemans Ferry to Yarramundi (including 10 by Sydney Water and 5 by Hawkesbury City Council and DPIE)

It is worth noting that the sites listed above are estuarine sites but several Councils (such as at least Northern Beaches, Central Coast and Hornsby Shire) also monitor a number of additional freshwater sampling sites – which are useful in informing catchment health estuary impacts.

Figure 24. *Location of water quality monitoring sites across the HNRS* (Water Technology, 2020)

The monitoring programs mapped above, as well as some others are listed below with web links provided:

- NSW Beachwatch (https://www.environment.nsw.gov.au/topics/water/beaches/beachwatch-water-quality-program)
- Sydney Water Sewage Treatment System Impact Monitoring Program (https://www.sydneywater.com.au/content/dam/sydneywater/documents/STSIMP-interpretive-report-2020-vol-one.pdf)
- Ku-ring-gai Council Water Quality and Aquatic Macroinvertebrate Sampling (https://www.krg.nsw.gov.au/Environment/Your-local-environment/Waterways/Water-Sensitive-City/Water-quality-monitoring)
- Hornsby Council "Hawkesbury Watch" Water Quality Monitoring Program (https://www.mhlfit.net/users/HornsbyShireCouncil-HawkesburyMonitoring)
- Central Coast Council Waterways Monitoring (https://loveourwaterways.centralcoast.nsw.gov.au/projects/water-quality-and-ecological-health-monitoring)
- Hawkesbury City Council Upper Hawkesbury River Healthy Waterways (https://data.hawkesbury.nsw.gov.au/pages/healthywaterways/#about)
- WaterNSW water quality and quantity monitoring program (https://www.waternsw.com.au/water-services/water-quality/monitoring-and-reporting)

Several long-term studies of the water quality in the HNRS provide important insight into the changes of the system over the last 50 years. These studies have highlighted several major water quality issues within the estuaries and are summarised in Table 11.

Table 11. Summary of relevant long term water quality studies within the HNRS

Study	Main WQ Variable	Trends or Issues	Location
Relative importance of natural and anthropogenic influences on the fresh surface water chemistry of the Hawkesbury Nepean River, south-eastern Australia Markich and Brown (1998)	Nutrients (NO_3, PO_4), Trace metals (Cu, Cd, Pb, Zn, Cr, Ni, Hg)	Observed the presence of nutrients (NO_3 and PO_4) and trace metals (Cu, Cd, Pb, Zn, Cr, Ni, Hg) in sediments and surface waters in the Hawkesbury estuary in excess of recommended guidelines.	Sediments and surface waters in the Hawkesbury estuary.
Brooklyn Estuary Processes Study Chapter 5 Water Research Laboratory (2002)	DO, temp, pH, salinity, turbidity, ammonia, Nitrogen, Phosphorus, chl *a*, faecal coliforms, enterococci	Bar Point and Spectacle Island are representative of the main Hawkesbury River conditions. There were no statistically reliable trends over time found due to the short duration of record.	Middle Estuary, with sites at Bar Point, Mullet Creek (x2), Mooney Mooney Creek (x2), Spectacle Island and Sandbrook Inlet.
Brisbane Water Historical Water Quality Data Review and Analysis WBM Oceanics (2003) (Summarised in CLT, 2008)	Temperature, pH, Turbidity, Secchi Depth, Salinity, DO, Ammonia, TN, TP, Chl *a*	The highest nutrient concentrations occurred upstream of Woy Woy Bay, notably in Correa Bay and in The Broadwater (near the mouths of Narara and Erina Creeks). There are also high nutrient concentrations observed near the mouth of Kincumber Creek.	Brisbane Water with monitoring sites at Cockle Creek, Narara Creek, Booker Bay, Erina Creek, Kincumber Creek, Woy Woy Creek.
Pittwater Estuary Processes Study Lawson and Treloar (2003)	pH, Turbidity, suspended solids, temperature, conductivity, salinity, DO, TN, ammonia, NO_x, TP, Chl *a*, Faecal coliforms, enterococci	Data indicates that water quality variables are poor within the tributaries and in embayments after rain, and reasonable during dry periods and in the main estuary body. Those areas that have been urbanised have 'health' issues (such as the eastern foreshores) whilst those areas with little or no urbanisation have good 'health'.	Barrenjoey Beach, Bayview Baths, Careel Bay, Clareville Beach, Elvina Bay, Great Mackerel Beach, McCarrs Creek, North Scotland Island, Paradise Beach Baths, Salt Pan Cove Baths, South Scotland Island, The Basin, West Head, Winji Jimmi Bay
Analysis of long-term water quality for effective river health monitoring in peri-urban landscapes—a case study of the Hawkesbury–Nepean river system in NSW Pinto et al. (2013)	Temperature, Suspended solids, Nitrogen, Chl *a*	Increasing Temperature, decreasing Suspended solids, decreasing nitrogen concentrations (though still high), decreasing Chl *a* concentrations though still high.	Poor water quality was identified across 98 kms between Yarramundi and Wiseman's Ferry.
Trends in water quality data in the Hawkesbury–Nepean River System, Australia Kuruppu and Rahman (2015)	Turbidity, Chl *a*, pH, Heavy metals	Since 2000, there has been decreasing trends for pH (more acid), nitrogen, dissolved oxygen and electrical conductivity and an increasing trend for levels of turbidity, Chl a, iron, aluminium, manganese, and silicate.	Water quality was related heavily to land use with rural and urban development near the estuary, and inputs of STPs impacting water quality negatively in the estuary.

Study	Main WQ Variable	Trends or Issues	Location
		Some improvements can be seen in water quality at certain stations. There was no real change in levels of NH_4, PO_4 or suspended solids	
Multiple studies of harmful algal blooms and toxic dinoflagellates in the Hawkesbury River estuary with a focus on Berowra Creek Ajani et al. 2016b, 2018a, 2020a	Harmful Algal Blooms (Toxic dinoflagellates)	Dinoflagellates from the toxigenus *Dinophysis* have increased in abundance in the Hawkesbury between 2003 and 2014. Unprecedented blooms of a new harmful/toxic dinoflagellate in Berowra Creek. Blooms are complex but are influenced by eutrophication (high nutrients) and low salinity. Not linked to rainfall. Toxic algae in Berowra Creek were linked to an increase in phosphorous and decrease in nitrogen in the water column.	Berowra Creek
Hornsby Shire Council Waterway Health Review (1995-2017) Hornsby Shire Council (2019)	Temp, pH, DO, Salinity, Turbidity, TSS, Chl-a, TN, TP, NH_3-N, NOx-N, Bacteria	Overall, the water quality at the majority of long-term freshwater sampling sites has remained relatively stable despite an ever growing population and increasing development pressure. Waterways in urban areas are displaying symptoms of 'urban stream syndrome'. Estuarine sites in the Hawkesbury River are exhibiting impacts from pressures that extend well beyond the Hornsby LGA, particularly with regards to increasing nutrient concentrations.	Berowra Creek, Cowan Creek, Lower Hawkesbury and their freshwater reaches
DPE Estuary Report Cards 2010 - Ongoing	Algae, water clarity, overall estuarine health	Report cards are available for the Hawkesbury River, Brisbane Water, and Pittwater. The report cards indicate that the Upper Hawkesbury River has the lowest scores but has exhibited a trend of improvement. Brisbane Water has good scores but has recently exhibited a declining trend, and Pittwater has maintained high scores.	Upper Hawkesbury River, Brisbane Water, Pittwater
Central Coast Waterways Report Card Program 2012 - Ongoing	Chl-*a*, Turbidity, Sea grass depth range	Water quality throughout Brisbane Water in 2020-21 was graded good with the exception of Kincumber Broadwater which received a fair grade. Heavy rainfall in March 2021 resulted in one significant chlorophyll-a trigger value exceedance at Woy Woy Bay, Cockle Bay and Booker Bay in April, the size of which was enough to cause the ecological health grade at all three sites to drop from excellent to good.	Central Coast waterways including Brisbane Water and Hawkesbury River tributaries

3.6.2 Spatial variability in water quality

WaterNSW has tested water quality monthly across multiple locations in the Hawkesbury-Nepean River system since 2000. The water quality is generally good with low turbidity and metal concentrations meeting the ANZECC guidelines as well as the concentrations of pH and total phosphorus. However, research has determined that there are two relatively "clean zones" (upstream of Yarramundi and downstream of Lower Portland) a relatively "polluted zone" (Between Yarramundi and Lower Portland) in the Hawkesbury (Pinto et al., 2013). These are illustrated in Figure 25 which shows a longitudinal plot of NOx variation along the estuary from Maldon (Upper Nepean) to Peat Island (Pinto et al., 2013).

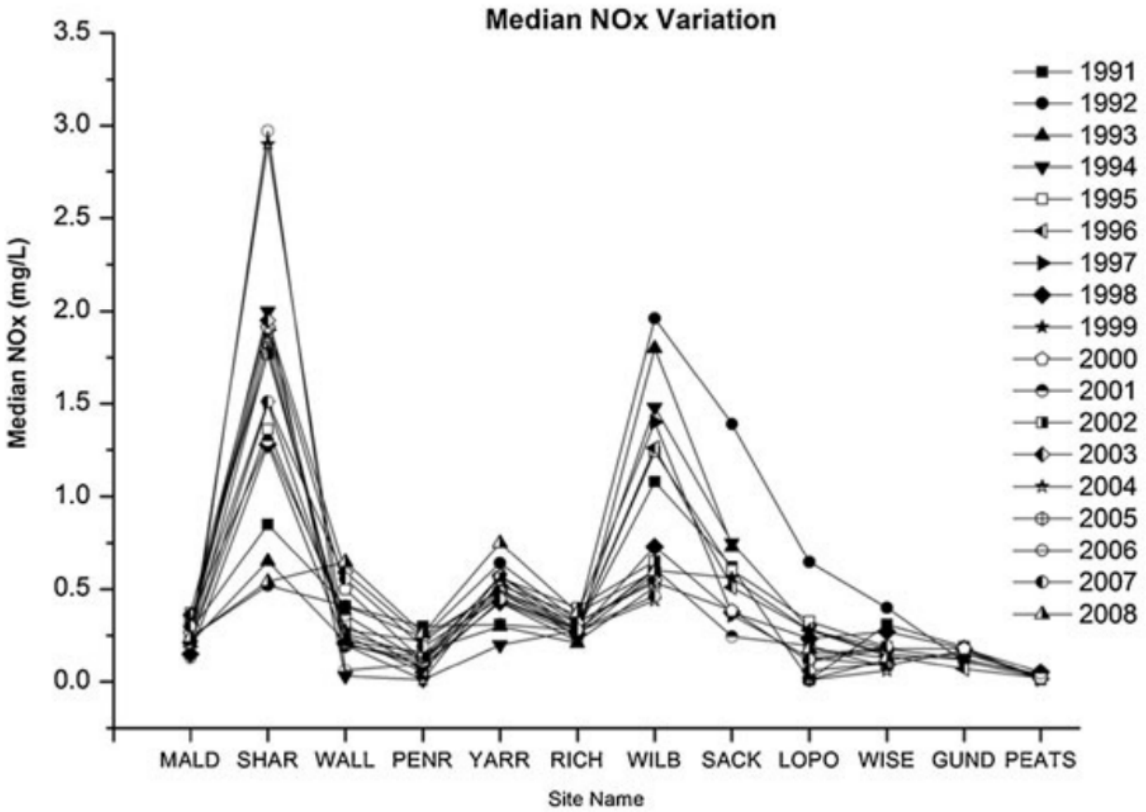


Figure 25. *Longitudinal plot of NOx for various years from Maldon in the Upper Nepean to Peats Ferry Bridge in the Hawkesbury.* (Pinto et al., 2013). *Site codes refer to the following locations, Maldon Weir, Sharpes Weir, Wallacia Bridge, Penrith Weir, Yarramundi Bridge, North Richmond, Wilberforce, Sackville Ferry, Lower Portland, Wisemans Ferry, Gunderman, Peats Ferry Bridge.*

There can also be problematic concentrations of dissolved oxygen and nitrogen within the system (BMT WBM, 2013). The highest concentrations of nutrients are observed between Windsor and Sackville, with major contributors including effluent from wastewater discharges into South, Cattai and Berowra Creeks, and intensive agricultural, with the impacts worsening during wet weather (Kimmerikong, 2005; Hornsby Shire Council, 2019). Due to the efforts by Sydney Water in improving the quality of wastewater treatment, and various efforts by other agencies and organisations in remediating areas of the catchment, nutrient concentrations gradually decreased between 1994-2011 (BMT WBM, 2013; Hornsby Shire Council, 2019). This pattern has perhaps been balanced by increased contributions from population growth and increasing development pressure in areas like Berowra Creek, where long-term freshwater sampling has found that water quality has remained stable (Hornsby Shire Council, 2019).

The abundance of enteric or faecal bacteria at estuarine sites is low and mostly similar to those at the reference sites. Even so, this is subject to circulation. Areas such as Marramarra Creek and Crosslands Reserve that are close to the tidal limits are more susceptible to freshwater catchment inputs, and areas such as embayments in Pittwater that are poorly circulated and impacted by urban runoff after rain, see higher concentrations of nutrients, bacteria and turbidity following rain (Pittwater Council, 2003).

Brisbane Water shows a high degree of spatial variability in water quality. Urban runoff and wet weather overflows impact Correa Bay, Kincumber Creek (heavily urbanised and the poorest water quality) and in The Broadwater near the mouths of Narara (highest pollutants due to larger flows) and Erina Creeks (CLT, 2008).

DPE Estuary Health Report Cards provide a high level grade for each of the three main waterways of the HNRS. Two water quality indicators, turbidity and chlorophyll *a*, are monitored to represent water quality condition – based on the findings of (Scanes et al., 2007). Both are nationally agreed indicators for monitoring water quality and can be assessed by comparing data against relevant trigger values suggested in the Australian water quality guidelines (ANZECC & ARMCANZ, 2000). Estuarine macrophyte and fish assemblage data also provide a longer-term integration of estuary ecosystem health status (OEH, 2016).

Each water quality report card gives an overall grade for the health of an estuary for a specific year based on combined measurements of water clarity and algal abundance. The grades range from A (excellent health) to E (very poor health):

- A – excellent
- B – good
- C – fair
- D – poor
- E – very poor.

The grades for each of the waterways is provided in Table 12.

Table 12. DPE Estuary Health Report Card Grades

Year	Algae	Water Clarity	Overall Grade
Upper Hawkesbury River			
2010-11	C	E	D
2013-14	D	C	C
2016-17	C	D	C
2020-21	C	B	C
Lower Hawkesbury River*			
2017-18	B	D	C
2018-19	C	C	C
2019-20	C	E	D
2020-21	B	E	C
Brisbane Water			
2010-11	A	A	A
2013-14	A	A	A
2016-17	B	A	A
2017-18	A	A	A
2018-19	A	A	A
2019-20	C	A	B
2020-21	C	A	B
Pittwater			
2017-18	A	A	A
2018-19	A	A	A
2019-20	A	A	A
2020-21	A	A	A

**The DPE report cards for the Hawkesbury River only consider the Upper Hawkesbury from Wiseman's Ferry to the tidal limit at Yarramundi. The scores for the Lower Hawkesbury have been determined for this report using a consistent method, but are not available from DPE.*

3.6.3 Sewage and wastewater treatment plants

The number of wastewater treatment plants and on-site sewerage systems has decreased significantly in Sydney over the last twenty years due to schemes such as the Priority Sewerage Program which built new sewerage systems for outlying areas of Sydney and decommissioned plants that discharged to local streams, mostly in the Hawkesbury-Nepean catchment and including villages in the Wollondilly, Blue Mountains, Windsor area, Galston and Glenorie and Hornsby. Sydney Water has also built several recycled water plants in the Hawkesbury catchment, the most significant of which is St Marys, which processes 33.5 ML of wastewater a day at a tertiary level, with the majority being treated at an advanced level before release into the Nepean River as a source of supplementary flows (Sydney Water, 2022a).

There are still twelve plants discharging over 1.2 ML of tertiary treated sewage into the Hawkesbury-Nepean system each day, with the largest plants at Penrith (discharging into Boundary Creek), Quakers Hill (discharging into Breakfast Creek to Eastern Creek), Riverstone (discharging into Eastern Creek to South Creek) and Rouse Hill (into Second Ponds Creek to Cattai Creek but also partially reused for a local recycling scheme) (Sydney Water, 2022b). The sediments at Cattai are exposed to high levels of treated effluent from Cattai and South Creeks, but as tidal flows affect this reach, they are quickly mixed (Pinto et al., 2014). The wastewater systems managed by Sydney that discharge into the Hawkesbury River Estuary and Pittwater Estuary are mapped in Figure 26.

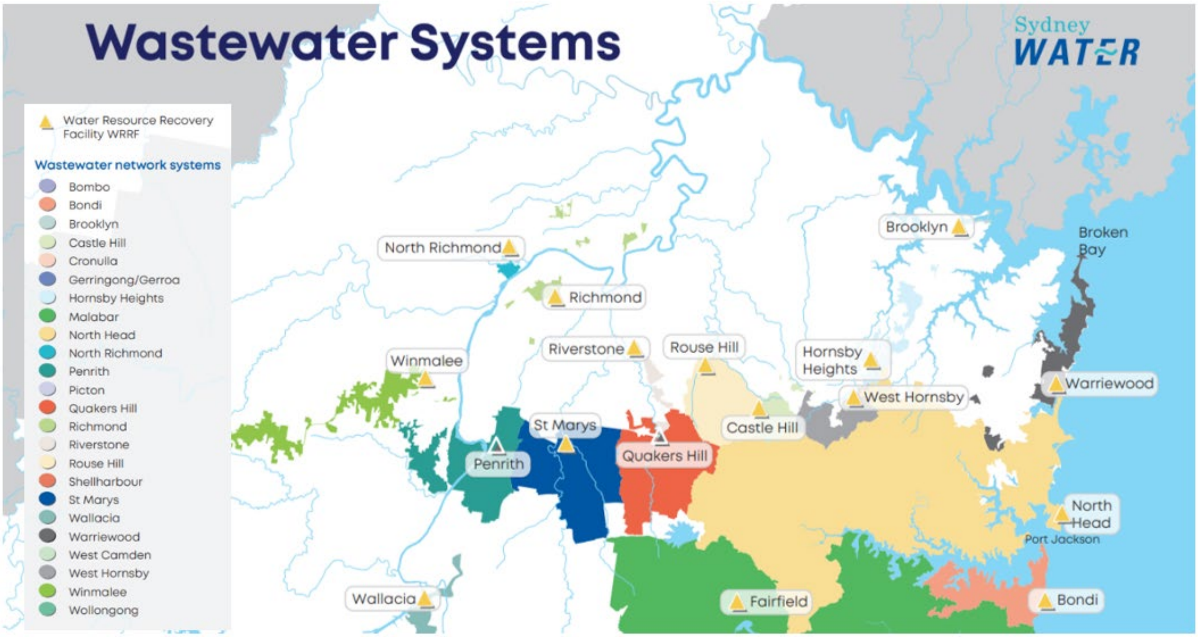


Figure 26. *Waste water systems (Sydney Water – map extracted for Hawkesbury River & Pittwater)*

Central Coast Council (formerly Gosford and Wyong) also manage a wastewater network that discharges into the HNRS on the north shore of the Hawkesbury Estuary as well as into Brisbane Water. The main sewer treatment plants that impact the HNRS managed by Central Coast Council include Kincumber Sewerage Treatment System, and Mooney Mooney & Cheero Point Sewerage Scheme.

3.6.4 Eutrophication and harmful algal blooms

Eutrophication is the unacceptable enrichment with nutrients of an aquatic system with the concomitant increase in biomass of undesirable plants, especially phytoplankton but potentially also benthic macroalgae and rooted angiosperms. In most cases, it is the increase in phytoplankton biomass that is of most concern, especially if those algae are toxic. Eutrophication in an ecological context is discussed in Section 4.3. Several studies have focused on potentially harmful algal blooms and what drives their productivity in the system (Larsson et al., 2017; Ajani et al., 2018; Ajani et al., 2020). These studies have shown that algal production is complex and may be driven by:

- High nutrient inputs
- In the Upper Estuary – mixing of waters by inflow events, and
- In the Lower Estuary – stratification and reduced mixing of the water column

Initial concerns about phytoplankton and algal blooms in the Hawkesbury occurred in the 1970s. Sewage inputs were contributing to upper-mid Hawkesbury aquatic weed infestations and the water was coloured dark green with evidence of fish kills. Detailed reports issued in 1983 by the State Government revealed excessive nutrients, algae and decreased oxygen levels in the river (Wolanski and Collis, 1976). Blue-green algae sampling conducted by (Pinto et al., 2014) found eutrophication was likely between Penrith and Sackville, with the risk of algal blooms highest during warmer months.

Since then, there has been some progress on reducing nutrients in the system with decreased nitrogen loading due to effluent treatment upgrade works in 2003 significantly decreasing chronic point source loading of nitrogen, lowering Chl *a* concentrations during warmer months when the risk of harmful algal blooms (HABs) is greatest (Larsson et al., 2017). Improvements to wastewater treatment have seen algae concentrations fall as a result of this source since 1986 (Simmons et al., 2016). However other sources of nutrients, including the internal sediment load within the estuary, can still contribute to HABs when stratification is disrupted, and sediments and cysts of HAB species such as *Alexandrium* sp are resuspended into the upper water column (Ajani et al., 2016).

In Brisbane Water, water quality issues relating to elevated turbidity, low concentrations of DO, and high concentrations of nutrients and chlorophyll a are more common in the upstream reaches of the estuary upstream of Woy Woy Bay and primarily in relation to inputs from Narara and Erina Creeks. These issues are more problematic following wet weather events, although this pattern is less obvious in the lower reaches of the estuary which are under a higher degree of marine/tidal influence.

Eutrophication is not as much of an issue in Pittwater Estuary due to efficient tidal flushing and the lack of wastewater inputs from sewage treatment plants. The former prevents large build-up of nutrients and algae within the estuary. However within the more enclosed embayments, particularly those that are surrounded by urban development (e.g. Crystal Bay, Winji Jimmi Bay, Browns Bay, Winnererremy Bay, McCarrs Creek, Careel Bay), it is possible that denitrification efficiencies are reduced, and that release of nutrients from sediments could be impacting on local water quality (Lawson & Treloar, 2003).

3.6.5 Other toxicants

Most organic chemicals and heavy metals transported through aquatic systems become bound to sediment particles. Estuaries, as the receiving system for most of the catchment sediment, can therefore have high concentrations of organic chemicals and heavy metal pollutants in their sediments, though often in localised areas near industrial areas land uses. This can lead to issues when macrophytes or phytoplankton uptake these elements and pass them to higher trophic levels through a process known as bioaccumulation. As an example, heavy metals can accumulate in the tissues of benthic feeders and filter feeders such as shellfish and be passed up the food chain to humans (Kench, 2009).

Metals in sediments throughout the estuary are typically close to background levels, but there are elevated levels in the headwaters of Berowra Creek, Cowan Creek and in southeast Pittwater (Matthai et al., 2009). For example, elevated concentrations of copper, mercury and lead exist in sediments in poorly circulated locations in the estuary on Cowan River and Berowra Creek (Matthai et al., 2009).

In addition to metals, organic chemicals are an issue for estuarine organisms, such as endocrine disrupters like estradiols and tributyltin (TBT). TBT was an antifouling agent (now banned since the late 1980s) that accumulates in bed sediments and causes the breakdown of organisms reproductive, central nervous and endocrine systems (Kench, 2009; Matthai et al., 2009). TBT alternatives used since this time for antifouling of boats have since also been found in sediments in the lower Hawkesbury River (Matthai et al., 2009). Estradiol inputs have also been found in the area near South Creek in levels that are capable of impeding on the natural reproduction of small estuarine fish species (Uraipong et al., 2018).

4 Ecological structure and function

This section outlines the ecological structure and functions (or processes) that are responsible for the continuing function and health of the HNRS estuaries. It is designed to help managers understand general ecological principles and aid them in effectively managing the HNRS estuary. A general overview of the dominant ecological structures, functions and processes of the HNRS is presented with a summary of the wider scientific literature and relevant examples and research. The aim is to increase localised understanding of these processes and inform future management decisions.

This section is focused on the Freshwater Tidal Pools, Upper, Middle and Lower Estuary zones (see Section 2.2 Functional zones), however it also addresses critical ecological interaction with the upstream freshwater reaches and the Contributing Catchment which influence the estuary. This is a necessary step in understanding and managing coastal waterways and estuaries holistically, with the surrounding terrestrial environment and catchment playing a large role in defining the ecology of estuaries.

Ecologists and conservation biologists have long recognised that ecosystems can be thought of as having two interacting elements (Odum, 1962):

- ecological structure – the living components of ecosystems, such as fish, birds and invertebrates and,
- ecological functions – the variety of food-web and biogeochemical processes that take place in ecosystems, such as organic-matter decay, energy transfer and nutrient regeneration (Odum, 1962).

In simple terms, the structural elements are those that can be quantified in terms of numbers or abundances: e.g. the biomass of fish, the number of koalas etc. The functional elements are those that have to be described in terms of rates; e.g. the rate of primary production, the rate of nutrient regeneration, the rate of N2 fixation. Understanding the existing ecological structures and functions within a given ecosystem and what supports productivity is fundamental in appropriately managing them.

Structural elements are often easier to measure than functional elements and they often form the basis of monitoring and intervention programs. Within estuaries such as the Hawkesbury Nepean, there are numerous ecological processes constantly at play, occurring at varying spatial scales from the catchment to localised habitats. Ecological processes within estuaries can be an indication of a healthy or degraded estuarine system, for example, ecological processes change in estuaries with increased urbanisation or reduced freshwater inflow (Cloern and Jassby, 2012; Chilton et al., 2021).

The ecological processes that are crucial to estuaries explored in this section include:

- primary and secondary productivity
- food-web structure
- nutrient regeneration and cycling
- decomposition processes
- ecological connectivity
- flow variability

4.1 Ecological structure

Understanding local habitats and ecological communities that are present within a system is fundamental to effective management as each relies on specific ecological processes. Habitats and ecological communities can also be a useful indicator of the ecological health of a system and whether ecological functions and processes are balanced. The first part of understanding them is knowing what is present within the system.

4.1.1 Flora

The term 'flora' includes all the plants in a given area, and this means not only the vascular angiosperms (e.g. trees, shrubs, grasses etc) but also all the other vascular non-flowering plants (e.g. ferns) as well as the algae, which can occur in the water column (phytoplankton) or on submerged surfaces (biofilms). Focus is usually given the angiosperms (i.e. flowering plants), and algae are considered most often in terms of water quality indicators. Given the length of the HNRS estuary and its transition from freshwater to marine waters there are many aquatic, intertidal and riparian floral communities within the HNRS system. A cross section of a typical estuarine wetland is provided in Figure 27. Boon (2017) listed the most important of these vegetation types as:

- Seagrasses (*Posidonia, Zostera* and *Halophila* spp.)
- Mangroves (*Avicenna marina* and *Aegiceras corniculatum*)
- Saltmarshes
- Freshwater/estuarine swamps and wetlands
- Riparian forests (*Casuarina* spp. and *Melaleuca* spp.)

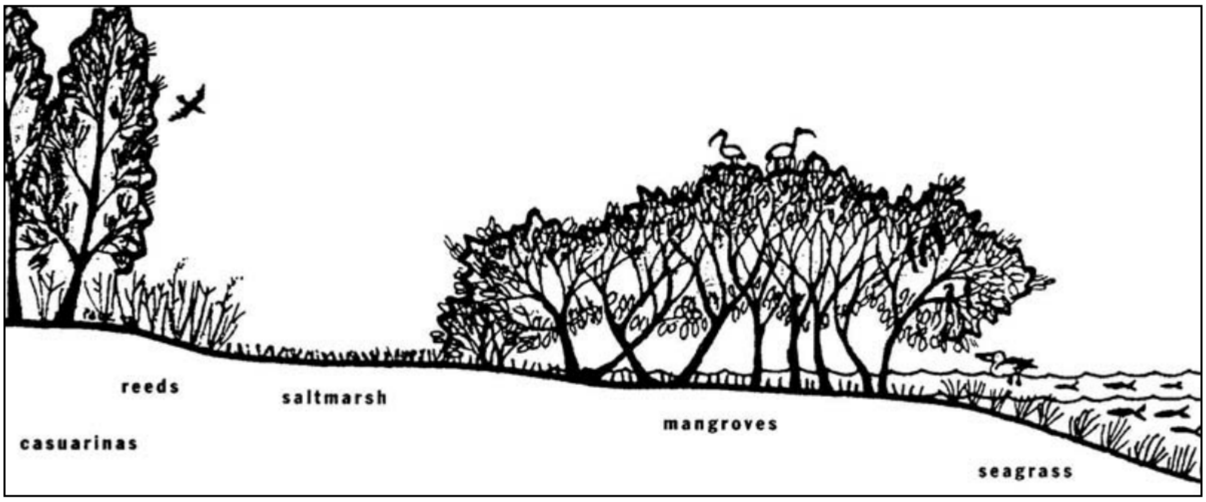


Figure 27. Cross section of a typical estuarine wetland. Reproduced from Wilton, 2002

An overview of the flora and ecological communities are presented in the Hawkesbury Nepean River System Stage 1 Scoping Study (Water Technology, 2020) with the dominant riparian and aquatic habitats and species along the estuary summarised in Table 13 below.

Table 13. Aquatic vegetation communities of the HNRS

Functional zone	Habitats and communities	Important species
Freshwater Tidal Pool and Upper Estuary	Freshwater Wetlands (back-swamps and lagoons) – usually dominated by She-oaks or paperbarks Riparian vegetation Freshwater submerged plants	She-oak (*Casuarina cunninghamiana*) Paperbarks (*Melaleuca spp.*) Rushes and reeds *(*e.g., *Phragmites australis* and *Typha* spp.*)* *Vallisneria*
Middle Estuary	Estuarine Wetlands as a floodplain community Mangroves Saltmarsh	She-Oaks (*Casuarina glauca*) Mangroves (*Avicennia marina and Aegiceras corniculatum*) Saltmarshes (*Juncus kraussii*)
Lower Estuary (including, Berowra and Cowan Creeks, Pittwater and Brisbane Water)	Seagrasses Saltmarsh Mangroves Riparian vegetation Estuarine swamp oak forests	Seagrasses (three main genera *Halophila, Zostera and Posidonia*) Saltmarshes (as above, *Sarcocornia quinqueflora, Suaeda australis, Sporobolus virginicus* and *Samolus repens*) Mangroves (as above) Riparian Swamp-Oaks (*Casuarina glauca*)

Terrestrial vegetation in the contributing catchment plays an important role in the estuary, providing habitats for terrestrial species, underpinning hydrological processes in the catchment, as well as lending to the social amenity of the area. Coastal swamp oak forest is an important terrestrial estuarine ecological community that can be intertidal (though not exclusively) and are important carbon sinks. The large, protected areas of native vegetation throughout the catchment act as natural filters of catchment runoff and thus improving water quality in the estuary (Boon, 2017b).

The key vegetation communities of the HNRS catchment are presented below in Table 14 using broad vegetation classifications to summarise the types of vegetation in the area and some of their dominant species (Keith, 2004; Boon, 2017b).

Table 14. Classifications of terrestrial vegetation in the region (Keith, 2004; Boon, 2017b).

Vegetation Communities	Location	Important Species
Warm Temperate Rainforest	Gullies and creeks in Lower Estuary e.g., Calna Creek a tributary to Berowra Creek, tributaries into Erina and Narara Creek	Coachwood, Sassafras, Lilly Pilly
Wet Sclerophyll Forest	Gullies and creeks across the estuary, areas with higher rainfall (>900mm). Often adjacent and upslope from warm temperate rainforest areas.	White Mahogany Tallowwood Blackbutt
Dry Sclerophyll Forest	Various types throughout the Cumberland Plain, Hornsby Plateau and alleys of the Colo and Macdonald Rivers. Often adjacent and upslope from wet sclerophyll forest.	Forest Red Gum Red Ironbark Range of native shrubs e.g., A*cacias* and G*revillias*

Sydney Hinterland Dry Sclerophyll Forest	Dural, Maroota and the Yengo and Wollemi National Parks	Yellow Bloodwood Red Bloodwood
Sydney Montane Dry Sclerophyll	Blue Mountains and Illawarra Plateau – World Heritage Area	Eucalypt dominated canopies. This area has high natural biodiversity as part of its protected listing and is critical to the high natural water quality of the area.
Freshwater wetlands on coastal plains	Swampy, saline, alluvial soils around the margins of estuaries and coastal lagoons, usually landward of Saltmarsh community when the two occur together. Examples of freshwater wetlands are located in Strickland State Forest in the western Brisbane Water catchment.	Estuarine Reedland, Estuarine Paperbark Scrub Swamp Oak Forest *Phragmites australis* (Common Reed), *Baumea Juncea, Juncus kraussii* and *samolus repens*.

Of particular importance to the estuary are the aquatic macrophytes e.g., the mangroves, saltmarshes and seagrasses. These provide important habitats for estuarine species such as fish, crabs, birds and invertebrates. Seagrass habitats are recognised as providing essential ecosystem services and being indicators of estuarine health and are under increasing threat globally (West and Glasby, 2021). Threats to seagrass communities in the HNRS include boating, coastal development, boat mooring, nutrient enrichment, turbidity, recreational disturbance in shallow areas, dredging and trawling. Similarly threats to saltmarsh are well documented and include coastal development and mangrove encroachment due to changing sediment delivery and sea level rise (Astles et al., 2010; Saintilan et al., 2014). Freshwater wetlands and swamps in the Hawkesbury Nepean region are also in decline regarding the biodiversity they support and their spatial coverage (Burgin et al., 2016). Current predictions indicate given the current trajectory native diversity will decrease significantly in the remaining freshwater wetlands of the Hawkesbury flood plain unless more emphasis is placed on maintaining wetlands – both natural and constructed (Burgin et al., 2016).

Extensive mapping of these habitats is described by (Creese et al., 2009) and mapped as part of the NSW Fisheries macrophyte habitat mapping program (DPI Fisheries, 2021). The most recent publicly available mapping for each estuary is presented in Figure 28 (Hawkesbury River estuary), Figure 29 (Brisbane Water), and Figure 30 (Pittwater).

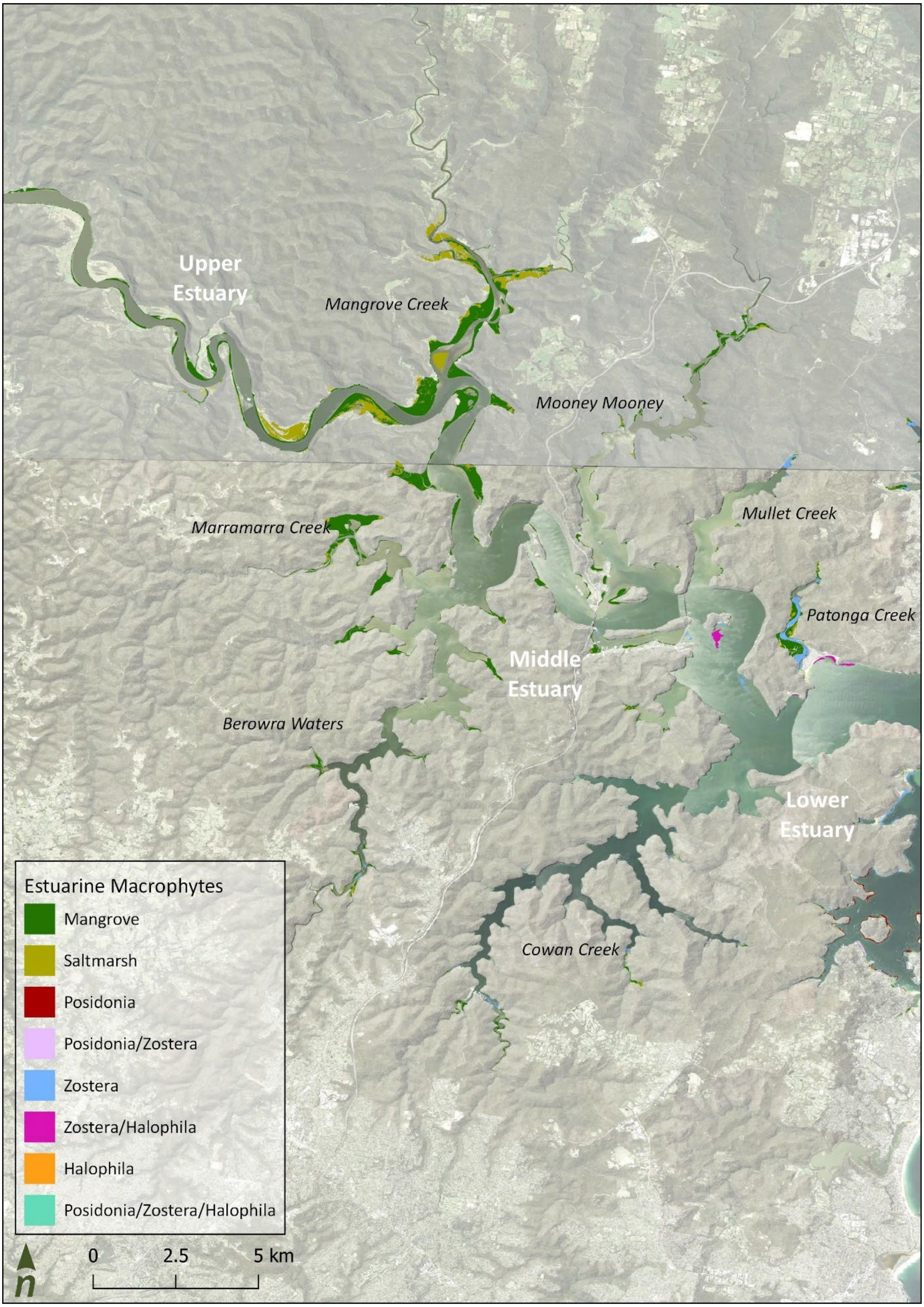


Figure 28. *Estuarine macrophytes in the Hawkesbury River estuary. Mapping undertaken in 2005 and 2008.*(DPI Fisheries, 2021)

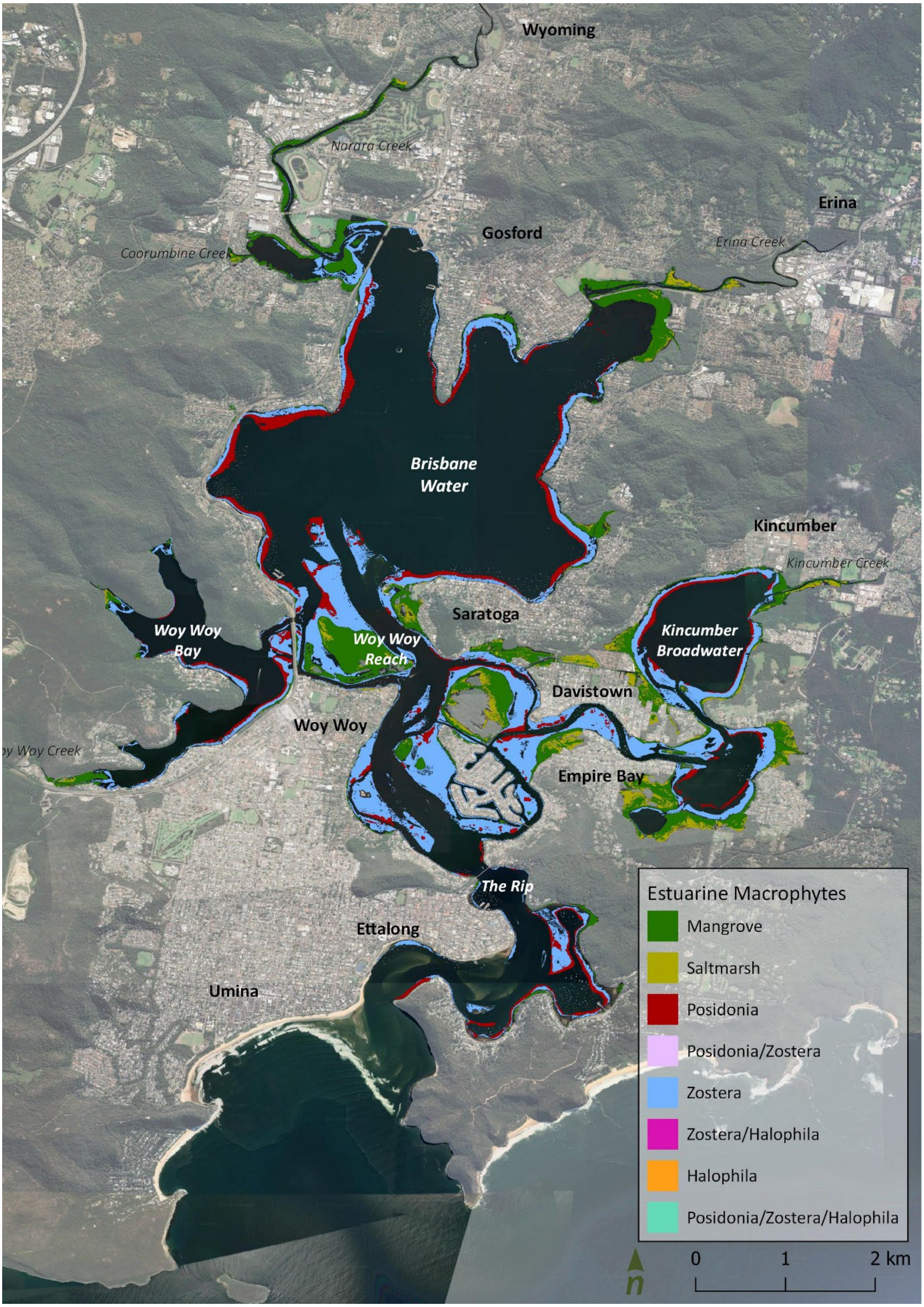


Figure 29. *Estuarine macrophytes in the Brisbane Water Estuary. Mapping undertaken in August 2020.* (DPI Fisheries, 2021)

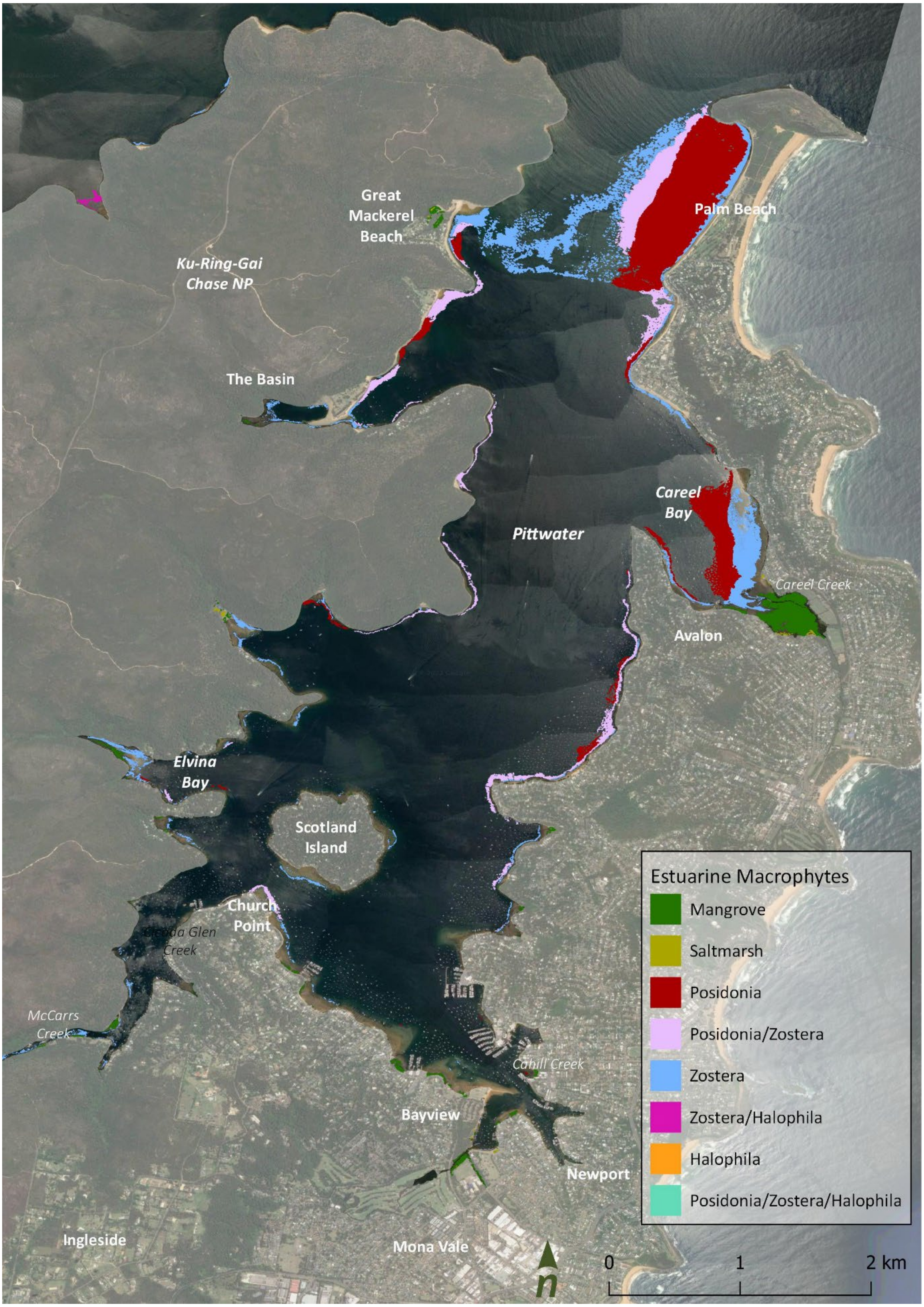


Figure 30. *Estuarine macrophytes in the Pittwater Estuary. Mapping undertaken in August 2019.* (DPI Fisheries, 2021)

Summaries of the temporal trends in DPI Fisheries data for estuarine macrophyte coverage for the HNRS are illustrated in Figure 31 (Hawkesbury River estuary), Figure 32 (Brisbane Water), and Figure 33 (Pittwater). Methods used for mapping are described in (Creese et al., 2009) and (West and Glasby, 2021). Due to differences in mapping techniques, areas from 1980 (light grey columns) may not provide an accurate measurement of macrophyte extent, limiting the ability to assess trends using that data. Mangrove and saltmarsh species have not been distinguished and saltmarshes include the low-marsh species and exclude higher-marsh species such as *Phragmites australis* and *Baumea juncea.*

However, Wilton (2002) provides useful data on the spatial extent of estuarine macrophytes in certain areas of the HNRS. This research mapped three locations in the HNRS: Courangra Point, Pelican, Rileys, and St Huberts islands in Brisbane Water and, Careel Bay in Pittwater, for 1940, 1965, 1974, 1986, 1996. The Careel Bay data are consistent with the DPI Fisheries Pittwater results for the year 2000- but there are significant discrepancies with the 1980 estimate for mangrove which would only be explained if there were major losses outside of Careel Bay during that time period. A summary of results from Wilton (2002) for these three locations are provided in Figure 34 (Courangra Point), Figure 35 (Pelican, Rileys, and St Huberts Island) and Figure 36 (Careel Bay).

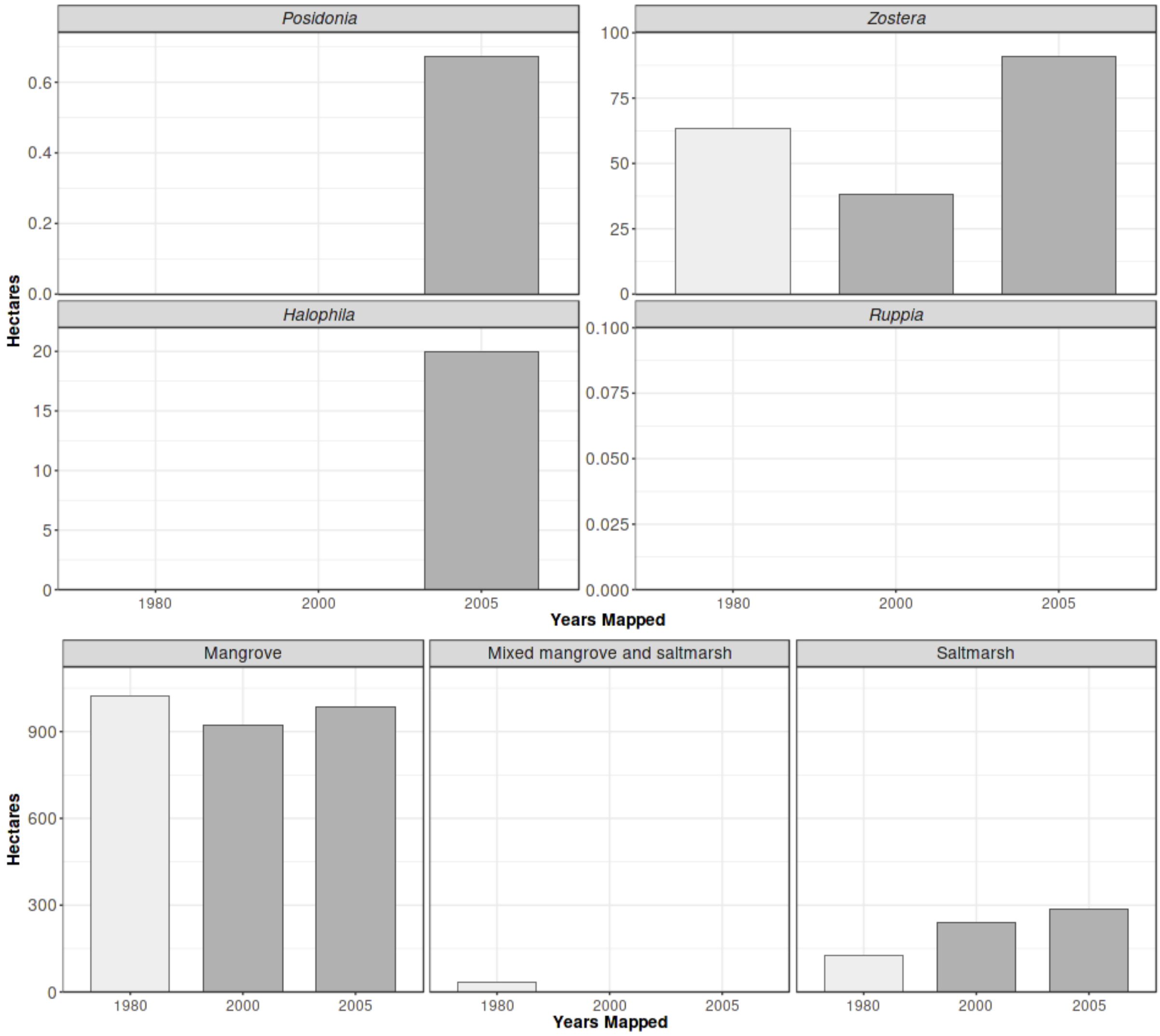


Figure 31. *Temporal trends in estuarine macrophyte coverage in the Hawkesbury River estuary.* (DPI Fisheries, 2021)

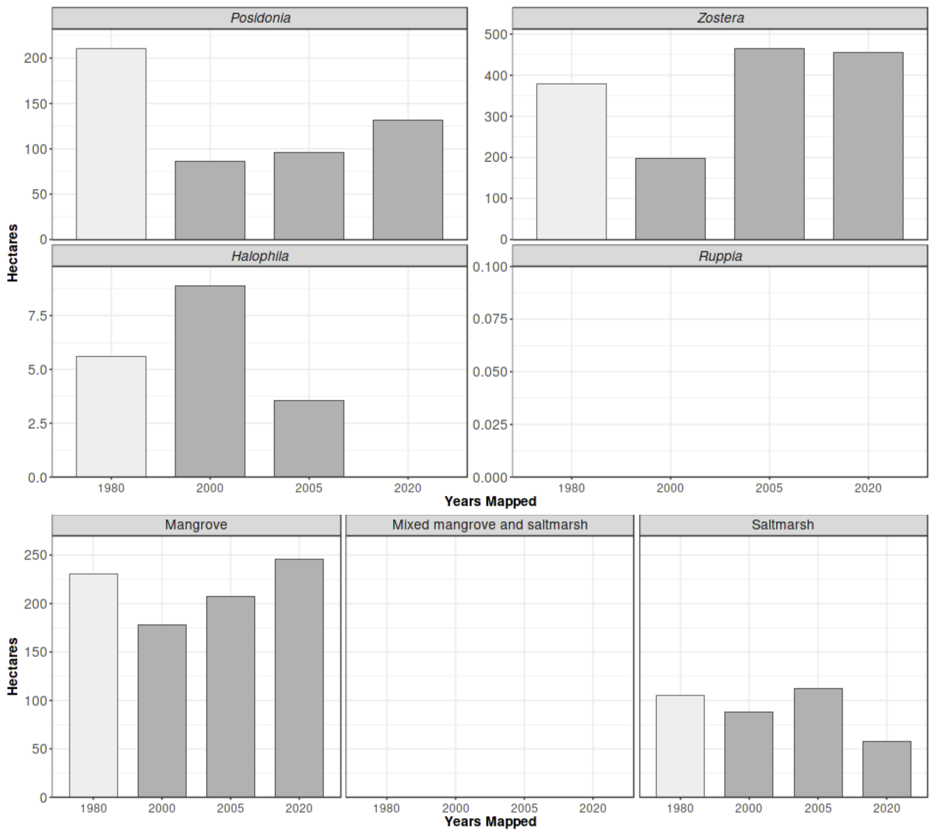


Figure 32. *Temporal trends in estuarine macrophyte coverage in the Brisbane Water estuary.* (DPI Fisheries, 2021)

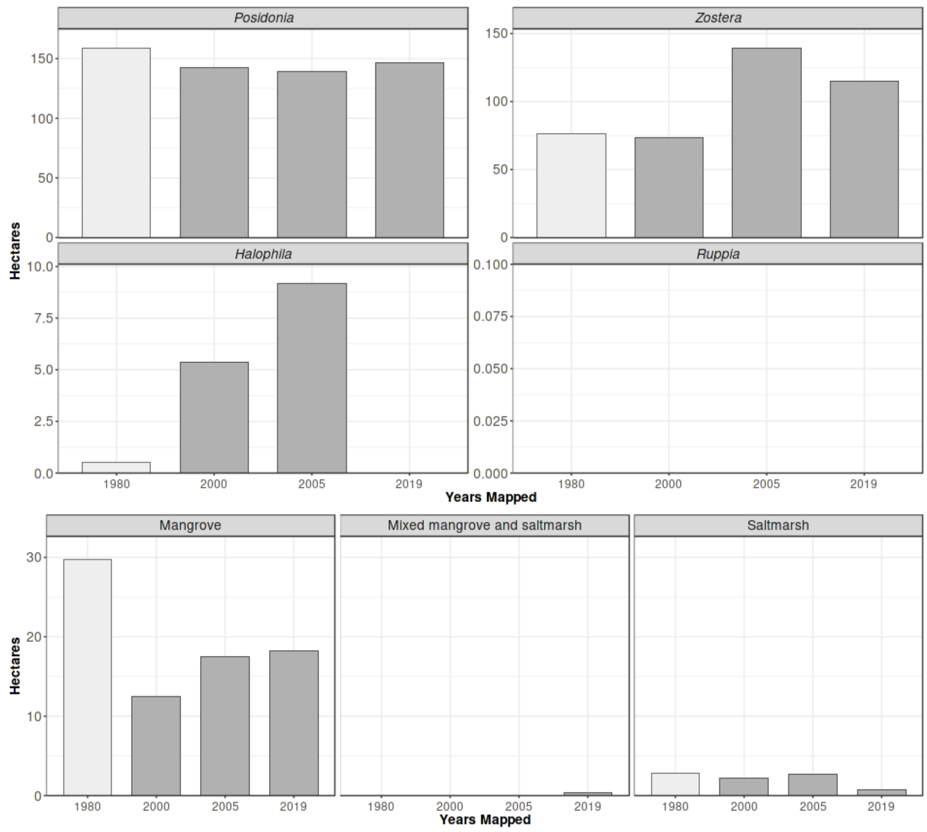


Figure 33. *Temporal trends in estuarine macrophyte coverage in the Pittwater estuary.* (DPI Fisheries, 2021)

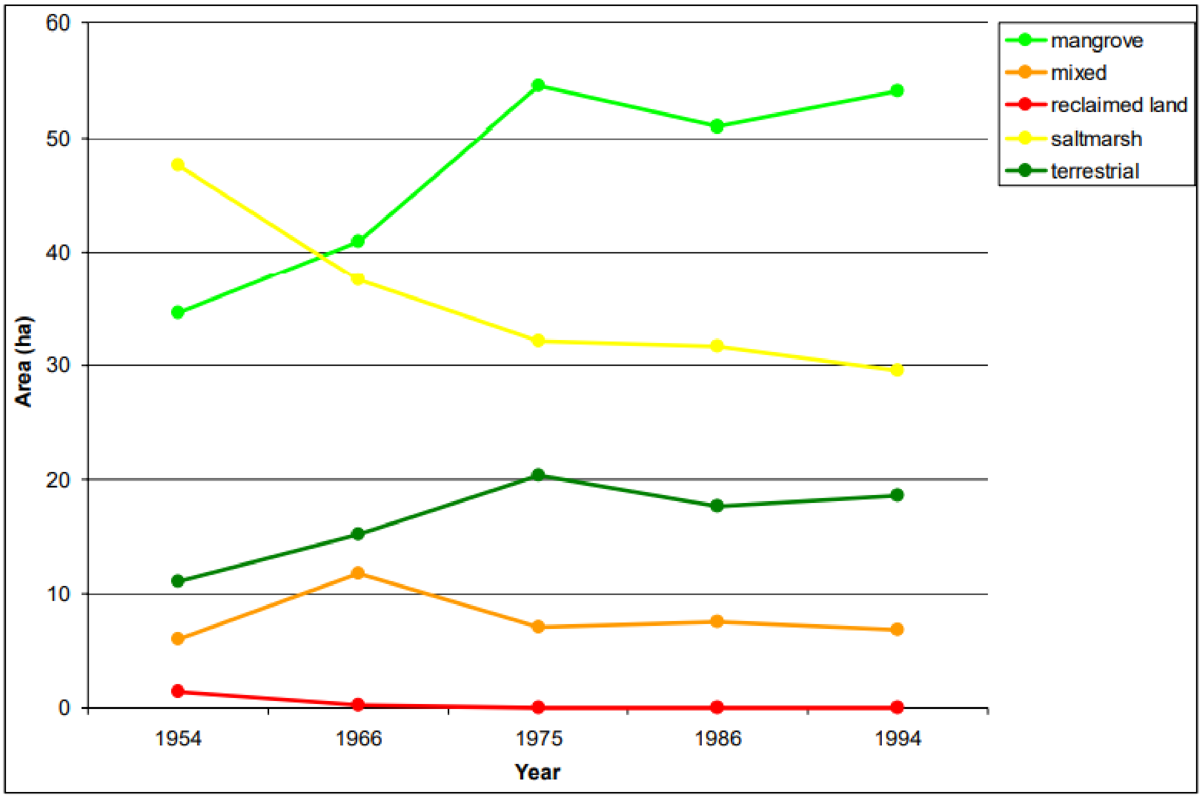


Figure 34. *Gross wetland habitat change at Courangra Point in the Hawkesbury River, 1954 to 1998. Reproduced from Wilton, 2002.*

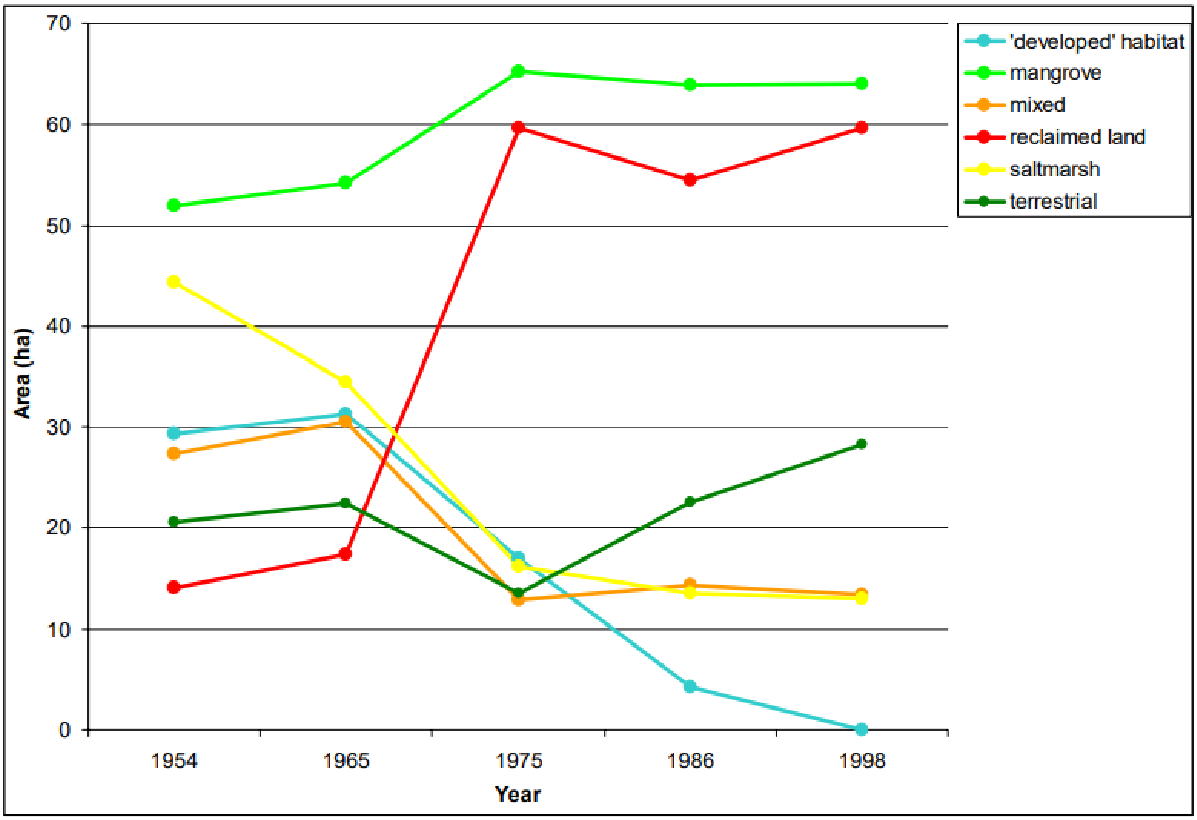


Figure 35. *Gross wetland habitat change at Pelican, Rileys and St Huberts Islands in Brisbane Water, 1954 to 1998. Reproduced from Wilton, 2002.*

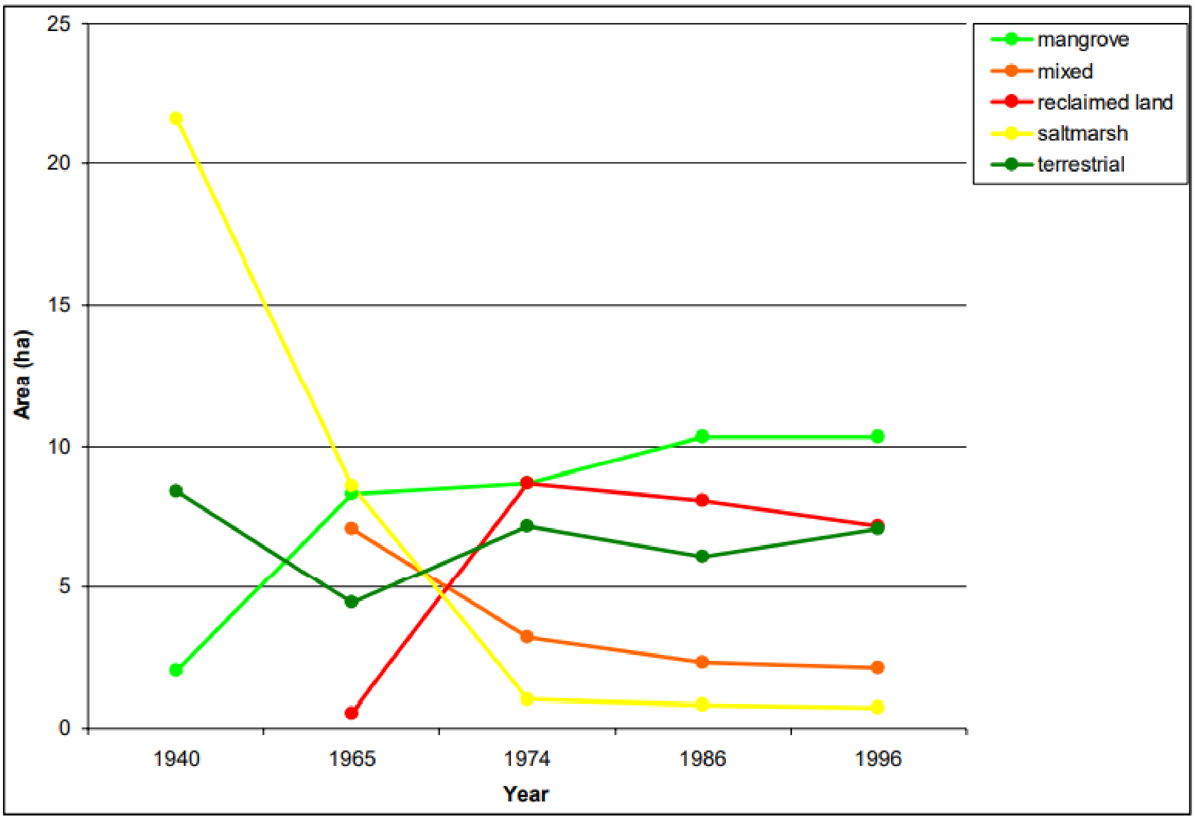


Figure 36. *Gross wetland habitat change at Careel Bay in Pittwater, 1954 to 1998. Reproduced from Wilton, 2002.*

Currently, many wetlands and the riparian edges of the Hawkesbury suffer from invasive flora and weeds that outcompete native species. There has been some indication that the restoration of more natural freshwater inflow regimes and disturbance events may be useful in restoring wetland flora (Howell et al., 1994b) and reducing invasive weed communities along the Hawkesbury (Howell and Benson, 2000b).

One of the recognised characteristics of the native vegetation of the Hawkesbury area is adaption to the low natural availability of phosphorus from the local substrate and soils, namely Hawkesbury Sandstone. With increased ecological disturbances and urbanisation in the catchment causing higher nutrient availability introduced or exotic species have or are becoming established throughout the Hawkesbury (King and Buckney, 2002). This is a particular problem regarding invasive weeds which outcompete native species throughout the catchment, but particularly in riparian areas. Invasive species can replace native species of flora but provide few of the same benefits e.g., habitats and food resources for native fauna or bank stability.

Examples of prominent invasive weeds in the HNRS include:

- False Bamboo
- Lantana
- Salvinia (aquatic species)
- Water Hyacinth (aquatic species)
- *Asparagus* spp.,
- Spiny Rush, *Juncus acutus*,
- Bitou Bush & Bone Seed,
- Privet (small and large leaved) and
- Camphor Laurel

Further information on invasive weeds in the Hawkesbury can be found in Common Riverbank Weeds of the Hawkesbury River, Lower Nepean River and Tributaries (Hawkesbury-Nepean Catchment Management Authority, 2007).

Many studies have assessed the present-day local vegetation and its degradation since the late 18th century. While these works are not a comprehensive and up-to-date spatial assessment of the vegetation of the area, collectively they present an understanding of the extensive scale of land clearing and change in the vegetation of the HNRS. Principal among these are the numerous works by Benson and Howell (Benson and Howell, 1990a; Benson and Howell 1990b; Benson and Howell 1994; Benson et al. 1996; Howell and Benson 2000a).

4.1.2 Fauna

Due to the extensive range of aquatic and riparian habitats across the HNRS combined with the large coverage of protected areas in the catchment, a diverse fauna that exist within the catchment and estuary. Estimates indicate that there are over 1,100 native vertebrates (inclusive of 160 fish species) and over 1,700 invertebrates (Gerhke and Harris, 1996; DLWC, 1997; WBM, 2003).

The majority of fish in the HNRS estuary are dependent upon access to multiple estuarine functional zones. While some fish species live only in freshwater, all estuarine, freshwater or marine respond to or require freshwater flows for part of their life cycle. The fish of the HNRS can be classified into six groups based on their presence within the different zones of the system and their use of the estuary and their migration patterns, all of which effect their freshwater flow requirements (Lloyd et al., 2012) (Figure 37).

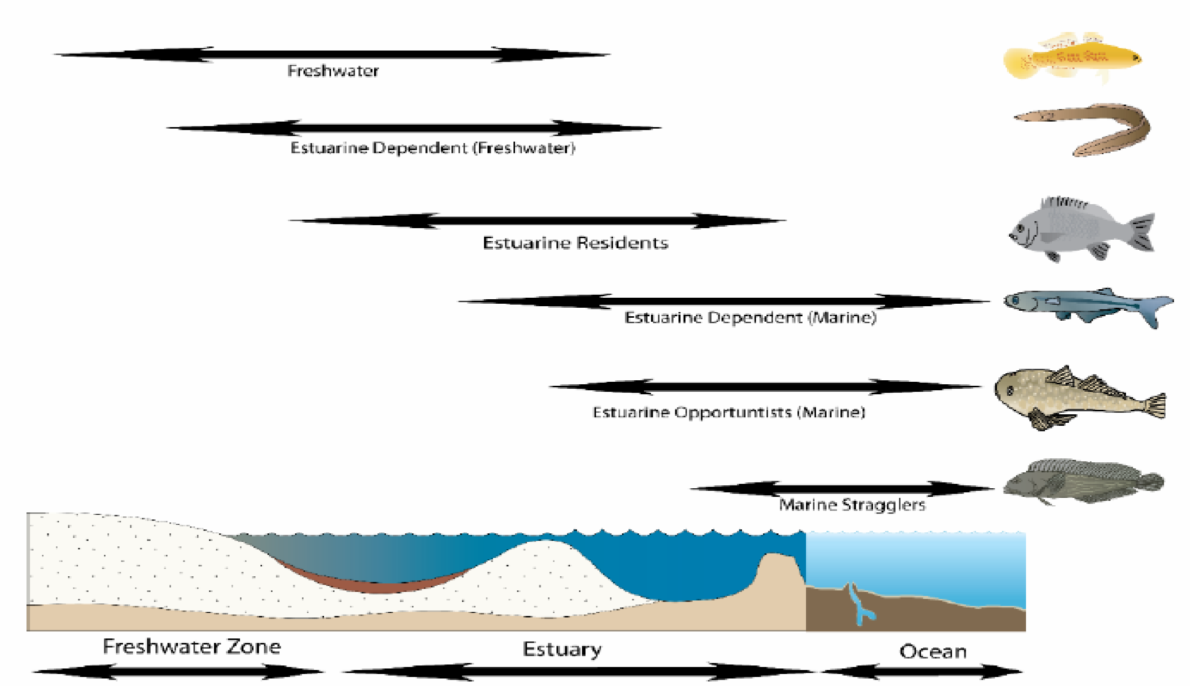


Figure 37. *Fish groups within the HNRS based on Lloyd et al. (2012) classification.*

Resident freshwater fish will be most common in the Freshwater Tidal Pool zone and further upstream, whereas the Estuarine Dependant (Freshwater) are found in both estuarine and freshwater reaches, often spending long periods in freshwaters, and the Estuarine Residents species are largely restricted to the Upper, Middle and Lower Estuary zones. The Estuarine Dependant (Marine), Estuarine Opportunists (Marine) and Marine Stragglers are less dependent on freshwater inflows for their life cycles.

In response to urbanisation, many of the smaller bush birds have declined in the Hawkesbury-Nepean and greater Sydney Region (Recher, 2010). Other species, mainly large birds, have increased in abundance. There have been increases in abundance of species including the Sulphur-crested Cockatoo *Cacatua galerita*, Galah *Eolophus roseicapilla*, Rainbow Lorikeet and Crimson Rosella *Platycercus legans,* Red-rumped Parrot *Psephotus haematonotus*, King Parrot *Alisterus capularis* and Little Corella C. *sanguinea*, Noisy Miner, K*oel Eudynamys orientalis*, Channel-billed Cuckoo *Scythrops novaehollandiae*, Pied Currawong, White Ibis *Threskiornis molucca,* Crested Pigeon *Ocyphaps ophotes* and Common Myna. With the exception of the Myna, all increasers are native to Australia and were present in Sydney prior to the 1950s (Recher, 2010).

Oysters are a commercially important fishery with in the HRNS with over 450 individual aquaculture leases covering approximately 600 hectares (Figure 38). There are three commonly found types of oysters in the HNRS – Sydney Rock Oyster (*Saccostrea glomerata),* Pacific Oyster (*Crassostrea gigas),* and Flat Oysters (from the Ostrediae and Pteriidae families) – with Sydney Rock and Pacific the most commercially significant types. The oyster industry in the HNRS suffered a near total collapse from 2004 – 2006 following the devastation wrought by QX disease (Butt and Raftos, 2007). QX is a parasitic infection with the protozoan parasite *Marteilia sydneyi* infecting oysters via an intermediate host, a polychaete worm *Nephtys australiensis.*

Figure 38. *Aquaculture leases in the HNRS (DPI Fisheries, 2021)*

Table 15 lists some of the typical and socially important species found within the estuary, although this list is far from exhaustive.

Table 15. Typical and socially valued fauna species of the Hawkesbury estuary.

Fauna group	Functional zone	Typical or Socially Important Species
Freshwater Fish	Freshwater Tidal Pool and Upper Estuary	Australian Smelt (*Retropinna semoni)* Gudgeon spp. (Family Eleotrididae) Freshwater Mullet (*Myxus petard)* Freshwater Herring (*Potamalosa richmondia)*
Estuarine/Marine Fish	Middle and Lower Estuary.	Dusky Flathead (*Platycephalus fuscus)* Yellowfin Bream (*Acanthopagrus australis)* Tailor (*Pomatomus saltatrix)* Sand whiting (*Silago* spp.) Mulloway (*Argyrosomus hololepidotus)*
Transitional Species	As the name suggest, these can be found throughout the HNRS at various life stages	Australian Bass (*Macquaria (Percalates) novemaculeata)* Eels (*Anguilla* spp.)
Invertebrates	Middle and Lower Estuary	Oysters (Sydney Rock, *Saccostrea glomerata;* Pacific Oyster (*Crassostrea gigas)* School Prawns (*Penaeid* spp.) Mud Crabs (*Scylla serrata)*
Birds	All zones	Silver Gulls (Seagulls, *Chroicocephalus novaehollandiae*) Cormorants and Egrets Pelicans (*Pelecanus conspicillatus)*
Reptiles	Contributing Catchment, Freshwater Tidal Pools, and Upper Estuary. Other species not listed can be found in other zones.	Green Turtles (*Chelonia mydas)* Green and Golden Bell Frog (*Ranoidea aurea)*
Marine mammals	Lower Estuary and in the marine zone.	Fur Seals (*A. pusillus doriferus)* Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) Seasonal Whale sightings (mainly Humpback Whales, *Megaptera novaeangliae)*

There are numerous invasive fauna present within the HNRS and its surrounding catchment that can influence some of the ecological processes surrounding the estuary. These include:

- Carp *(Cyprinidae* spp.*) and* Mosquito Fish (*Gambusia* spp.) in freshwater reaches of the study area (Gehrke et al., 1999; Graham et al., 2005).
- Cats, foxes, dogs and rabbits into national parks (Recher, 2010)
- Mallard ducks

Because most of the introduced fish species are freshwater and cannot tolerate or breed in high salinities, the impact of invasive faunal species is low in the more saline estuary zones, with most invasive fish being present in upstream freshwater reaches (NSW Department of Primary Industries, 2006) and the terrestrial species having limited indirect impacts on the estuary (e.g., erosion and sediment transport can be increased slightly in tributaries by riparian rabbit burrows). Domestic farm animals are also present in agricultural areas of the HNRS catchment and impact the estuary by contributing excess nutrients from their manure (Burkholder et al., 2007) and by contributing to bank erosion with agricultural runoff contributing approximately 25% of nitrate and 40-50% of phosphorous loads to the system (Pinto et al,, 2013).

4.1.3 Listed and protected species and communities

With extensive urban and agricultural pressures throughout the HNRS and the wider greater Australian eastern seaboard many ecological communities and native species are listed as endangered or protected under the *Environment Protection and Biodiversity Act (1999) (Cth), NSW Biodiversity Conservation Act 2016, and Fisheries Management Act 1994.* There are also international agreements that protect migratory birds and their habitat including the Chinese Australian Migratory Bird Agreement (CAMBA), Japanese Australian Migratory Bird Agreement (JAMBA) and Republic of Korea Australian Migratory Bird Agreement (ROKAMBA).

A high level assessment of listed and protected species recorded in the HNRS area was undertaken using the NSW BioNet Atlas. A summary of protected flora and fauna under NSW and Commonwealth legislation recorded in the HNRS are provided in Table 16 and Table 17, respectively.

Table 16. Summary of listed and protected species under NSW legislation recorded in HNRS

Class	Total # of NSW protected species recorded in HNRS	NSW Biodiversity Conservation Act 2016					NSW National Parks & Wildlife Act 1974
		Critically Endangered	Endangered	Endangered Population	Vulnerable	Extinct	Protected
Amphibia	52		4		3		52
Aves	429	2	12	1	49	1	429
Flora	594	15	70	7	78	2	451
Gastropoda	2		2				
Insecta	3		3				
Mammalia	114		5	2	23	1	114
Reptilia	108		4		5		108
Total	1302	17	100	10	158	4	1154

Table 17. Summary of listed and protected species under Commonwealth legislation and international agreements recorded in HNRS

Class	Total # of C'th protected species recorded in HNRS	Commonwealth Environmental Protection & Biodiversity Conservation Act 1999				International Agreements		
		Critically Endangered	Endangered	Vulnerable	Extinct	CAMBA	JAMBA	ROKAMBA
Amphibia	6		2	4				
Aves	55	4	11	6		33	38	34
Flora	116	10	36	67	3			
Gastropoda	1		1					
Insecta	1			1				
Mammalia	15		4	10	1			
Reptilia	8		3	5				
Total	202	14	57	93	4	33	38	34

Floral and ecological communities may be threatened throughout the estuary and catchment by a combination of land clearing, stock grazing, riparian erosion, invasive species competition and recreational activities such as boating (Recher et al., 1993; Creese et al., 2009; Burgin and Hardiman, 2011). Importantly many terrestrial species are already protected by the large coverage of national parks surrounding the estuary.

A high-level assessment of threatened ecological communities (TECs) in the Hawkesbury estuary was undertaken using the “Protected Matters Search Tool”. Identified TECs for the estuary and its river dependant environments include:

- *Posidonia australis* seagrass meadows of the Manning-Hawkesbury bioregion
- Subtropical and temperate coastal saltmarsh
- Swamp Oak floodplain Forest of NSW North Coast, Sydney Basin and SE Corner Bioregions
- Coastal Upland Swamps in the Sydney Basin Bioregion
- River-flat eucalypt forest on coastal floodplains of southern NSW and Victoria.

A high-level assessment of threatened areas also returned several terrestrial TECs that, though they are indirectly related to the river and estuary, must be protected to ensure its continued health and function. These include:

- Littoral Rainforest and Coastal Vine Thickets of Eastern Australia,
- Shale Sandstone Transition Forest of the Sydney Basin Bioregion,
- Subtropical and Temperate Coastal Saltmarsh,
- Blue Gum High Forest of the Sydney Basin Bioregion,
- Castlereagh Scribbly Gum and Agnes Banks Woodlands of the Sydney Basin Bioregion,
- Coastal Swamp Oak Forest of New South Wales and South East Queensland ecological community,
- Turpentine-Ironbark Forest of the Sydney Basin Bioregion,
- Duffys Forest Ecological Community in the Sydney Basin Bioregion,
- Western Sydney Dry Rainforest and Moist Woodland on Shale.

4.2 Primary and secondary productivity and food webs

Estuarine ecosystems are extremely productive compared with many other ecosystems (e.g., deserts, rivers and the open ocean) producing large amounts of biomass (e.g., plants and animals) (Day et al., 2012). Factors that contribute to increased productivity of estuaries include their transitional nature, high habitat heterogeneity and naturally high availability of nutrients as a receiving system of coastal catchments (Savage et al., 2012). This productivity can be broken into two types:

- Primary productivity (producers) – Production by autotrophs, mostly plants be it from algae or vascular plants, using photosynthesis (less commonly chemosynthesis) to convert CO_2 into living biomass.
- Secondary productivity (consumers) – Production by heterotrophs, such as bacteria, fungi and animals, that feed on or decompose primary production for their carbon and energy needs.

Estuarine food webs generally rely on high primary production to sustain high levels of secondary productivity (Day et al., 2012). A simplified version of an estuarine food web is provided in Figure 39. The main primary producers of the system are phytoplankton, seagrass, saltmarsh, mangroves and benthic microalgae on mudflats. This material can be produced *in situ* (autochthonous) or imported from other areas such as on adjacent floodplains and washed into the estuarine system (allochthonous). In some cases, the material is consumed while still alive (herbivory) but in other cases it enters the food web only after decomposition by microbes such as fungi and bacteria (detritivory). For example, many phytoplankton species can be consumed directly by smaller consumers such as zooplankton, crabs and even some small juvenile fish. Some seagrasses are also directly consumed by herbivores such as swans. In contrast, seagrasses, saltmarsh and mangroves generally needs to be broken down ('conditioned') first by microbes before they can be consumed by the rest of the food web (Mann, 1988).

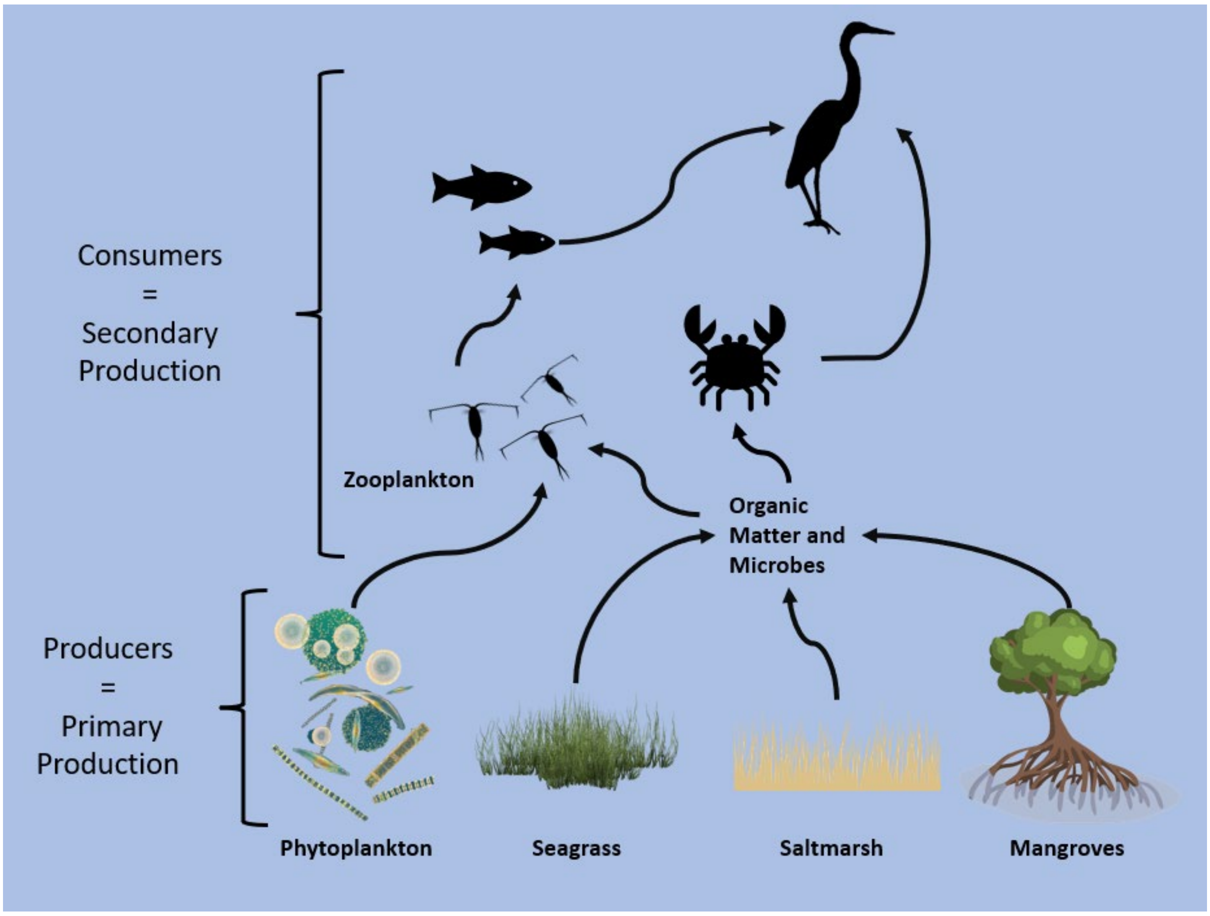


Figure 39. *Simplified diagram of an estuarine food web*

While the above figure represents a classical and simplified estuarine food web, the reality is that estuarine food webs are far more complex. For example, some consumers feed directly upon primary producers. Figure 40 (below) represents the food web of Puget Sound in the Pacific-Northwest of the USA and was constructed as part of a mass balance modelling project to evaluate food web structure and complexity to aid in ecosystem-based management (Harvey et al., 2010). To this point no similar whole ecosystem mass balance studies, quantifying the relative primary and secondary production of a system and its keystone species, has been carried out in the HNRS estuary. There are however various studies exploring food web interactions in Brisbane Water which highlight the importance of periodic inundation of saltmarsh habitats for providing nutrients and energy into the HNRS food web (Alderson et al., 2013; McPhee et al., 2015; Hewitt et al., 2020).

In terms of secondary productivity of the HNRS estuary, it supports one of the top commercial fin fisheries in NSW (annual catches worth $1.3 million) and the second most productive school prawn fishery in NSW (annual catches worth ~ $1.1 million) (Water Technology, 2020). Formerly, it was also capable of supporting a large oyster fishery before the onset of oyster specific diseases (e.g., *Qx in 2003/04 and POMS in 2013*) which have substantially reduced their production.

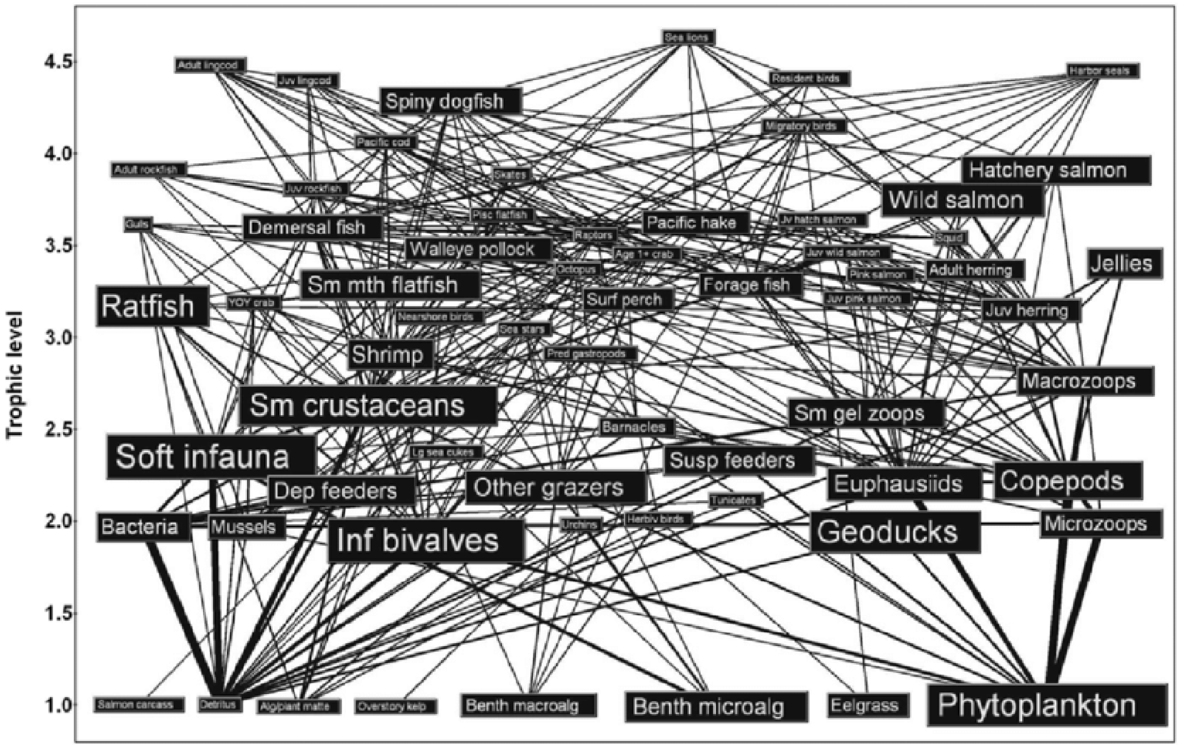


Figure 40. *Estuarine food web of the Puget Sound* (Harvey et al., 2010)

Multiple studies within the area have shown the benefits of saltmarsh and mangrove habitats to the productivity of wetland birds and fish. These estuarine macrophytes release important organic matter and zooplankton resources for juvenile fish and school prawns ((Mazumder et al., 2011; McPhee et al., 2015; Saintilan and Mazumder, 2017; Hewitt et al., 2020) and provide important nesting habitats and food resources for birds (Hughes 2004) and threatened species of bats (Gonsalves et al., 2012; Gonsalves et al., 2013). These estuarine habitats are also highly utilised by fish which opportunistically swim into inundated saltmarsh during high tides (Mazmuder et al., 2006).

Previous studies have also proposed that large inputs of terrestrial material to the estuary from coastal wetland forest may contribute to estuarine productivity under flood conditions (Clarke and Allaway, 1996). Likewise, the productivity of certain estuarine related fin fisheries (e.g., flathead and whiting) has also increased during flood periods either as a function of increased resources transported by floods or increased habitat availability (Gillson et al., 2012).

Considerable effort has been put into understanding the productivity of mangroves and saltmarsh in the HNRS estuary. This is partially driven by the carbon sequestration opportunities that arise when tidal flows are re-introduced to degraded wetlands, prompting the resurgence of highly productive saltmarsh and mangrove communities (Saintilan, 1997; Saintilan et al., 2013; Lamont et al., 2020). Recent development of a blue carbon accounting model uses Australian data to estimate abatement from carbon and greenhouse gas sources and sinks arising from coastal wetland restoration (Lovelock et al., 2022). The method credits carbon stored and emissions avoided through the introduction of tidal flow to help establish coastal wetland ecosystems. The Carbon Credits (Carbon Farming Initiative – Tidal Restoration of Blue Carbon Ecosystems) Methodology Determination 2022 came into effect on 19 January 2022.

4.3 Nutrient dynamics and cycling

Naturally high nutrient inputs are fundamental to the productivity of estuaries. As the most downstream part of coastal catchments, estuaries receive high inputs of nutrients, most importantly nitrogen and phosphorus which are critical to primary productivity and photosynthetic processes.

Nutrient dynamics in estuaries usually follow a standard process which is described below:

- Catchment input – Particulate and dissolved forms of nitrogen and phosphorous enter the Upper Estuary from point (direct) and non-point (diffuse) sources within the Contributing Catchment. These resources are generally transported downstream by freshwater flows, with inputs of nutrients usually increasing with freshwater discharge.
- Exchange with floodplain – Some nutrients can be deposited onto the flood plain and into adjacent wetlands during flow events with biological uptake of nutrients also occurring along the edges of the river and estuary.
- Exchange with tidal habitats – Intertidal habitats such as mangroves and saltmarsh in the Middle and Lower Estuary store large amounts of nutrients through rapid biological uptake due to high productivity by their standing stock of vegetation and use by high microbial and benthic processing. Particulate forms of nutrients can be exported from these areas when organic matter is resuspended during high tides.
- Trophic relay – nutrients brought in from other areas via organisms entering the system (fish bring in nutrients form the ocean through migration).
- Ocean inputs – especially important for silica, which is often a limiting nutrient for diatoms.
- Internal recycling – nutrients already in the system are made available by sediment resuspension or bioturbation.
- Urban and agricultural inputs – Significantly high inputs of nutrients (namely nitrogen and phosphorous) enter the catchment from urban and agricultural landscapes through sewerage treatment plants and the use of fertilisers and household and industrial products. These nutrients enter the estuary in high concentrations, particularly during rainfall events where flows move quickly across impervious surfaces.
- Stratification – Nutrient stratification is the process where the water column becomes stratified with high concentrations of nutrients trapped at the bottom of the water column. When stratification breaks down these high concentrations of nutrients can rise to the surface and cause algal blooms. Nutrient stratification presents a significant issue in the HNRS in the upper reaches of Berowra and Cowan creeks where there is little freshwater inflow to mix the water.
- Algal production and export to coast – Nutrients are exported to the Lower Estuary and coastal zones where marine phytoplankton and seagrasses have a greater ability for nutrient uptake and fixation and subsequently biomass production due to lower turbidity in these areas. Phytoplankton production in coastal zones and the marine zones of estuaries can often increase after increased periods of freshwater discharge and export of nutrients to the estuary.

If nutrient inputs are substantially increased during low flow periods due to changes in catchment land use (e.g., agriculture) or flushing of the estuary is reduced through reduced freshwater inputs, this can lead to eutrophication of the estuary (See Section 3.6). Eutrophication is the unacceptable enrichment with nutrients of an aquatic system with the concomitant increase in biomass of undesirable plants, especially phytoplankton but potentially also benthic macroalgae and rooted angiosperms. In most cases, it is the increase in phytoplankton biomass that is of most concern, especially if those algae are toxic. Algal bloom cause ecological problems in estuaries as:

- High densities of phytoplankton due to high nutrients decrease light penetration through the water column, thus affecting the growth of submerged angiosperms such as seagrasses.
- Dead algal cells from the bloom are processed by microbes and lead to….

- Microbial breakdown of organic matter consumes oxygen from the water column, leading to anoxia and, potentially, to fish kills
- Some species of algae, including most commonly cyanobacteria and dinoflagellates, may produce toxins that are harmful to humans, livestock or pets.

A conceptual comparison of the effect of eutrophication on estuaries is shown in Figure 41.

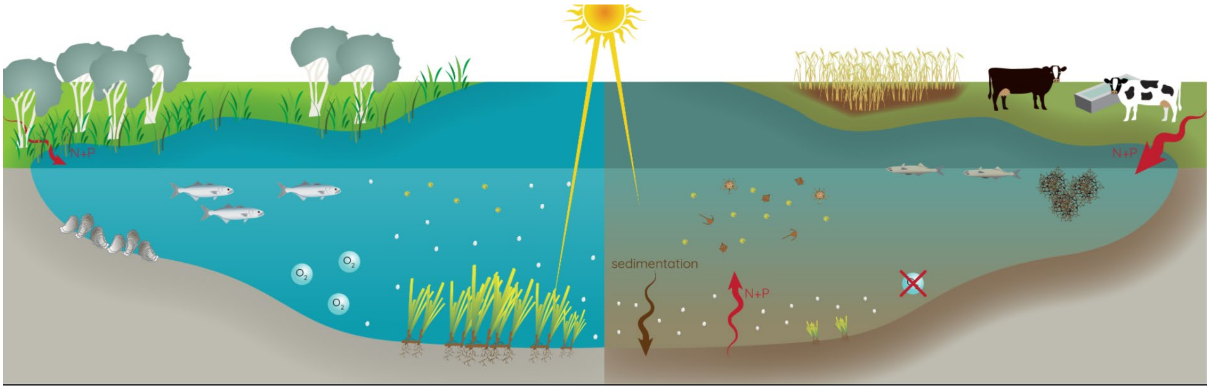


Figure 41. *Conceptual figure of the effect of eutrophication of estuaries from the Department of Water and Environmental Regulation, WA. An interactive version of this diagram is available through the DWER, WA Website* (Department of Water and Environmental Regulation, 2022)

The Hawkesbury River estuary has a long-known history of nutrient pollution (Wolanski and Collis, 1976) with notable increases in nutrient inputs to the system since the 1970s (Collis, 2014). This is largely due to its proximity to the Sydney region and the accompanying sewage treatment plans (Rush, 2003), and urban and agricultural practices that take place on the floodplain near the Upper and Middle Estuary. The condition of the estuary in terms of its eutrophication has become significantly degraded since the 1970s (Collis, 2014).

Concentrated nutrient inputs from both point source inputs and diffuse sources in the Contributing Catchment during rainfall events have a significant influence on the phytoplankton, benthic macroinvertebrates and overall water quality within the estuary (Pinto et al., 2014b; Larsson et al., 2017). Long term monitoring (over the last 30 years) has identified that the Hawkesbury is defined by “cleaner” upper (beyond the tidal limit) and lower (Middle and Lower Estuary functional zone) sections but has higher nutrient and pollutant concentrations within the Upper Estuary zone, approximately 100 kms between Yarramundi and Wisemans Ferry (Boon, 2017). The major cause of this nutrient pollution is generally attributed the nutrient rich wastewater inputs of sewerage treatment plants across the Hawkesbury Nepean floodplain to the system (Pinto et al., 2013).

Recent research has indicated that the threat of harmful algal blooms (HABs) should be of increasing concern in the Hawkesbury with dinoflagellate and diatom blooms driven by nutrient inputs and low salinities in Freshwater Tidal Pool and Upper Estuary zones, highlighting how inputs of nutrients by freshwater discharge may trigger bloom events (Ajani et al., 2020). Similarly, the discovery of a new potentially harmful diatom species for the first time in the estuary indicates the ecological disturbance in the estuary, with high nutrient concentrations allowing an invasive species to proliferate in the estuary (Ajani et al. 2018).

Some areas in Brisbane Water can also be subject to eutrophication in the areas near urbanised catchments. Therefore, the effects of nutrient enrichment on seagrasses and algal dynamics can be assumed to be more likely to occur in the upper reaches of the estuary in proximity to Erina and Narara Creeks and/or following wet weather events. In addition, these ecological impacts are likely to be more noticeable after more intense rainfall events.

4.4 Ecological connectivity

The connectivity of the estuaries to their upstream habitats and along their length (longitudinal connectivity) and to their adjacent terrestrial habitats such as wetlands and intertidal areas (lateral connectivity) is fundamental to their ecological health and productivity (Figure 42).

Longitudinal connectivity is crucial to the movement of organisms through the system such as diadromous fish which as part of their life history may need to move from freshwater habitats to estuarine or marine habitats (Duarte et al., 2021). Longitudinal connectivity is also important for the transfer of estuarine resources including sediments, nutrients and organic matter. Longitudinal connectivity can be interrupted by structures such as dams and weirs and has been shown to disrupt estuarine ecology and productivity (Hall et al., 2011; Seguardo et al., 2014.

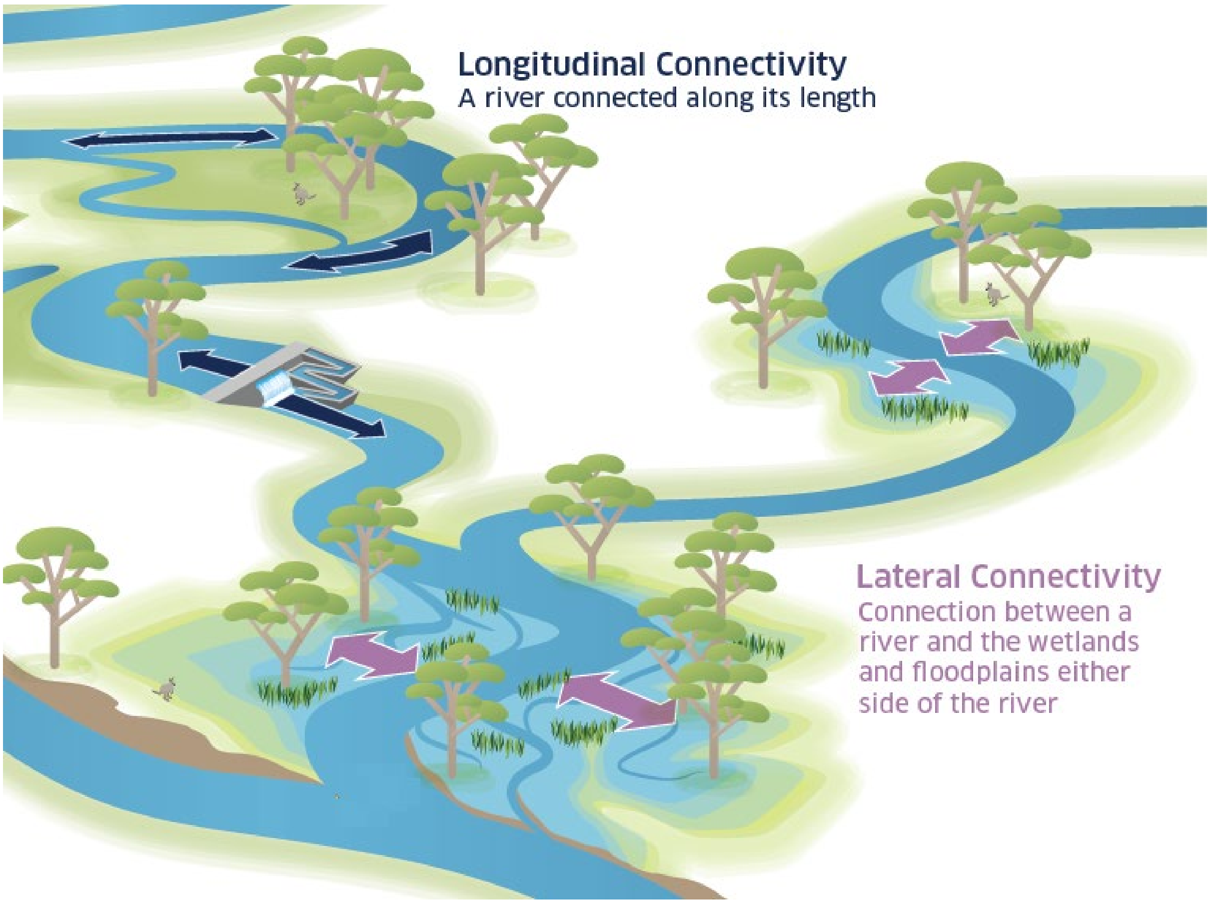


Figure 42. *Longitudinal and lateral connectivity within a riverine/estuarine system* (CEWO Flow-MER, 2022)

Lateral connectivity between estuaries and their adjacent wetlands, floodplains, intertidal and littoral habitats is also essential to the natural ecological processes of estuaries. Lateral connectivity in estuaries can be established by larger freshwater inflow events connecting the estuary to floodplains, back channels and wetlands or through tidal processes which can connect the estuary with intertidal mangrove, saltmarsh and mudflat habitats on a diurnal basis. The connection of these areas with the estuary can allow for the transfer of resources like organic matter and nutrients between the landscape and the estuary. Lateral connectivity can also provide areas for shelter or foraging for estuarine organisms and disperse larvae and seeds (Saintilan and Mazumder, 2017). In this way lateral connectivity can contribute to the productivity of estuaries and can aid in the recruitment of fish and bird populations as well as the recovery of floodplain vegetation.

4.4.1 Longitudinal connectivity

Within the Hawkesbury River estuary itself, longitudinal connectivity is largely functional. From Yarramundi to the ocean the estuary is unimpeded by physical structures such as dam, weirs or barrages. This allows the successful migration of diadromous fish species and motile organisms, like penaeid prawns, to estuarine habitats and breeding grounds as well as allowing estuarine species to utilise coastal and marine habitats. Likewise, major tributaries of the system such as the Macdonald, Colo and Grose Rivers are all largely unregulated (with the Colo and Grose listed as Wild Rivers) and are longitudinally connected from their head waters to the estuary. The only exceptions to these unregulated estuarine tributaries are Mangrove Creek and

Mooney Mooney Creek with their respective upstream storages (Figure 18– previously displayed) and some smaller storages such as Pymble Gold Club Dam.

In contrast, longitudinal connectivity is disrupted frequently upstream of Yarramundi with many dams, weirs and road crossings present. The major water storage structures and weirs have been documented in Section 3.3. Structures such as causeways, pipes and culverts, can prevent fish passage by creating a physical blockage, a hydrological barrier, or by forming artificial conditions that act as behavioural barriers to fish (NSW Department of Primary Industries, 2006). In total there are 41 diadromous species in the Hawkesbury, 19 of which require access to estuarine waters (Gerhke and Harris, 1996) with many suffering population declines due to restricted habitat access (Gehrke et al., 1999).

The installation of 10 new vertical slot fishway systems between Penrith and Douglas Park from 2009 - 2010 has successfully increased the longitudinal connectivity of the river system expanding the distribution of several species, including the sea mullet and the freshwater mullet which require access to the lower reaches of the Hawkesbury River estuary as part of their life cycle (Rourke et al., 2018). It is still too early to tell how effective the fishways have been in providing longitudinal connectivity for other species that require access to the estuary such as Australian Bass as populations may require a long time to recover. Consistent monitoring is needed to ascertain the effectiveness of these fishways (Rourke et al. 2018).

Longitudinal connectivity has also been disrupted by low freshwater discharge making shallow riffle habitats (e.g., Bishops Point) along a 20 km stretch between Yarramundi (the start of the estuary) and Penrith Weir difficult for fish to navigate. Research on Australian Bass, an endemic species that spawns in the estuary, has indicated that increasing flow rates in this region from 500 ML/Day to >1,000 ML/Day allows effective downstream migration for adults (Reinfelds et al., 2020). The same study also showed that juvenile Australian Bass required a flow between 100 – 250 ML/day for their upstream migration to freshwater habitats as flows greater than 250 ML/day inhibited their swimming ability through these riffle habitats. Further work is required to ascertain flow rate requirements for the migration of other diadromous species which rely on longitudinal connectivity to the estuary.

The longitudinal connectivity within Brisbane Water estuary is generally intact, but there are small dams within the Narara Creek tributary that disrupt connectivity from the Upper Estuary type zones of this system. There are no significant structures in Pittwater that disrupt longitudinal connectivity.

4.4.2 Lateral connectivity

Lateral connectivity in an estuary is a function of two opposing forces. First, tidal inundation results in the periodic submergence of low-lying land closest to the waterbody (Boon et al., 2016). Mangroves are typically inundated twice daily as tides in the HNRS are semi-diurnal. More elevated land is submerged only on the highest tides (e.g., spring tides and the HAT), including typically saltmarshes, and the most elevated land, often vegetated with woody taxa such as paperbarks and she-oaks, only by exceptional events such as storm surges. Second, variations in freshwater flows coming down the river result in a mosaic of floodplain inundation regimes, varying according to discharge, distance from the ocean and elevation. A complex pattern of inundation with seawater and freshwater results, with obvious impacts on plant distributions and faunal habitats.

There are two major aspects which limit the lateral connectivity between the river/estuary and its adjacent habitats in the HNRS including in Brisbane Water and Pittwater. These are:

- **physical constraints on flow** – including structures such as causeways, and various flood and erosion mitigation works, seawalls, levees and transport links that incidentally modify the flow of water though that may not be their intended design.
- **reductions in freshwater inflow** – through river regulation.

This reduction in lateral connectivity and inundation of adjacent environments has been exacerbated by floodplain development reducing the coverage of wetlands on the floodplain with which the estuarine waters can connect (Burgin et al., 2016). This loss of connectivity with the floodplain is expected to have impacts on the productivity of both the floodplain and the estuary with reduced energy, nutrient and sediment exchange between these habitats. While environmental flows are in place for the Hawkesbury River and its main downstream regulatory structures Warragamba Dam and Penrith Weir, these flows are unlikely to foster ecological connections laterally with the catchment due to the low discharge coming through them (Warner, 2014).

The importance of adjacent tidal wetlands, mangroves and saltmarsh within the estuary has been mentioned in the discussion on food webs in section 4.2, highlighting the importance of these areas to the productivity of estuarine species.

An overall estimate of the value of coastal wetlands to the HNRS estuary and its fisheries has not yet been conducted but could provide information about the importance of these habitats to the estuary and the need for their protection via enhancement of lateral connectivity (Abrantes et al., 2019).

4.5 Freshwater inflows and flow variability

Freshwater inflows are important in sustaining ecological processes in estuaries with the discharge of freshwater from rivers providing important resources and functions for estuaries (Chilton et al., 2021). In estuaries (including the Hawkesbury River, Brisbane Water and Pittwater) the variability of freshwater inflows, in terms of the quantity, timing and quality of inflow (also known as a systems hydrology or flow regime (see Section3.3)), is an important force governing the biogeochemical nature of estuaries (Alber, 2002). Variations in freshwater inflows regulate the ecology of estuarine systems by changing the physical conditions of estuaries depending on the amount of water discharged, subsequently altering the biological production and distribution of some estuarine communities (Figure 43).

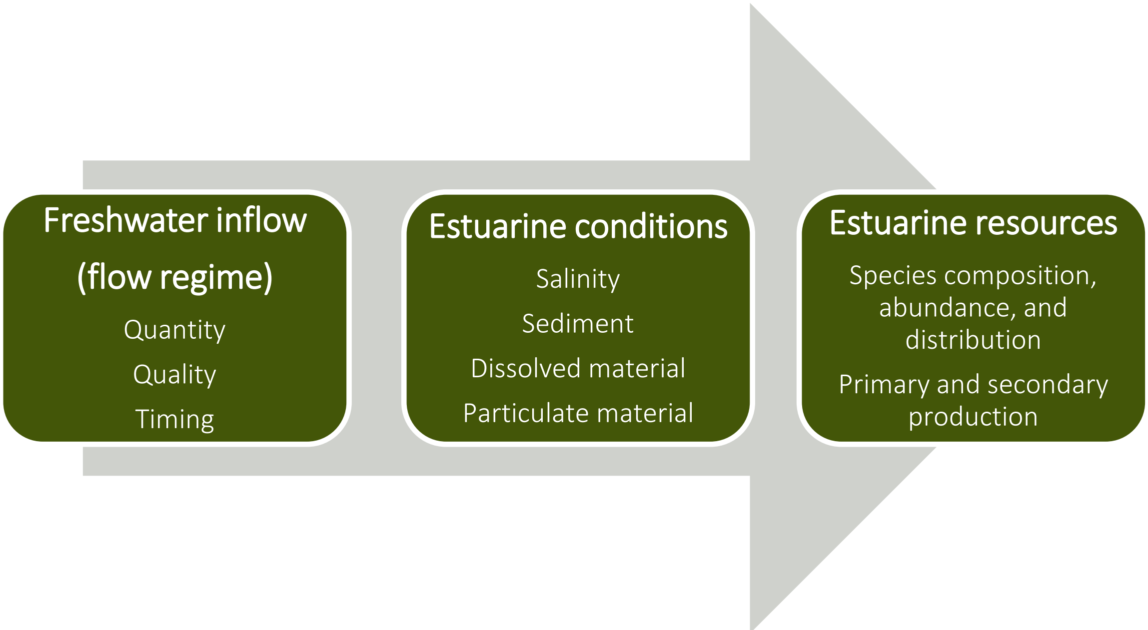


Figure 43. *Diagram showing the relationship of freshwater inflows to estuarine conditions and ecological processes. (Adapted from Alber, 2002), Freshwater inflows and flow regimes influence estuarine conditions and in turn estuarine resources.*

The estuarine ecology of the HNRS has evolved around its natural flow regime, with inflows performing important functions that characterise the ecology of the system. Examples of how freshwater inflows can influence estuarine habitats and species are include in Table 18.

Table 18. Ecological functions of various freshwater flow components important in maintaining ecological structure and function in aquatic systems (Drinkwater and Frank, 1994; Gillanders and Kingsford, 2002; Gawne et al., 2020).

Flow component	Characteristics	Ecological functions
Cease-to-flow	No surface flow (but water may remain in the thalweg, as a non-flowing 'chain of ponds' system)	• Provides major ecological disturbance • Sediment drying
Base flow	Minimum continuous flow in channel, covering a portion of the stream bed	• Volumetric provision of aquatic habitat for obligate aquatic organisms (e.g., fish) • Provides saturated habitat for macroinvertebrates • Maintains longitudinal connectivity along the channel for movement of biota, detritus and inorganic substances • Provides conditions for in-stream and fringing vegetation to flourish • Maintains soil moisture for shallow rooted plants near the flow path and deep-rooted plants within a wider range of the channel • Prevents colonisation of stream bed by terrestrial vegetation
Freshes	Periodic increases in flow, often of relatively short duration, covering the entirety of the stream bed and various distances (depths) up the bank	• Provides minor ecological disturbance • Provides additional (lateral) saturated habitat for macroinvertebrates • Maintains and expands longitudinal connectivity along the channel for movement of biota, detritus and inorganic substances • Biological triggers (e.g., cues for fish movement or breeding) • Maintains vertical plant zonation along benches and levees • Dispersal of biota • Enhances plant recruitment • Prevents terrestrialisation of stream bed • Recharge soil moisture levels at higher elevations up the bank to facilitate plant growth, particularly in dry years • Moves organic matter from benches into stream, to support food-web structure
High flows	Flows that connect most habitats in the channel with water of various depths and velocities, but less than bankfull	• Provides major ecological disturbance • Extended habitat connectivity • Biological triggers (e.g., fish breeding) • Maintains vertical plant zonation • Propagule dispersal • Enhances plant recruitment

		• Prevents terrestrialisation of stream bed • Promote dominance of riparian species on lower bank • Recharge soil moisture levels at higher elevations up the bank to facilitate plant growth, particularly in dry years • Movement of organic matter from benches into stream
Bankfull	High flows within the channel just reaching bank level, may engage with low-lying parts of the floodplain via flood runners, yielding a series of 'commence to flow' values for wetland inundation	• Provides major ecological disturbance • Maintains lateral connectivity with floodplain and low-lying wetlands (e.g., via flood runners) • Maintains geomorphological structure of stream bed and benches • Maintains sediment delivery to tidal wetlands
Overbank	Flows that overtop the bank and extend onto the floodplain, inundating all wetlands	• Provides major ecological disturbance • High-power geomorphological processes (e.g., channel formation, movement of gravel and cobbles, washing out of accumulated sediment from pools and other quiescent habitats) • Maintains lateral connectivity via overbank floodplain inundation and sediment delivery • Maintains inundated floodplain wetlands as aquatic refugia

Freshwater inflow and sediment deposition are essential to the formation of intertidal mangrove and saltmarsh habitats in the HNRS estuary. Research suggests that increased deposition of sediments in the Upper Estuary, due to anthropogenic changes to catchment land use and reduction in inflow frequency and magnitude, has led to the seaward expansion of mangrove habitats (Saintilan and Hashimoto, 1999) and potentially the transgression of mangroves into saltmarsh habitats, however other factors such as eustatic sea level rise have also contributed to this trend (Saintilan and Williams, 1999). Although an increase in mangrove coverage in the estuary may provide numerous benefits for the system – including improved carbon sequestration, improved intertidal habitat and an adaptive buffer to sea level rise – it is leading to the loss of saltmarsh habitat (Lamont et al., 2020). Decreases in saltmarsh coverage will likely have a significant ecological impact on ecosystem services and estuarine food webs due to their importance in providing energetic subsidies to multiple trophic levels, habitat to fauna and estuarine energetic cycling processes (Kelleway et al., 2017).

If natural flow regimes are disrupted by reducing freshwater discharge quantity and variability to the estuary this can result in its degradation through a breakdown in its ecological processes (Drinkwater and Frank., 1994; Gillanders and Kingsford, 2002; Chilton et al., 2021). However, the processes affected depends on whether freshwater inflows are reduced during high flow or low flow periods. The difference in potential negative impacts of inflow variation at different flow conditions is explained in Table 19.

Table 19. Summary of the potential negative impacts of inflow reduction or variation at low flow and medium-high flow conditions (adapted from Drinkwater and Frank, 1994; Gillanders and Kingsford, 2002; Chilton et al, 2021).

Possible impacts of inflow reduction and variation on estuaries processes	
At Low flow	At Medium-High Flows
• Decreased connectivity with freshwater ecosystems • Increased salinity and duration of high salinity periods in Upper Estuary • Increased risk of depleted oxygen at depth and stratification in Upper Estuary • Aggravation of pollution problems/increased water residence time • Reduced dispersal of eggs and larvae • Increased risk of invasive species • Reduced secondary productivity	• Reduced flushing of deeper sections of estuaries • Reduced connectivity to adjacent ecosystems (wetlands/floodplains) • Reduced inputs of organic material and nutrients • Decline of *Juncus kraussii* saltmarsh in the upper estuary

As previously discussed (Section 3.3), the Hawkesbury River estuary is heavily influenced by its highly variable flow regime which depends on localised weather patterns and regional climate drivers such as the El Niño / La Niña Southern Oscillation. It is also dominated by two major multi-decadal flow regimes (Warner, 2014); a flood dominated regime (FDR) where discharge to the river is high relative to its long-term average and a drought dominated regime (DDR) where discharge is reduced relative to its long-term average (Erskine and Warner, 1998). While the specific influence of these regimes is not known on the ecology of the estuary some general conclusions can be drawn (Table 20).

During FDRs and La Niña periods where greater rainfall results in greater discharge, the estuary may have a greater connectivity with the catchment and floodplains, an increased input of terrestrial resources and sediments, greater mixing of the water column, a lengthy salinity gradient and a change in biological communities with more freshwater and estuarine species present. This contrasts with the characteristics of the estuary during DDRs and El Niño periods where reduced rainfall and discharges result in reduced connectivity with the floodplain and catchment, a reduced input of terrestrial nutrients, organics and sediments, stratification of the water column in upstream areas where tidal processes have a reduced influence, a pronounced and short salinity gradient and greater amounts of marine transient and invasive species.

Table 20. Potential flow on effects and characteristics of the Hawkesbury River Estuary under the flood- and Drought-Dominated Regime proposed by (Warner, 2014)

Flood Dominated Regime and La Niña	Drought Dominated Regime and El Niño
• greater freshwater input • increased connectivity with the catchment, floodplain and wetlands • increased input of terrestrial nutrients and organics • reduced risk of stratification • flushing of sediment build up and pollutants • long saline gradient • more estuarine representative community	• reduced freshwater input • decreased floodplain and catchment connectivity • reduced natural input of nutrients and organics • increased risk of stratification • reduced flushing • short saline gradient

Ecological management of the Hawkesbury during the drought dominated regime presents numerous management issues due to the relative lack of inflows regulating the estuarine conditions (Table 20). However, due to the significant reduction of inflows by anthropogenic means, e.g., damming and regulation, these challenges can also be present during FDR when discharge is limited (e.g., a combination of FDR and El Niño).

Previous studies have linked increased freshwater inflows to the Hawkesbury estuary with the increased productivity of gillnet fisheries and catches of certain finfish species e.g., tailor, dusky flathead and whiting, (Gillson et al., 2009; Gillson et al., 2012; Warner, 2014). However, the catch of species such as bream increased during periods of reduced inflow.

Alteration in the natural patterns of these ecological processes can often be traced back to anthropogenic influence on catchment land use or the hydrology of the Hawkesbury estuary and its tributaries. Figure 44 presents a summary of the way estuarine environments and ecological process in them can be affected by reduced freshwater inflow, a major driver of estuarine degradation worldwide (Chilton et al., 2021).

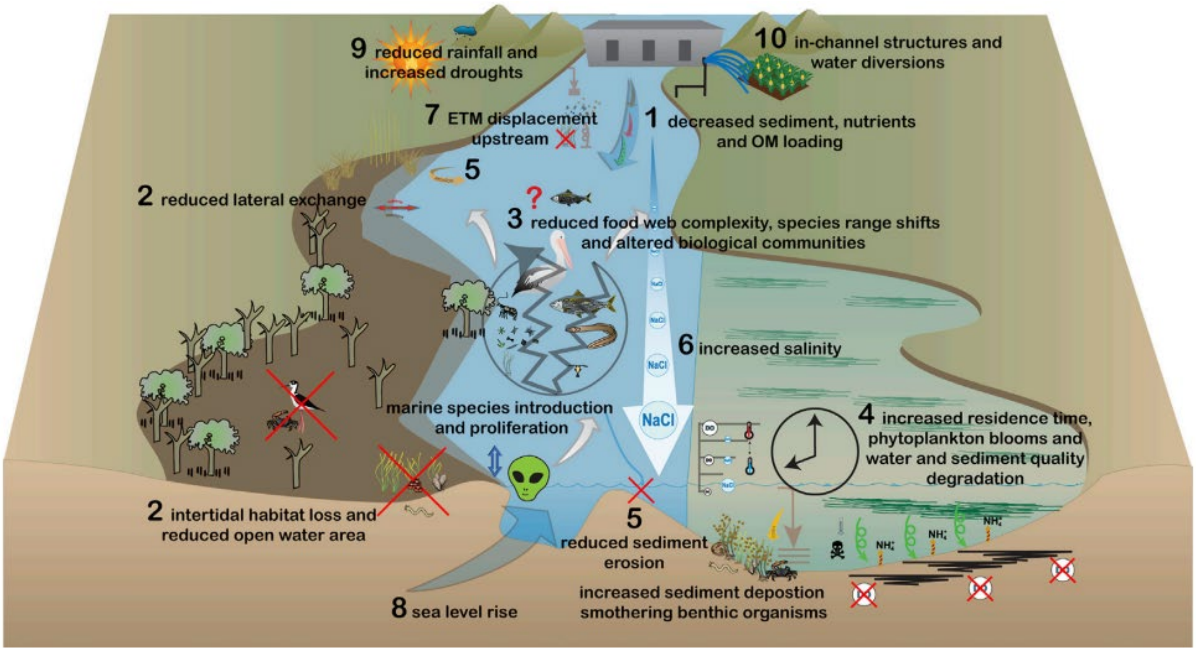


Figure 44. *Overview of the impacts of reduced freshwater inflows on estuarine environments.* (Chilton et al., 2021)

Maintaining estuarine environments and processes through providing adequate freshwater inputs is an important element in increasing the resilience of the Hawkesbury River estuary and its ecological inhabitants against future changes through climate change and eustatic sea level rise (Gillanders and Kingsford, 2002; Gillanders et al., 2011). However, current environmental flow releases in the Hawkesbury are approximately 3% of the long-term average flow to the estuary, far short of the recommended 80% required for effective ecological maintenance of systems (Warner, 2014). As the reduction in freshwater flows into the Hawkesbury River estuary is predominantly driven by the need for a metropolitan water supply, and the population that the water supply services is projected to grow with a high level of certainty, it is highly unlikely that significant changes to the environmental water inputs will occur. This indicates that the Hawkesbury River estuary has experienced an irreversible shift to a new freshwater input regime.

Brisbane Water and Pittwater are not subject to the same level of freshwater extraction for human consumption and therefore their flow regimes are relatively more natural than the Hawkesbury River estuary.

5 Stressors, vulnerabilities and synthesis

This section explores the pressures and stressors that are impacting on the physical processes and ecological health of the Hawkesbury-Nepean River system estuaries. An ecosystem vulnerability assessment considers the impacts of identified stressors on critical habitats of the HNRS. This information is synthesised into a series of conceptual diagrams that illustrate the key components of the system and their interconnected relationships.

5.1 Pressures and stressors

Healthy ecological function underpins the value of the estuaries of the HNRS. Therefore, it is essential to consider stressors that threaten to disrupt important ecological and physical processes that underpin a healthy estuary. These stressors arise from historical and ongoing activity within the estuaries and their catchments which have altered physical inputs and outputs, leading to responses within the ecology of the system. There are also ongoing and intensifying trends such as urbanisation of the catchment and climate change that will increase stress on the HNRS estuaries. Understanding these stressors including their source and the ecosystem response they induce provides important knowledge needed to facilitate effective management.

Stressors can be characterised by the pace and duration over which they occur (Astles et al., 2010) (Figure 45 and Figure 46).

- Pulse stressor - is a short-term phenomenon in which the human activity occurs for a discrete period and then stops. Examples include an isolated pollution event or damage from a boat running aground.
- Press stressor - occurs when the activity does not stop such as altered hydrology due to urbanisation within the catchment.
- Ramp stressor - is when a disturbance steadily increases over time and may or may not stop such as some of the effects of climate change or increasing urbanisation.

Multiple stressors within an estuarine system can interact with cumulative effects. These may be additive, antagonistic, or synergistic (Crain et al., 2008; Astles et al., 2010).

- Additive effects - each stressor produces its own effect but does not interact with the effects of other stressors. An example is the effect on water quality arising from sediment contamination from pollutants and increased turbidity from dredging.
- Antagonistic effects - the consequences of one stressor act against the consequences of another stressor. An example is the increased water flow from altered catchment hydrology eroding accumulated sediments from catchment run-off which in turn alleviates the negative effects of over-sedimentation.
- Synergistic effects - occur when the consequences of two or more disturbances interact to produce a combined different consequence than either of the disturbances acting on their own. For example, different salinities interact with increased nutrients to change the magnitude and type of effect on habitats and benthic organisms.

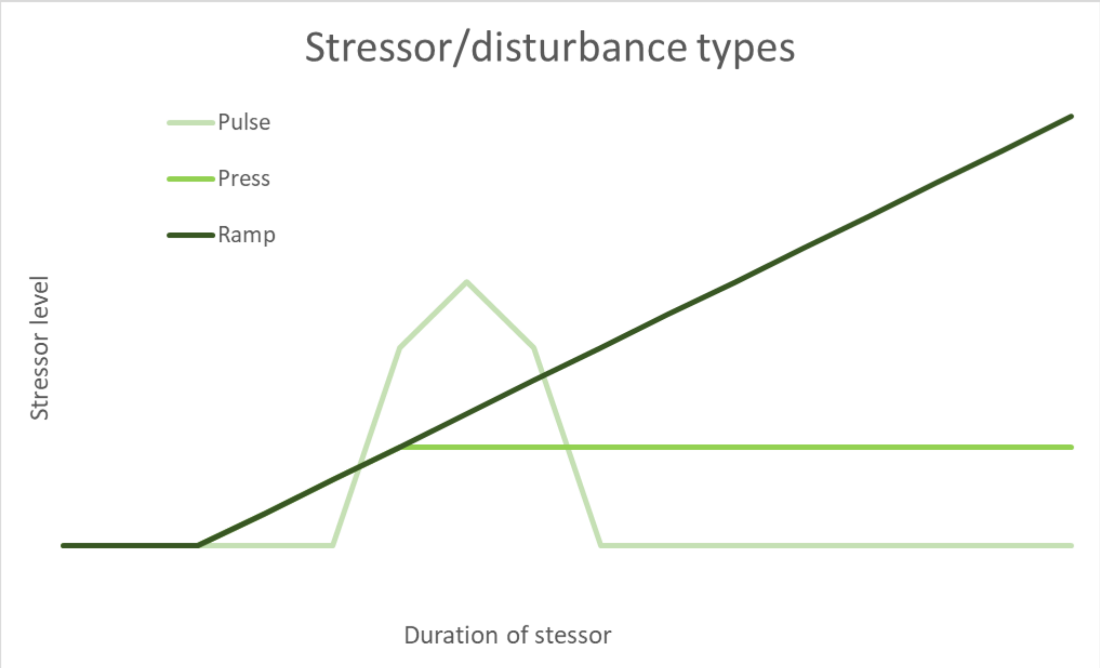


Figure 45. *Example of the level of stress different stressors (pulse, press and ramp) can have on an ecosystem through time.*

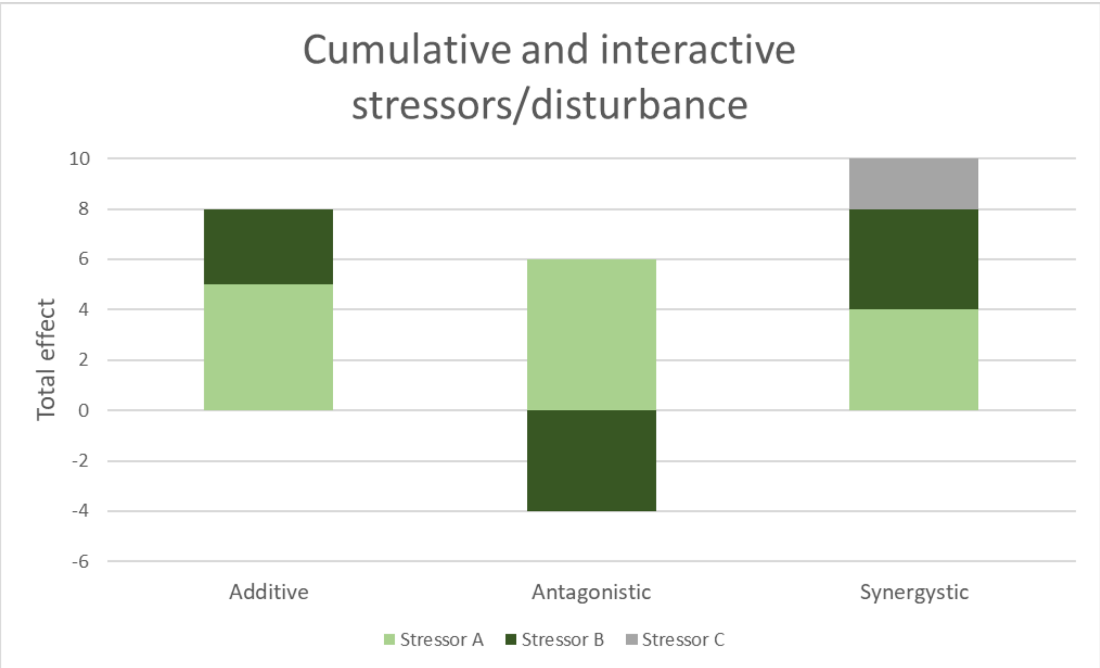


Figure 46. *Example of classification of stressor interactions that can occur in ecosystems*

Climate change will lead to cascading impacts throughout ecosystems. Changes in environmental patterns such as rainfall, temperature, bushfires and sea level will disrupt the existing ecological equilibrium with uncertain outcomes. However, some emerging trends are clear although the rate and magnitude of change is dependent on future global greenhouse gas emissions. Sea level is projected to rise with a high certainty, similarly, mean sea and land surface temperatures are projected to increase. Regional scale projections suggest with relative uncertainty that there will be a decrease in mean annual rainfall in the HNRS area, but that this will be accompanied by more intense floods. This will have impacts on flood and bushfire regimes (Earth Systems and Climate Change Hub, 2020).

Direct anthropogenic impacts are the result of urban, industrial and agricultural development within the contributing catchment and foreshores of the system. Urbanisation includes the alteration of land uses from more natural to more developed. Urbanisation is tied to population growth which is accompanied by increased industrial activity, resource consumption and waste production. Urbanisation can be considered as a source of multiple anthropogenic stressors. There are several high growth regions projected for the wider HNRS Catchment – particularly the proposed Western Parkland City outlined in A Metropolis of Three Cities – the Greater Sydney Region Plan (Greater Sydney Commission, 2018). The Plan outlines a significant growth corridor in between Campbelltown and Penrith that includes the proposed Badgerys Creek Aerotropolis. This indicates that the trend for these stressors is increasing into the future.

A comprehensive list of threats and stressors associated with the Hawkesbury-Nepean River system and its comprising estuaries have been identified as part of the Stage 1 Scoping Study (Water Technology, 2020). This list is aligned with the Marine Estate Management Strategy Threat and Risk Assessment (BMT, 2017) and was developed through stakeholder engagement, and a review of previous coastal and estuary studies and management. Threats and stressors identified in Stage 1 cover a broad range of issues including coastal hazards and public access, and governance which, while important in the greater context of coastal management, are not directly related to ecological processes and structure and function and are beyond the scope of this report.

This list has been refined to describe stressors that impact the most directly on the ecological function of the Hawkesbury-Nepean River system estuaries. Stressors have been grouped under two overarching pressures that are and will be applied to the HNRS system, namely climate change and direct anthropogenic impacts. These important stressors are described in more detail in Table 21. The alignment between the Stage 1 list of stressors and the list used in this report is tabulated in Appendix A. This list is also used in the following section to as the basis for an ecosystem vulnerability assessment and in Section 6 as a reference for management options that are available to address each stressor.

Table 21. Summary and description of important stressors impacting the HNRS.

Pressure	Stressor Linked Scoping Study Stressor IDs	Functional zones most impacted	Description
Climate change	**Sea level rise** *Long term hazards* - 1.1, 1.2, 1.3 *Climate change impacts* - 3.1 3.6, 3.7, 3.8, 3.9	Freshwater tidal pool, Upper, Middle and Lower Estuary	Scenarios regarding rising sea levels and climatic change pose multiple threats to the coastal and estuarine habitats of the HNRS estuary. Rising eustatic sea levels will threaten the estuarine section of the HNRS, with major implications for fringing wetland and shoreline habitats. Rising eustatic sea levels may result in longer periods of inundation for shoreline habitats which is likely to adversely affect their suitability as habitats for estuarine species and reduce their ecosystem function in this way. These affects are further compounded considering the degrading effect that increased storm surges may have on shoreline habitats e.g., erosion. The habitable range of important estuarine macrophytes is dependent on tidal regimes and factors such as the duration of inundation and salinity. As sea level rises, low lying land will become more regularly inundated and saline water will infiltrate further upstream. This will cause changes in the distribution of macrophyte communities and the ecosystems they support. Unimpeded, these macrophytes will naturally migrate in response to sea level rise, however there are often natural or man-made barriers to this migration. Sea level rise will also lead to changes in the geomorphology of estuaries and the coastline such as increased shoreline erosion and bank instability. Rising sea levels can also have impacts on tidal dynamics, especially important in the entrance to Brisbane Water. If the tide moves towards a more flood-dominant tide (incoming), sediment will move landward with more sediment at marsh boundaries and accretion and deposition in navigable channel—therefore requiring more dredging to continue use. If more ebb-dominant tides occur, sediment will move seaward, and this will lead to erosion and less sediment supply to marshes (Passeri et al., 2016).
	Ocean acidification and rising temperatures *Climate change impacts* – 3.2, 3.3 *Habitat disturbance* – 5.6, 5.7	Lower Estuary, Middle Estuary	Global oceans become warmer and more acidic as heat and carbon are absorbed from the atmosphere. This change in water chemistry effects estuarine organisms in complex ways. Increased ocean temperatures and ocean acidification are expected to have a negative impact on ecological health and biodiversity of the river system – e.g., increased number of jellyfish, increased algal blooms, introduction of aquatic/marine pest species (bryozoans like *Amathia verticillate*) and diseases (POMS etc) (Ducotoy et al., 2019; Byers, 2020) More acidic water inhibits the ability for certain organisms to produce carbonate leading to weaker shells leading to increased vulnerability to damage and disease, reducing their viability (Sanford et al., 2014, Bhuiyan et al., 2022). Certain species may favour warmer conditions, and as these extend their range and establish themselves in new areas, there may be widespread and complex ecological impacts (Madeira et al., 2012).
	Altered estuarine hydrology *Event based hazards* - 2.3, 2.5 *Climate change impacts* - 3.4, 3.5	All functional zones, predominantly Freshwater Tidal Pools, Upper and Middle Estuary.	Climate change will affect predominant weather patterns which influence the natural flow regime of the Hawkesbury and Nepean Rivers to the estuary. Changes to the timing, magnitude, frequency and duration of freshwater inflow events through changing rainfall patterns can have negative effects in estuaries by changing the hydrologic patterns of estuarine systems The frequency and intensity of floods and storms are likely to be affected by climate change (IPCC, 2022). Rainfall extremes are projected to increase throughout the 21st century which in turn will affect water resources along the catchments. Reductions to freshwater inflow through changing rainfall patterns and potentially river regulation may lead to reduced flushing of pollutants from the system, reduced inputs of key resources like organic carbon and nutrients, reduced transport of organisms and a repositioning of the tidal freshwater zone and the tidal wedge (Drinkwater and Frank, 1994).

Pressure	Stressor Linked Scoping Study Stressor IDs	Functional zones most impacted	Description
			Changes to water inflows and chemistry effects important physical processes such as mixing, stratification, and flushing with the associated changes in water quality and sediment dynamics contributing to various ecological impacts.
	Habitat migration and squeeze *Climate change impacts* – 3.9 *Habitat disturbance* – 5.1 *Recreation and tourism* – 8.4	All functional zones	Landward migration of coastal wetlands will occur in response to sea level rise (Saintilan and Hashimoto, 1999). However, coastal development and geological landscape characteristics will form a barrier to wetland migration in some areas, resulting in habitat squeeze (Saintilan et al., 2022). Saline tolerant habitats may also migrate upstream and landward as tidal influence and groundwater salinisation occurs with sea level rise.
	Increased intensity and distribution of bushfires *Event based hazards* - 2.4 *Water Pollution and Sediment Contamination* - 4.5 *Hydrologic Modifications* - 6.3	Contributing Catchment, Freshwater Tidal Pools, Upper and Middle Estuary	Changes in the frequency and severity of wildfire will also have very significant impacts on the catchment and thus also on the river and estuary. Bushfires play an important role in ecological function. The seasonality and spatial variability of bushfires is connected to the lifecycle processes of certain species and post-fire recovery provides opportunities for certain plants to establish. Climate projections show that much of southern Australia may become warmer and drier, and as a result is likely to bring an increasing bushfire risk (Hennessy et al., 2005; van Oldenborgh et al., 2021). A warming planet will change the frequency, intensity and distribution of bushfires. Bushfire season is expanding, altering the timing for inter-connected seasonal ecological processes. Bushfires also contribute to erosion by removing stabilising vegetation and creating pyrogenic sediments. Combined with increased frequency and intensity of floods and storms, these sediments can be more thoroughly flushed into estuaries contributing to damaging sedimentation and diminished water quality.
Direct anthropogenic impacts	**Catchment and foreshore development** *Habitat disturbance* - 5.1, 5.3, 5.4, 5.5 *Recreation and tourism* - 8.1, 8.2, 8.3, 8.4, 8.5 *Access and availability* - 9.1, 9.2	All functional zones	Development within the catchment and on, or near, the foreshore can lead to clearing or degradation of terrestrial and riparian vegetation and potentially disruption of ecological structure and function by reducing key habitats e.g., saltmarsh (Kelleway et al., 2017). Increased development is accompanied by increased visitation and the associated pollution and disturbances. Foreshore structures such as jetties can result in light reduction to the seabed, loss of seagrass habitats and reductions in benthic faunal community abundance and diversity, however, appropriate design of jetties can ameliorate help to ameliorate these impacts (Gladstone and Courtenay, 2014). Development can also promote hardening of foreshores when built assets are threatened by erosion or flooding. Hardened foreshore often creates simplified (relative to naturally dynamic or complex) substrates that reduce the diversity of organisms that can establish themselves (Gittman et al., 2016).

Pressure	Stressor Linked Scoping Study Stressor IDs	Functional zones most impacted	Description
	Stormwater runoff *Water Pollution and Sediment Contamination* - 4.1, 4.3, 4.5	Freshwater Tidal Pools, Upper and Middle Estuary	Developed catchments consist of increased ground imperviousness as roads, buildings, drainage and other hard surfaces replace vegetation and wetlands. Natural catchments retain water and contribute to effective nutrient cycling processes and these important ecosystem services are diminished with development in catchments (Hasan et al., 2020). Impervious surfaces cause higher runoff velocity and volume, transporting urban and industrial pollutants and causing localised erosion. Receiving waters within the estuary are affected as increased nutrient loads and altered flow regimes disrupt ecological processes and can contribute to adverse events such as algal blooms and proliferation of aquatic weeds (Pinto et al., 2013; Ajani et al., 2018).
	Agricultural runoff *Water Pollution and Sediment Contamination* - 4.2	Freshwater Tidal Pools, Upper and Middle Estuary	Agricultural practices often involve the use of fertilisers and pesticides that contribute excess nutrients and pollutants to runoff. Receiving waters within the estuary are affected as increased nutrient loads and altered flow regimes disrupt ecological processes and can contribute to adverse events such as algal blooms (Pinto et al., 2013)
	Sewage and wastewater runoff *Water Pollution and Sediment Contamination* – 4.4 *Hydrologic Modifications* – 6.2	Freshwater Tidal Pools, Upper and Middle Estuary	Over 40 WWTPs discharge to the Hawkesbury River estuary introducing increased nutrient loads (Rush, 2003; Pinto et al., 2013) which contributes to the proliferation of algae blooms/aquatic weeds across the Upper Hawkesbury Estuary (BMT WBM, 2013). WWTP discharges and sewer overflows also contain faecal pollutants. Many foreshore and rural properties are not connected to reticulated sewage systems and operate on-site treatment systems. The performance of these systems is variable across many locations across the catchment, with many systems not designed for the usage applied (e.g., holiday rental scenarios).
	Water extraction – surface and groundwater *Hydrologic Modifications* - 6.1, 6.2	Freshwater Tidal Pools, Upper and Middle Estuary	As the HNRS system provides the majority of drinking water to the Greater Sydney Area it is subject to large amounts of extraction and alteration to its natural flow regime (Warner, 2014) which can have impacts on estuarine ecology and fish assemblages (Gehrke et al., 1999). Reduction of total discharge of freshwater reduces the flushing capability of the estuary which is important for removing pollutants and sediments from the waterways. Reduction in specific flow components (eg freshes), alters the prevailing conditions and disrupting the ecological communities that have adapted to a specific flow regime. This creates new dominant conditions which supports different species and communities Altered seasonality in freshwater flows impacts environmental signals that flora and fauna use for various biological functions. Reductions and alterations to groundwater supplies impacts on groundwater dependent ecosystems and can impact the hydrology in different functional zones including by disrupting destratification.

Pressure	Stressor Linked Scoping Study Stressor IDs	Functional zones most impacted	Description
	Barriers to longitudinal and lateral connectivity *Habitat Disturbance* - 5.1, 5.2, 5.3, 5.4, 5.5 *Recreation and tourism* - 8.4	All functional zones	Longitudinal connectivity can be interrupted by structures such as dams and weirs. This has been shown to disrupt estuarine ecology and productivity for example by creating barriers to fish passage. Reduction in lateral connectivity caused by reduced inundation of estuarine adjacent environments has been exacerbated by floodplain development reducing the coverage of wetlands on the floodplain with which the estuarine waters can connect (Burgin et al., 2016).
	Erosion and Sedimentation *Long Term Hazards* – 1.2 *Habitat Disturbance* – 5.1, 5.2, 5.3, 5.4, 5.5 *Hydrologic Modifications* -6.3	Freshwater Tidal Pools, Upper and Middle Estuary	Erosion of riverine and estuarine banks, arising from destabilised bank conditions due to changing catchment conditions, degraded foreshore vegetation, uncontrolled stock access, informal public access, or waterways usage can lead to active erosion. This effects ecological processes by reducing foreshore vegetation corridors on land and increasing turbidity within the water column as suspended sediments are transported by fluvial and tidal currents. This can hinder photosynthesis of seagrasses which are also potentially smothered by sedimentation. There are additional social and economic impacts of this process.
	Dredging *Water Pollution and Sediment Contamination* -4.6 *Hydrologic Modifications* – 6.4	Middle and Lower estuary	Dredging can result in physical disturbance and habitat loss resulting from sediment re-suspension and turbidity, especially when polluted sediments are mobilised. It can also destabilise foreshore banks and alter estuarine hydrology.
	Sediment contamination *Water Pollution and Sediment Contamination* -4.5, 4.6	Upper Middle and Lower Estuary	Water borne contaminants originating from historical and ongoing urban and industrial activities typically adsorb onto suspended particulate material and can accumulate and become immobilised in sediment. Contamination can impact on benthic communities that establish within the sediment. Other estuarine ecosystems are impacted when contaminated sediment is remobilised by disturbances such as dredging, floods, or turbidity in the water column.
	Invasive species *Habitat Disturbance* – 5.6, 5.7	All functional zones	Urban and commercial activities can introduce invasive species that outcompete native species. Some examples of invasive species include aquatic and terrestrial weeds and pests. Sources such as gardening, agriculture, and accidental introduction via incoming vessels provide multiple vectors. The impacts of climate change as well as urbanisation can facilitate conditions that promote the proliferation new and existing invasive species.

Pressure	Stressor Linked Scoping Study Stressor IDs	Functional zones most impacted	Description
	Commercial fishing *Commercial Fishing and Boating* – 7.1, 7.2, 7.3	Middle and Lower Estuary	Although highly regulated, commercial fishing acts as stressors to the estuarine system. Fishing extracts biomass from the system and introduces waste products such as discarded fishing gear which can impact on habitat functions.
	Recreational fishing *Recreation and tourism* – 8.1	Freshwater Tidal Pool, Upper Middle and Lower Estuary	Although highly regulated, recreational fishing act as stressors to the estuarine system. Fishing extracts biomass from the system and introduces waste products such as discarded fishing gear which can impact on habitat functions. Fishers on the foreshore can disturb intertidal habitats which support important ecosystems.
	Active boating *Commercial Fishing and Boating* – 7.4 *Recreation and Tourism* – 8.2	Freshwater Tidal Pool, Upper Middle and Lower Estuary	The Hawkesbury River estuary is a popular location for aquatic recreation including power boating and water skiing. Powered boats create wake waves that contribute to bank erosion and instability, contributing to turbidity in the water column and sedimentation.
	Passive boating *Recreation and Tourism* – 8.3	Freshwater Tidal Pool, Upper Middle and Lower Estuary	Anchors and moorings can destroy seagrass and benthic habitats, as can accidental vessel grounding in shallow water. Vessel sourced pollution including rubbish, fuel, oil, and anti-fouling agents can have negative ecological impacts.
	Swimming *Recreation and Tourism* – 8.3	Freshwater Tidal Pool, Upper Middle and Lower Estuary	Swimmers can introduce rubbish to the environment. Sunscreen can also slough off recreational water users and impact on sensitive ecosystems.

5.2 Ecosystem vulnerability

Ecosystem vulnerability can be defined as the potential for loss of habitat, function, or ability to contribute to important eco-physical processes (Weißhuhn et al., 2018). Understanding the relative vulnerability of different ecosystem components can help to prioritise management efforts by targeting stressors with the most severe potential impact or focusing on interventions designed to protect the most vulnerable populations.

A semi-quantitative vulnerability assessment has been undertaken to determine which key habitats within the HNRS estuary system are most at risk from the identified stressor and are likely to merit the most management effort. An assessment approach loosely based on Astles et al. (2010) has been used where scores are assigned to rate the impact that each stressor has on various habitats. A detailed explanation of the vulnerability assessment method is provided in Appendix B.

The ecosystem vulnerability assessment considers three factors as follows:

- **Sensitivity** – susceptibility of a habitat to a hazard, disturbance or stressor.
- **Scarcity –** a measure of how rare or common a type of habitat is. This considers both the presence of available habitat as well as the actual distribution within the estuarine system.
- **Adaptive capacity** – characterizes the ability of a habitat to cope with the hazard and its consequences. Contributing factors to adaptive capacity include resistance to stressors (structure, form, attachment) and resilience (regrowth, recolonisation, reproduction, replenishment of structure) (Astles et al., 2010).

The stressors considered in the assessment are listed previously in Table 21. The representative habitats considered include:

- Saltmarsh
- Mangroves
- Seagrass
- Riparian vegetation
- Forested coastal wetlands
- Mudflats (intertidal / subtidal)
- Sandflats (intertidal / subtidal)
- Rock reef (intertidal / subtidal
- Water column – riverine (Freshwater Tidal Pools and Upper Estuary)
- Water column – estuarine (Upper, and Middle Estuary)
- Water column – marine (Lower Estuary)

Table 22 displays the results of the semi-quantitative ecosystem vulnerability assessment as well as providing an indication of the relative impact that each stressor has by averaging its impact rating for each habitat type. The nature of this assessment indicates that the results should be used as a high level guide for understanding the relative vulnerability of various ecosystems to a range of stressors.

Saltmarsh and seagrass have been identified as the most vulnerable ecosystems and are discussed in detail below. Mangroves are often present on the seaward fringe of saltmarsh habitats and their coincident response to stressors is also discussed below. Riverine and estuarine aquatic habitats are also vulnerable with the main stressors associated with runoff pollution, freshwater extraction, and altered hydrology associated with changing rainfall patterns due to climate change. Riparian vegetation is most vulnerable to foreshore development and active boating which creates wake waves that contribute to bank erosion.

Table 22. Ecosystem vulnerability assessment results. Details on methodology provided in Appendix A.

Ecosystem	Stressors																				Sensitivity score	Adaptive capacity			Vulnerability rating
	Sea level rise	*Ocean acidification and rising temperatures*	*Altered estuarine hydrology*	*Habitat migration and squeeze*	*Bushfire*	*Foreshore development*	*Urban stormwater runoff*	*Agricultural runoff*	*Sewage and wastewater runoff*	*Water extraction – surface and groundwater*	*Barriers to longitudinal and lateral connectivity*	*Erosion and sedimentation*	*Dredging*	*Invasive species*	*Sediment contamination*	*Commercial fishing*	*Recreational fishing*	*Active boating*	*Passive boating*	*Swimming*		**Scarcity**	**Resistance**	**Resilience**	
Saltmarsh	5	4	4	5	4	4	4	4	4	4	5	4	2	4	3	3	2	2	2	2	71	5	5	5	86
Seagrass	3	4	4	3	3	4	4	4	4	3	2	5	5	3	5	4	3	4	3	3	73	4	4	4	85
Water column - riverine	1	2	5	2	3	2	5	5	5	4	4	4	4	3	4	4	3	4	1	1	66	3	3	4	76
Water column - estuarine	1	4	4	2	3	2	4	5	4	5	4	3	4	3	4	4	4	4	1	1	66	2	5	3	76
Riparian vegetation	3	3	3	4	3	4	4	3	3	3	4	4	3	3	3	2	2	4	3	3	64	4	5	3	76
Mangroves	4	2	3	4	2	4	3	3	3	3	4	3	2	3	3	3	3	4	2	3	61	3	5	5	74
Mudflats	3	4	3	3	2	3	2	3	3	3	2	4	4	3	5	3	3	3	1	3	60	3	5	3	71
Forested coastal wetlands	4	3	4	4	5	5	3	3	3	4	3	3	2	3	2	1	1	1	1	1	56	4	4	4	68
Sandflats (intertidal / subtidal)	2	4	2	3	2	3	2	2	3	3	2	4	4	3	4	3	3	3	2	3	57	3	5	2	67
Rock reef (intertidal / subtidal)	3	3	3	3	2	4	3	2	3	2	2	2	3	3	2	2	4	2	3	3	54	3	3	4	64
Water column - marine	1	4	2	2	2	2	3	3	3	3	3	3	4	3	2	4	4	4	1	1	54	2	3	2	61
Stressor impact rating	2.7	3.4	3.4	3.2	2.8	3.4	3.4	3.4	3.5	3.4	3.2	3.5	3.4	3.1	3.4	3.0	2.9	3.2	1.8	2.2					

5.2.1 Seagrass

Seagrass is particularly vulnerable to water quality impacts from urban, agricultural and sewage runoff which can introduce excessive nutrients and other types of pollution that cause detrimental water chemistry, sediment contamination, and turbidity which limits photosynthesis (Macreadie et al., 2017). Erosion and sedimentation can also increase turbidity but additionally can smother seagrass habitat. Activities such as dredging and active boating also pose elevated threats to seagrass habitat as they disturb and resuspend sediments and can directly destroy seagrass beds. Sea level rise may also threaten seagrass habitats with increases in water depth altering the habitable zone where sufficient sunlight can penetrate the water column (Grech et al., 2012).

Seagrass communities are formed from species whose life history strategies can be described as colonising, opportunistic or persistent. They occupy habitats defined by the range and variability of their abiotic environment. This results in seagrass meadows that are either transitory or enduring. Transitory meadows may come and go and able to re-establish from complete loss through sexual reproduction. Enduring meadows may fluctuate in biomass but maintain a presence by resisting pressures across multiple scales (Kilminster et al., 2015).

The main seagrass types in the HNRS are *Halophilia, Zostera* and *Posidonia. Halophilia* and *Zostera* are colonising or opportunistic and exhibit characteristics that increase their resilience to stressors. *Posidonia* on the other hand, is a persistent seagrass with slow shoot turnover, long time to first sexual reproduction, no seed dormancy, and therefore has a slower ability to recover from disturbances (Kilminster et al., 2015, Figure 47).

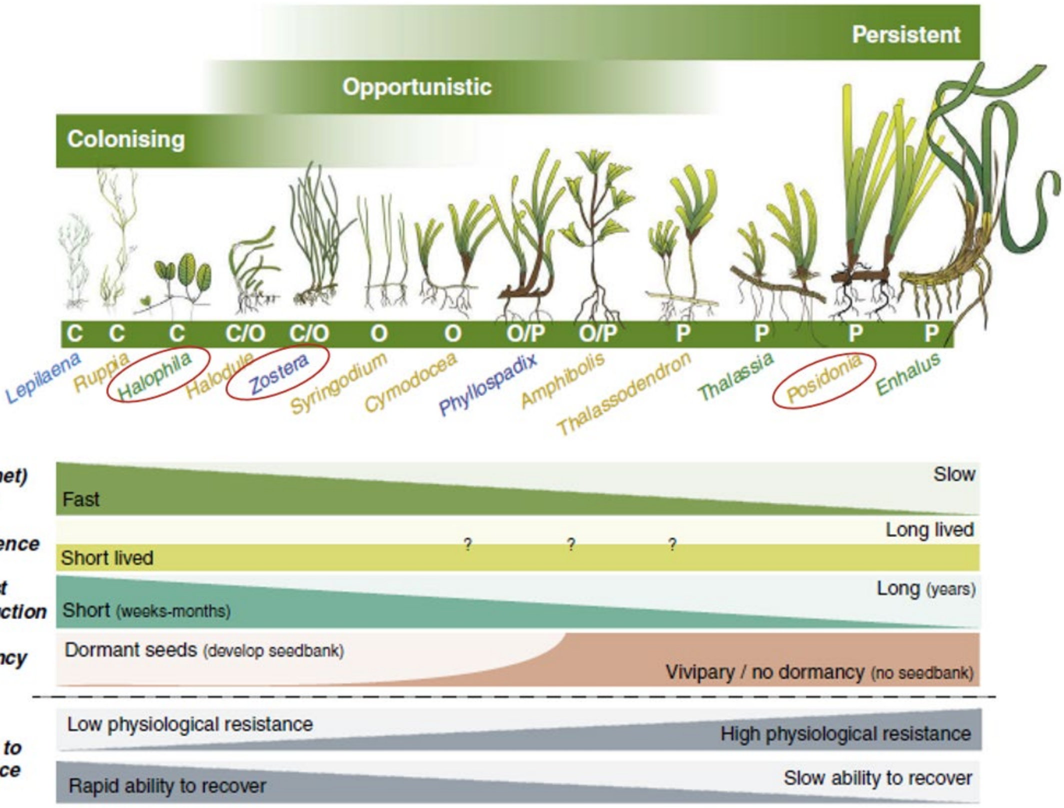


Figure 47. *Diagram showing dominant traits among colonising (C), opportunistic (O) and persistent (P) seagrasses, with respect to shoot turnover, genet persistence, time to reach sexual maturity and seed dormancy* (Kilminster et al., 2015).

5.2.2 Saltmarsh and mangroves

Sea level rise (SLR) is one of the main threats resulting from climate change predicted to impact on low lying coastal habitats such as saltmarsh and mangroves. The rise in sea-level has been predicted to result in a range of additional processes that threaten coastal habitats. At sites unconstrained by either man-made structures or natural geological forms, SLR is unlikely to result in much change in extent of saltmarsh habitat. However at sites that have development landward constraints, reduction in the extent of saltmarsh habitat can be expected to increase, particularly if engineering solutions like shoreline hardening are implemented more frequently to protect coastal assets (Schuerch et al., 2018).

The permanence of saltmarsh and mangroves is dependent upon the duration and frequency of upstream sediment supply, tidal inundation and height above sea level all of which are likely be altered under both climate change scenarios (Spanger – Siegfired et al., 2014; Lovelock et al., 2015). Saltmarshes are also able, in part, to combat SLR through vertical sediment accretion which increases the marsh elevation. However it is difficult to determine from literature a generic regional response of saltmarshes owing largely the site based variability in both SLR and accretion rates. Some research has suggested that the rates of vertical accretion will notionally keep pace with the rates of water level increase (Kirwan et al., 2016). However, under both medium and high emission climate scenarios more recent research has shown that south eastern Australia saltmarshes have a consistent deficit in vertical accretion relative to local sea-level trends (Saintilan et al., 2022). This is likely to lead to continued saltmarsh losses across medium to longer timeframes, particularly at sites where lateral migration is constrained.

Adding to the future threat, SLR has also been shown to translate into a net competitive advantage of mangroves in saltmarsh environments, meaning that at sites with paired mangrove saltmarsh ecosystems there will be a greater threat of mangrove encroachment (Saintilan and Hashimoto, 1999; Saintilan and Williams, 1999; Saintilan et al., 2014). Mangrove encroachment into saltmarsh habitats has been recorded at the temperate edge of their range on five continents (Saintilan et al., 2014), leading to an impact on saltmarsh reliant fauna (e.g. Orange-bellied Parrots). Increasing winter temperatures, altered rainfall patterns and sea level rise have all resulted in mangrove encroachment in saltmarsh habitat globally (Osland et al., 2022). However, encroachment can be moderated by local factors such as sedimentation rates, biological interactions between vegetation types, tidal ranges and geomorphic setting (see Whitt et al 2020 and references therein) (Whitt et al., 2020). Surface Elevation Tables (SETs) were installed in 2002 in Berowra Creek and Marra Marra Creek. These SET installations allow the monitoring of sediment accretion and surface elevation change in the mangrove and saltmarsh, and measurements have been ongoing for 20 years. Though not published, the data indicate that mangroves are increasing in elevation at ~2.5mm per year, and saltmarsh at ~1.5 mm per year, well below the rate of sea-level rise over the period of measurement (5.7 mm per year). This result is consistent with results from comparable systems.

Counter to temperature factors enhancing mangrove encroachment, a predicted increase in the longevity and severity of drought conditions with the concurrent effects of increased evaporation, lower rainfall and depleted groundwater may lead to stunted mangrove growth therefore slowing mangrove encroachment (Lovelock et al., 2016). Regardless of the process that becomes ultimately dominant, it is highly likely that changing precipitation and temperature regimes predicted under both the medium and higher emission scenarios will alter saltmarsh and mangroves dynamics and the species composition of these sites.

It is likely that the predicted variability in freshwater availability will have an influence on saltmarsh response to climate change scenarios. The climate predictions for South-eastern Australia are for more variable rainfall patterns leading to more frequent and prolonged periods of drought. This will lead to variability in salinization of groundwater and surface waters in saltmarsh ecosystems and the availability of freshwater for saltmarsh species. A reduction in freshwater has been linked to numerous subsurface processes in saltmarsh ecosystems in other parts of the world. Reduced water accumulation and lower water table in sediments leads to compaction and subsidence of marsh sediments, lowering marsh elevations and thereby increasing the risk of permanent inundation and encroachment by mangroves (Kennish, 2001). This is compounded by freshwater extractions from catchment water resource development. This is likely to increase with both climate change and increasing urban populations. Combined with greater saltwater intrusion (from sea-level rise), a salinisation of the middle and upper reaches of the estuary is expected. This could shift the dominant saltmarsh vegetation from the brackish water rush *Juncus acutus* to the more halophytic saltmarsh community (*Sporobolus virginucus, Sarcocornia quinqueflora* association).

Intertidal coastal habitats are threatened by the desirability of their coastal location as well as their close proximity to urban areas and development. Their relatively flat profile and apparent low vegetative complexity makes them highly attractive for land reclamation. Some are drained and levees are constructed, converting them for a range of human uses including sports fields, canal developments, industrial estates and agricultural areas(Creighton et al., 2015).

There are a number of other threats that are likely to influence the extent and condition of saltmarsh ecosystems into the future including pest and stock disturbance, weeds, disturbance of saltmarsh fauna, and bushfire.

5.3 Synthesis of important estuarine processes and conceptual diagrams of HNRS

The sections above provide an overview of the key physical and ecological processes that are occurring in the Hawkesbury-Nepean River system estuaries. These processes generate and support the diverse multitude of values associated with the estuaries. Pressures and stressors and their impact on ecosystem vulnerability are also discussed, providing an overarching narrative of the current state and future trend of estuarine health and function. A synthesis of this information is illustrated in a series of conceptual diagrams that highlight the main structure, driving processes, and stressors that are important in understanding the system as a whole.

Conceptual diagrams are simplified ways of expressing what we know about complex systems. They bring together collective knowledge and perspectives about the how a complex system is structured and how it functions They also help identify critical components and how they interact. They are very widely used in ecological analysis, impact assessment and the adaptive management of natural systems, as well as to assist community engagement.

Conceptual diagrams must have a focus if they are to be effective, and a model that attempts to 'be all things to all people' will fail. It is important to stress that a single conceptual diagram cannot − and should not − attempt to include all aspects of a given system. It has to concentrate only on the most salient aspects in order to be a useful tool in estuarine management. Accordingly, in this section three conceptual models of the Hawkesbury-Nepean River system are presented.

The first, Figure 48, provides an overview of the entire river system, from its source near Goulburn in the south, to where is debouches into the Pacific Ocean at Broken Bay. This overview diagram is essential to better understand and manage the Hawkesbury-Nepean River System estuaries, because so many of the ecological processes that occur in the estuaries are contingent upon phenomena that occur in the freshwater reaches upstream and in the contributing catchment (e.g. interception of freshwater flows in dams and reservoirs, inputs of nutrients and sediments from agricultural land use).

The diagram of the entire catchment highlights:

- how the underlying geology has shaped the land use patterns in the catchment which have led to various stressors caused by urbanisation to arise in some areas, while more natural and conservation based land use dominate others.
- the impact of upstream diversions on river discharge, especially from the Nepean River and its tributaries, and the impact this has on reducing hydrological connectivity along the river.
- the impact of altered land use in the upper catchment, resulting in increased sediment loads to the river.
- the overwhelming effect of increased nutrient loads on ecological structure and function, and especially in terms of degraded water quality and the occurrence of noxious algal blooms.

The second, Figure 49, focuses on the estuarine reach in particular. Here phenomena, such as tidal influences, operate that are not relevant in more upstream reaches. This diagram highlights location specific issues that are critical management imperatives.

The diagram of the estuaries highlights:

- The location and extent of important estuarine ecosystems such as seagrass, mangroves and saltmarsh
- the reduced flushing capacity of the upper estuary through reduced freshwater discharge from upstream and the increased tidal and marine flushing of the lower estuary.
- nutrient enrichment, caused both by the downstream flow of nutrients from upstream reaches and localised inputs of nutrients within the estuarine section (e.g. from South Creek and from sewage treatment plants discharging directly into the estuary) and their resultant impact on the frequency and intensity of algal blooms in the estuarine reach of the river system.
- the adverse impact of urbanisation of the tributaries that enter the Hawkesbury River from the south (e.g. South Creek, Cattai Creek), especially in terms of pollutant load and altered hydrology.
- the adverse impact of urban development along the estuary foreshore and on the islands in the middle reaches of the estuary.
- The damage caused to seagrass and benthic habitat by recreational boating activity including moorings, anchors and propeller damage.
- the beneficial role played by inputs from the Grose, Colo and MacDonald Rivers, which drain largely protected areas (e.g. national parks) to the north of the Hawkesbury.

The third, Figure 50, focusses on the interaction between physical-chemical processes (summarised in Section 3), ecological structure and function (summarised in Section 4), and key stressors (summarised in Section 5.1).

The estuarine processes diagram highlights:

- the impact of reduced freshwater discharge on the longitudinal position of the tidal wedge in the estuary.
- the influence of wave and tidal energy in sediment and hydrodynamics in the lower and middle estuary
- the importance of lateral connectivity for biodiversity and food web function, noting the impact of water level variations, rising eustatic sea levels and periodic storm surges on ecological structure and function.
- connection between catchment inputs and eutrophication that can lead to algal blooms, stratification and the generation of sediments and anoxic bottom conditions.
- the movement of fish throughout the estuary and their role in nutrient transport and dynamics.

Figure 48. *Overview of the Hawkesbury Nepean River system catchment*

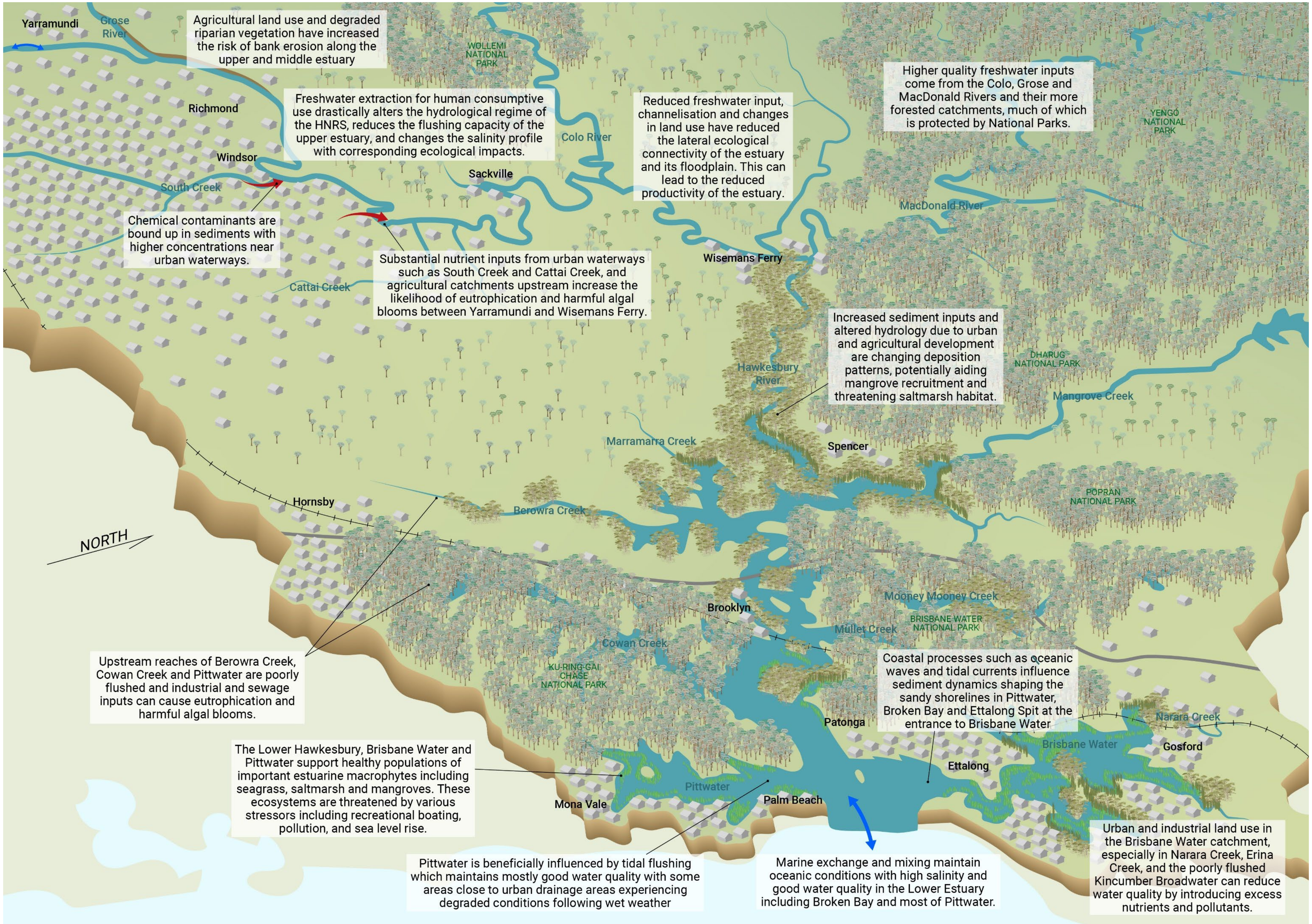


Figure 49. *Overview of the HNRS estuary*

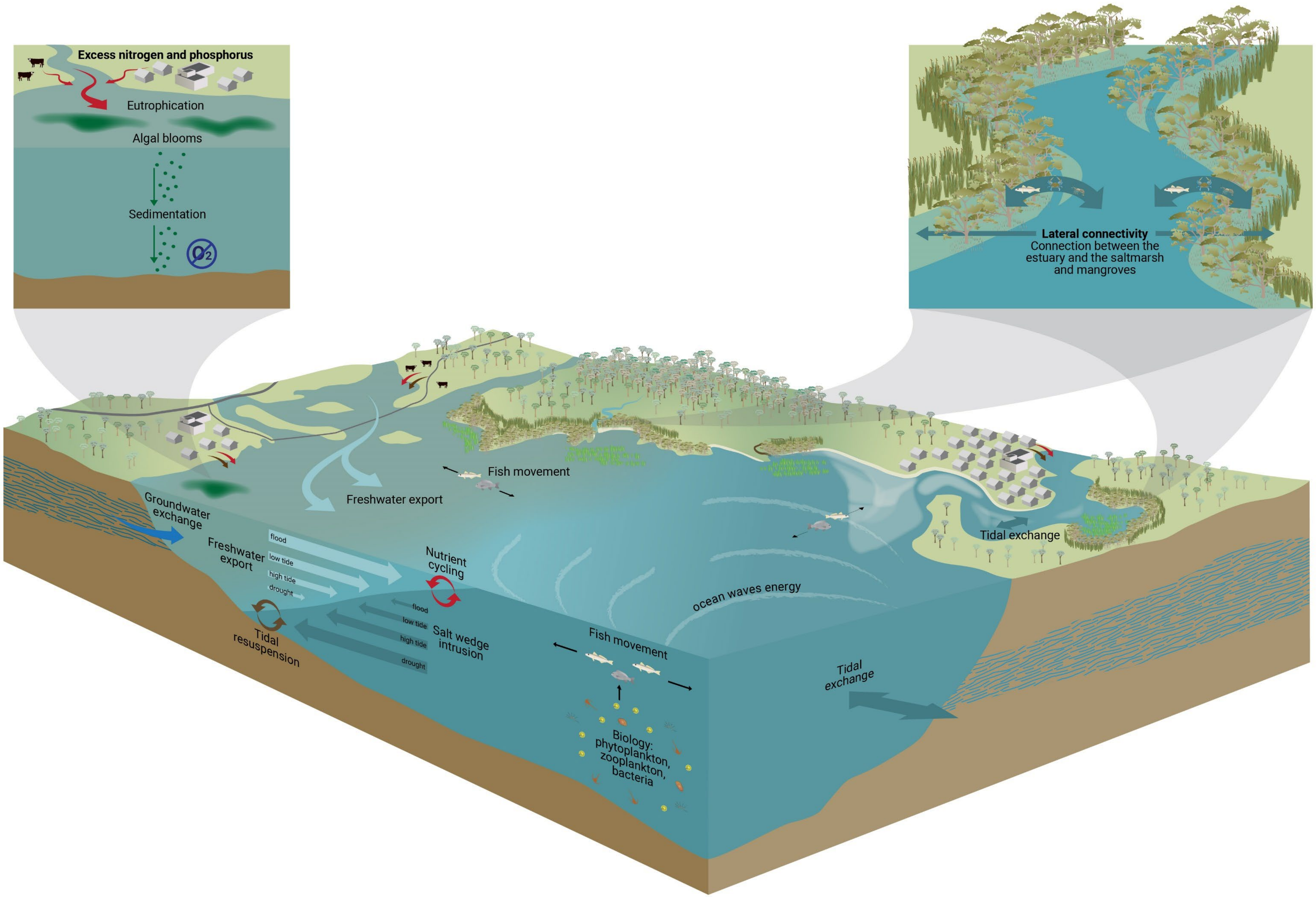


Figure 50. *Conceptual model of critical processes operating HNRS estuary*

6 Management to enhance estuarine values

This section is designed to connect knowledge and understanding of the ecological and physical processes described in Sections 3, 4, and 5 with management opportunities and to provide context to guide management decisions related to the physical and ecological health of the HNRS.

Discussion in this section includes:

- Management context
- Management opportunities
- Strategic planning as a management tool
- Knowledge gaps and future research areas

6.1 Management context

Management of the HNRS is the responsibility of numerous stakeholders. Local government and state government agencies support management activities within their respective capacities to achieve integrated and coordinated management. This has been identified as a major challenge due to a lack of coordination across the river system and catchment between the estuary councils, catchment councils, and state government agencies. This has historically resulted in significant jurisdictional ambiguity across governance bodies, and a reduced ability to address system-wide issues and threats.

The NSW Coastal Management Framework supports local and state governments in designing and implementing Coastal Management Programs (CMPs). The framework is underpinned by two key pieces of legislation, the *Coastal Management Act 2016* (CM Act) and chapter 2 of the Resilience and Hazards SEPP 2021 (RH SEPP), formerly the CM SEPP 2018). Additionally, the Marine Estate Management Strategy, developed in accordance with the *Marine Estate Management Act 2014,* sets the overarching framework for the NSW Government to coordinate the management of the marine estate. It identifies priority threats, outlines how these will be addressed, and aligns with the NSW Coastal Management Framework.

The CM Act defines the coastal zone as comprising four coastal management areas:

- Coastal Wetlands and Littoral Rainforests Area
- Coastal Vulnerability Area
- Coastal Environment Area
- Coastal Use Area.

The CM Act establishes management objectives specific to each of these management areas, reflecting their different values to coastal communities. The CM Act specifies a hierarchical approach to applying management objectives and development controls with the hierarchy proceeding in the order of the list above.

The RH SEPP gives effect to the objectives of the CM Act 2016 from a land use planning perspective, by specifying how development proposals are to be assessed if they fall within the coastal zone (OEH, 2019). The RH SEPP streamlines coastal development assessment requirements, identifies development controls for consent authorities to apply to each coastal management area to achieve the objectives of the CM Act, and establishes the approval pathway for coastal protection works (OEH, 2019).

The RH SEPP provides a map of land currently classified as within the coastal zone, except for Coastal Vulnerability Area. A detailed description of all 4 coastal management areas is provided in the Stage 1 Scoping Study.

The key coastal management areas from an ecological perspective are the Coastal Environment Area (CEA) and the Coastal Wetlands and Littoral Rainforests Area (CWLRA). With the CWLRA being the coastal management area with the most restrictive management objectives and development controls, thereby providing the most ecological protection. Table 23 provides a comparison of the geographical scope and management objectives of these two coastal management areas.

Table 23. Comparison of Coastal Environment Area and Coastal Wetlands and Littoral Rainforest Area

Coastal Environmental Area	Coastal Wetlands and Littoral Rainforests Area
The CEA is widespread, covering coastal features throughout NSW such as coastal waters, estuaries, coastal lakes, coastal lagoons, and land adjoining those features including headlands and rock platforms, beaches, dunes and foreshores. Within estuaries, the coastal environment area extends upstream to the extent of tidal influence. A nominal landward buffer of 500 m (100 m for Greater Metropolitan Sydney) is included.	Coastal wetlands and littoral rainforests area are defined as the land which displays the hydrological and floristic characteristics of coastal wetlands or littoral rainforests, as well as a surrounding 100 m buffer proximity area to manage impacts of adjacent development. Coastal wetlands are dominated by the following vegetation types: mangroves, saltmarshes, melaleuca forests, casuarina forests, sedgelands, brackish and freshwater swamps, and wet meadows. Littoral Rainforests are defined by their dominant vegetation which include riberry broad leaved lilly pilly, tuckeroo, brush box, yellow tulip, baurela, red olive plum, plum pine, cabbage palm and various figs.
Management objectives from CM Act	
• to protect and enhance the coastal environmental values and natural processes of coastal waters, estuaries, coastal lakes and coastal lagoons, and enhance natural character, scenic value, biological diversity and ecosystem integrity. • to reduce threats to and improve the resilience of coastal waters, estuaries, coastal lakes and coastal lagoons, including in response to climate change. • to maintain and improve water quality and estuary health. • to support the social and cultural values of coastal waters, estuaries, coastal lakes and coastal lagoons. • to maintain the presence of beaches, dunes and the natural features of foreshores, taking into account the beach system operating at the relevant place; and • to maintain and, where practicable, improve public access, amenity and use of beaches, foreshores, headlands and rock platforms.	• to protect coastal wetlands and littoral rainforests in their natural state, including their biological diversity and ecosystem integrity. • to promote the rehabilitation and restoration of degraded coastal wetlands and littoral rainforests. • to improve the resilience of coastal wetlands and littoral rainforests to the impacts of climate change, including opportunities for migration. • to support the social and cultural values of coastal wetlands and littoral rainforest; and • to promote the objectives of State policies and programs for wetlands or littoral rainforest management.

The Coastal Vulnerability Area also has the potential to enhance and protect ecological process as it is meant to include areas potentially inundated as a result of sea-level rise. This allows a mechanism to determine retreat pathways for coastal wetlands, which is part of the intended purpose of identifying these areas. These areas should be identified to facilitate planning for future wetland.

6.2 Management opportunities

The NSW Coastal Management Manual Part B: Stage 3 (OEH, 2019) provides guidance on developing management actions for the coastal zone. The manual defines the following five strategic approaches into which management actions can be categorised:

- Alert – includes coastal management actions that seek to 'watch and wait' such as monitoring change and setting thresholds, low regret responses and research to improve knowledge.
- Avoid future impact – includes recommending proactive land use planning and encouraging new development only in locations of low-risk.
- Active intervention – includes coastal management actions that seek to protect assets or accommodate change in any of the coastal management areas, while maintaining current systems and values.
- Planning for change – includes coastal management actions that seek to facilitate habitat migration and transformative changes to natural systems. For built areas, this includes planning to relocate or redevelop assets to consider the dynamic and ambulatory nature of the shoreline. It may be timed to commence as opportunities arise or when thresholds of exposure, impact and risk are exceeded.
- Emergency response – includes coastal management actions to address residual risk in emergency situations.

In general, coastal management actions that may have the effect of alerting and avoiding risk are appropriate for estuarine environments that are in good condition or where current threats are relatively low. Active intervention coastal management actions are appropriate when threats are currently impacting on the health, function or resilience of estuarine ecosystems. Coastal management actions that are part of the planning for change group of recommended actions may be considered when the changes to condition and function are likely to be permanent. Emergency response coastal management actions may include preparation for coordinated and rapid response to protect sensitive habitats, such as measures to control the spread of oil, sewage or other pollutant spills.

The natural ecosystems of the HNRS have experienced large scale alteration and degradation since European colonisation (Benson and Howell, 1994). Significant shocks, creating imbalance and shifts in the physical and ecological equilibrium, have occurred in the past 200 years. Stressors associated with urbanisation and agriculture have also been introduced to the system with no realistic chance of disappearing. In fact, the source of these stressors is likely to increase in magnitude. However, our understanding of the physical and natural processes of the HNRS has also improved drastically. This understanding presents opportunities to restore the ecosystem and its habitats with new approaches.

In some situations, removing the pressure may allow the system to recover naturally; in other situations, active rehabilitation or offsets may be required. It has been demonstrated that investment into restorative opportunities within estuaries provides substantial economic returns in the form of more productive fisheries, improved flood control, carbon sequestration, and improved water quality (Creighton et al., 2015). These benefits support a strong business case for increased and targeted investment into improving the estuarine function of the HNRS.

It is generally considered easier and more cost-effective to protect and enhance coastal ecosystems that are in good condition than to attempt to return areas in a poor condition to their natural state. In fact, return to a pre-colonisation ecological state is not possible. Therefore, effort to improve estuarine function is focused on both managing and reducing stressors as well as restoring, rehabilitating, re-establishing, protecting and conserving various processes and habitats. Restoration of estuarine systems can be achieved by maximising the following objectives (Creighton et. al., 2015):

- Restore longitudinal and lateral connectivity – ensure fish passage and nutrient flux and incorporate nature-based solutions and design into new foreshore development and stabilisation to promote improvement of fish habitat, including the use of emerging techniques such as oyster beds to aid in bank stabilisation.

- **Rehabilitate degraded floodplain wetlands** – allow more natural fluxes of water, and reshaping landforms to remove drains and levees.
- **Identify and protect accommodation space for vulnerable estuarine habitats** – especially saltmarsh and freshwater wetlands, to allow for natural migration in response to sea level rise. This will ensure continued lateral connectivity.
- **Re-establish mussel and oyster reefs** – which provide valuable habitat and nursery areas for many estuarine fish species, as well as performing valuable water-quality improvement functions.
- **Protect and re-establish seagrass beds** – limiting anchoring, as well as using seagrass-friendly moorings in areas subject to heavy boating is likely to be an important component of this action. Difficulty arises when balancing this with the need for navigational channels which require dredging.
- **Provide adequate freshwater flows to the lower reaches of coastal floodplain rivers** – examine opportunities for increasing or optimising environmental flows.

Emerging practices around Blue Carbon may provide local business with the opportunity to invest in tidal restoration of degraded mangrove and saltmarsh and in doing so gain carbon credits. By working together, participating councils could develop a portfolio of sites suitable for blue carbon habitat restoration, making these available to a growing market willing to invest in emission reduction opportunities Viability of projects is likely to be greater if they are clustered into a single portfolio, so coordination between councils would be advantageous. (Lovelock et. al., 2022).

Effective monitoring is fundamental to estuarine management and restoration. The benefits of implementing a well designed estuary ecosystem health monitoring program include providing a basis upon which to determine appropriate management actions, monitoring the effectiveness of management and contributing to the ongoing adaptive management of estuaries and their catchments.

6.2.1 Management actions to address identified stressors

Over the years, several management studies and plans have been developed for the coastline and estuaries of the Hawkesbury-Nepean River system. These have been prepared in various forms, including Coastal Zone Management Plans (CZMPs) and Estuary Management Plans (EMPs). These documents have been developed over the last 20 years and cover a range of study areas within and across the estuary system. They also each provide a comprehensive list of management actions, agreed upon by stakeholders, that if implemented will help to achieve positive outcomes within the HNRS. The most relevant, currently adopted studies and management plans are listed in Table 24.

Table 24. Existing management plans for the HNRS

Plan	Source	Year	Status	LGA's Covered	# of Actions
Upper Hawkesbury Estuary Coastal Zone Management Plan	BMT WBM	2014	Complete - Certified	The Hills, Hawkesbury City	39
Lower Hawkesbury Estuary Management Plan	BMT WBM	2008	Complete	Central Coast, Hornsby	147
Brisbane Water Estuary Coastal Zone Management Plan	Cardno (CLT)	2012	Complete	Central Coast	183
Pittwater Estuary Management Plan	BMT WBM	2010	Complete	Northern Beaches	41
Gosford Beaches Coastal Zone Management Plan	Worley Parsons	2017	Complete - Certified	Central Coast	111
Pearl Beach Lagoon CZMP	BMT WBM	2017	Complete - Certified	Central Coast	9

An audit of the implementation status of management actions from select plans (Lower Hawkesbury, Pittwater, Gosford Beaches, and Pearl Beach Lagoon) was undertaken in the Stage 1 Scoping Study (Water Technology 2020, Appendix E). The audit classified each action by its implementation status as one of the following:

- Completed
- Implemented and ongoing
- In progress / incomplete
- Not commenced / outstanding
- No longer applicable
- Unknown

While the approach used to develop each of the plans varied, many classified their list of management actions into categories. These categories are listed in Table 25.

Table 25. Management plans and action categories

Management plan	Action categories
Upper Hawkesbury Estuary CZMP	• Design and Mapping • Development Services • Infrastructure Services • Parks and Recreation • Regulatory and Environmental Services • Strategic Planning
Lower Hawkesbury EMP	• Capital work • On-ground work • Compliance • Education • Planning • Research
Brisbane Water Estuary CZMP	• Commercial development • Cultural Heritage • Foreshore Development • Governance • Habitat and Species Conservation • Information Communications and Education • Recreational Usage • Sedimentary Processes • Water and Sediment Quality
Pittwater EMP	• Activity Controls / Modifications, • Community Education, • Compliance, • Development Controls, • Environmental and Heritage Rehabilitation, • Land Management Controls, • New / Improved Services and Assets, • Planning Controls, • Pollution Reduction Measures
Gosford Beaches CZMP	Management actions not categorised
Pearl Beach Lagoon CZMP	Management actions not categorised

Table 26 considers management actions that can be implemented with the goal of addressing the identified stressors that are negatively impacting the ecological function of the HNRS. The actions from the management plans have also been assessed for their ability to address each stressor, with key actions from each CZMP/EMP highlighted. The key relevant existing CZMP actions that address each stressor have been tabulated in Appendix C.

Table 26. Management options to address identified stressors

Stressor Linked Scoping Study Stressor IDs	**Management options to address stressor**	**Key relevant existing CZMP actions**
Sea level rise *Long term hazards* - 1.1, 1.2, 1.3 *Climate change impacts* - 3.1 3.6, 3.7, 3.8, 3.9	• **Monitoring** – long timescale changes in water levels, astronomical tides, meteorological events, rainfall patterns, catchment conditions, habitat health and distribution, rates of vertical accretion. • **Planning controls** – including Coastal Management Areas, LEPs, DCPs, PoMs • **Ecosystem migration facilitation** – mapping and reserving accommodation space for habitat migration and supporting land care activities to encourage establishment of desired habitat and removal of weeds. • **Maintain, enhance, and expand healthy estuarine ecosystems** – promote resilience to changing conditions via increased longitudinal and lateral connectivity, thus supporting biodiversity. • **Planned retreat and change land use –** where deemed appropriate, infrastructure and assets can be moved landward, and the subsequent available space can be used to accommodate resilient natural foreshores that can adapt to SLR. • **Blue Carbon -** creation or enhancement of Blue Carbon habitat including tidal reinstatement of isolated wetlands consistent with the Blue Carbon Methodology (Lovelock et al, 2022). Scoping the possibility of Blue Carbon projects in the estuaries that might quality for carbon credits under the Commonwealth's new Blue Carbon Method (tidal reinstatement). Viability of projects is likely to be greater if they are clustered into a single portfolio, so coordination between councils would be advantageous. • **Community and stakeholder education –** about the latest science, SLR projections, estuarine responses, and the benefits of adaptive management.	**Upper Hawkesbury CZMP actions** SLR1, SLR2, 43 **Lower Hawkesbury CZMP actions** 13, 26, 43, 80 **Pittwater CZMP actions** 1b, 3a **Brisbane Water CZMP actions** E08, P16, P43, P46, P60, R19, R40, R42, W60, W71 **Gosford Beaches CZMP actions** PA5, PE18, PE21
Ocean acidification and rising temperatures *Climate change impacts* - 3.2, 3.3 *Habitat disturbance* - 5.6, 5.7	• **Monitoring** – long timescale changes in water quality, catchment conditions, habitat health and distribution, and ecological indicators. • **Planning controls** – including Coastal Management Areas, LEPs, DCPs, PoMs to protect and enhance habitat resilience • **Ecosystem migration facilitation** – mapping and reserving accommodation space for habitat migration and supporting land care activities to encourage establishment of desired habitat and removal of weeds. • **Conserve areas important for the biodiversity of invertebrates –** attention should be paid to priority sites that represent the greatest proportion of species, protecting biodiversity, and allowing for natural, long term adaptation to changing conditions.	**Upper Hawkesbury CZMP actions** ME2, WQ8 **Lower Hawkesbury CZMP actions** 26, 43, 44, 45 **Pittwater CZMP actions** 6c **Brisbane Water CZMP actions** P19, R20, R22, W123

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
	• **Maintain, enhance, and expand healthy estuarine ecosystems** – promote resilience to changing conditions via increased longitudinal and lateral connectivity, thus supporting biodiversity. • **Encourage targeted research –** see knowledge gaps and future research areas (Section 6.4) • **Community and stakeholder education -** about the latest science, CC projections, estuarine responses, and the benefits of adaptive management.	
Altered estuarine hydrology *Event based hazards* - 2.3, 2.5 *Climate change impacts* - 3.4, 3.5	• **Monitoring** – long timescale changes in overland and groundwater flow quantity and timing, water quality, catchment conditions, habitat health and distribution, ecological indicators. • **Improve quality/quantity of environmental flows –** ensuring sufficient freshwater is released to flush pollutants and promote estuarine ecological processes and resilience. • **Manage water supply and demand –** including reuse/recycle of water from Sewage Treatment Plants (STPs) and other elements of water sensitive urban design (WSUD) • **Maintain, enhance, and expand healthy estuarine ecosystems** – promote resilience to changing conditions via increased longitudinal and lateral connectivity, thus supporting biodiversity.	**Upper Hawkesbury CZMP actions** WQ7, WQ2, LPD3, 47, 64 **Lower Hawkesbury CZMP actions** 83, 85, 88, 115, 122 **Pittwater CZMP actions** 3b **Brisbane Water CZMP actions** P04, P30, R24, W01 **Pearl Beach Lagoon CZMP actions** 8
Habitat migration and squeeze *Climate change impacts* - 3.9 *Habitat disturbance* - 5.1 *Recreation and tourism* - 8.4	• **Monitoring** – long timescale changes in habitat health and distribution, ecological indicators. • **Planning controls –** including Coastal Management Areas, LEPs, DCPs, PoMs to prevent further habitat squeeze due to foreshore development. • **Ecosystem migration facilitation** – mapping and reserving accommodation space for habitat migration and supporting land care activities to encourage establishment of desired habitat and removal of weeds. • **Planned retreat and change land use –** where deemed appropriate, infrastructure and assets can be moved landward, and the subsequent available space can be used to accommodate resilient natural foreshores that can adapt to SLR. • **Blue Carbon -** creation or enhancement of Blue Carbon habitat including tidal reinstatement of isolated wetlands consistent with the Blue Carbon Methodology (Lovelock et al, 2022). Scoping the possibility of Blue Carbon projects in the estuaries that might quality for carbon credits under the Commonwealth's new Blue Carbon Method (tidal reinstatement). Viability of projects is likely to	**Upper Hawkesbury CZMP actions** ARH2, ARH3, SLR2, 13, 43, 63 **Lower Hawkesbury CZMP actions** 13, 25, 26, 27, 43, **Pittwater CZMP actions** 1b, 1c, 6c **Brisbane Water CZMP actions** P16, P20, P28, P30, P43, P48, P49, P50, R19, R22, R42, W60, W70, W71 **Gosford Beaches CZMP actions**

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
	be greater if they are clustered into a single portfolio, so coordination between councils would be advantageous. • **Eco-friendly foreshore design –** including ecofriendly seawalls, and nature based bank stabilisation. • **Maintain, enhance, and expand healthy estuarine ecosystems** – promote resilience to changing conditions via increased longitudinal and lateral connectivity, thus supporting biodiversity. • **Community and stakeholder education –** to increase support for protection of ecosystems and ecological processes on private land and in public recreational areas.	O43, PA5, PE18, **Pearl Beach Lagoon CZMP actions** 5
Increased intensity and distribution of bushfires *Event based hazards* - 2.4 *Water Pollution and Sediment Contamination* - 4.5 *Hydrologic Modifications* - 6.3	• **Monitoring and post-fire recovery programs –** long-term monitoring programs should incorporate the quantification of pyrogenic carbon, nutrients, and metals concentration. • **Maintenance of natural vegetation buffers and prevention of fires to reach the water's edge –** buffer zone width (riparian protection zone) should be appropriate for different sections of the waterway. The size of the necessary buffer zone to avoid bushfire impacts will most likely vary depending on estuary type, land use, hillslope erosion, and catchment hydrology. • **Installation and maintenance of sediment traps –** to capture pyrogenic sediments in post-fire runoff.	**Upper Hawkesbury CZMP actions** 38, 42 **Lower Hawkesbury CZMP actions** 15, 57, 129, 131, 143 **Brisbane Water CZMP actions** R22, R24, W06, W07, W14
Catchment and foreshore development *Habitat disturbance* - 5.1, 5.3, 5.4, 5.5 *Recreation and tourism* - 8.1, 8.2, 8.3, 8.4, 8.5 *Access and availability* - 9.1, 9.2	• **Planning controls** – including LEPs, DCPs, and Coastal Management Areas, to guide development assessments and planning in the catchment and on the foreshore. Should be informed by carrying capacity of catchment determined by catchment and estuarine models. • **Utilise WSUD in the catchment –** incorporating best practise sediment, erosion and stormwater controls, water reduction devices and maximal permeable surfaces, constructed wetlands, sediment, and detention basins. • **Enforce compliance with development and construction consent conditions** – (e.g. in subdivisions) to minimise sediment delivery and destruction of riparian vegetation corridors. • **Develop and implement guidelines for foreshore structure design –** including ecofriendly seawalls, jetties, pontoons, boat ramps, dinghy storage, and slipways. Include policy to minimise impact by encouraging less destructive options (i.e., pontoon rather than a boat ramp)	**Upper Hawkesbury CZMP actions** ARH5, FP1, FP3, FP4, LPD5, WQ1, WQ2, LPD3, WQ5, 21, 72, 78 **Lower Hawkesbury CZMP actions** 1, 2, 4, 6, 7, 8, 9, 12, 14, 50, 143, 144 **Pittwater CZMP actions** 1c, 2a, 3e, 3f, 3h, 4f, 7a, 7b **Brisbane Water CZMP actions** C01, C05, C13, C14, E07, E09, P35, P45, P47, P48, R05, R14, R24, R31, W01, W69, W77, W85, W91, W93 **Pearl Beach Lagoon CZMP actions**

Stressor Linked Scoping Study Stressor IDs	**Management options to address stressor**	**Key relevant existing CZMP actions**
	• **Reduce impact of marinas –** by mandating pump-out services, reducing operations waste, and developing effective spill controls and responses. • **Community and stakeholder education –** to increase support for protection of ecosystems and ecological processes on private land and in public recreational areas.	6
Stormwater runoff *Water Pollution and Sediment Contamination* - 4.1, 4.3, 4.5	• **Monitoring** – long timescale changes in water quality, catchment conditions, habitat health and distribution, ecological indicators. Program design should incorporate dry weather and event monitoring of both the tributary mouths and main waterbody. Sampling in the main waterbodies should incorporate vertical profiling. • **Modelling** – review and update (if available) the nutrient budget for the estuary to assess the potential for eutrophication of the more enclosed portions of the waterway. The analysis should assess current conditions and conditions under climate change scenarios. Reference should be made to the water quality modelling undertaken for the estuary as a whole. • **Planning controls** – including LEPs, DCPs, and Coastal Management Areas, to guide development assessments and planning in the catchment and on the foreshore. Should be informed by carrying capacity of catchment determined by catchment and estuarine models. • **Utilise WSUD in the catchment -** incorporating best practise sediment, erosion and stormwater controls, water reduction devices and maximal permeable surfaces, constructed wetlands, sediment, and detention basins. Regular WSUD asset maintenance is critical. • **Enforce compliance with development and construction consent conditions** – (e.g. in subdivisions) to minimise sediment delivery and destruction of riparian vegetation corridors. • **Enforce compliance with pollution controls** – including illegal dumping, EPA licenses, waste disposal sites, dog faeces, and spill management. This also includes preventing certain activities such as coal seam gas and sand mining • **Improve quality/quantity of environmental flows –** ensuring sufficient freshwater is released to flush pollutants and promote estuarine ecological processes. • **Maintain, enhance, and expand healthy riparian vegetation –** to provide a healthy and functional buffer that captures sediments and nutrients before they enter the waterways. • **Community and stakeholder education –** to increase awareness of commercial, industrial, and urban impacts on water quality and the estuarine environment.	**Upper Hawkesbury CZMP actions** ARH1, RA1, WQ2, LPD3, WQ6, WQ7, WQ8, 17, 48, 51, 56, 89 **Lower Hawkesbury CZMP actions** 1, 7, 30, 42, 45, 50, 51, 54, 83, 85, 94, 101, 106, 108, 111, 112, 116, 119, 121, 133, 143, 148 **Pittwater CZMP actions** 3b, 3c, 3d, 7b **Brisbane Water CZMP actions** C02, C03, C10, C15, E02, E18, P01, P02, P04, P05, R01, R03, R04, R05, R06, R10, R24, R44, W01, W04, W06, W07, W09, W10, W122, W14, W44, W51, W91 **Gosford Beaches CZMP actions** O31, O47, PA21 **Pearl Beach Lagoon CZMP actions** 4, 5, 6

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
Agricultural runoff *Water Pollution and Sediment Contamination* - 4.2	• Monitoring – long timescale changes in water quality, catchment conditions, habitat health and distribution, ecological indicators. Program design should incorporate dry weather and event monitoring of both the tributary mouths and main waterbody. Sampling in the main waterbodies should incorporate vertical profiling. • Modelling – review and update (if available) the nutrient budget for the estuary to assess the potential for eutrophication of the more enclosed portions of the waterway. The analysis should assess current conditions and conditions under climate change scenarios. Reference should be made to the water quality modelling undertaken for the estuary as a whole • Community and stakeholder education – to increase awareness of agricultural impacts on water quality and the estuarine environment and provide guidance on actions landholders can take to reduce their negative impact. Promote best practise catchment management including minimising impacts from fertilisers, chemicals, pesticides, and threat of weeds to bushland, and encourage the removal of exotic species and replacement with suitable indigenous plants, domestic animals. Important elements of this engagement are highlighting win-win opportunities where landholders are shown how these actions can benefit them and the environment. • Enhance and maintain riparian vegetation buffers – via planting of native vegetation and fencing of riparian zone to prevent stock access. Minimise clearing of native vegetation. • Planning controls – including LEPs, DCPs, and Coastal Management Areas, to define and map minimum buffer widths for riparian/foreshore vegetation, and guide development assessments and planning in the catchment and on the foreshore. • Public-Private partnerships – provide incentives to landholders to conserve significant habitats and native vegetation identified on private land (e.g. through property vegetation plans and voluntary conservation agreements), and incentives for the establishment of riparian filters to treat run-off from areas which may generate potentially high pollutant loads in runoff (eg, livestock, turf farms etc).	Upper Hawkesbury CZMP actions ARH1, ARH3, ARH5, WQ3, WQ8, 35, 42, 48, 49, 57, 76 Lower Hawkesbury CZMP actions 11, 13, 25, 27, 29, 48, 52, 55, 56, 57, 120, 124, 143

Stressor Linked Scoping Study Stressor IDs	**Management options to address stressor**	**Key relevant existing CZMP actions**
Sewage and wastewater runoff *Water Pollution and Sediment Contamination* - 4.4 *Hydrologic Modifications* - 6.2	• **Monitoring** – long timescale changes in water quality, catchment conditions, habitat health and distribution, ecological indicators. Program design should incorporate dry weather and event monitoring of both the tributary mouths and main waterbody. Sampling in the main waterbodies should incorporate vertical profiling. • **Modelling** – review and update (if available) the nutrient budget for the estuary to assess the potential for eutrophication and the influence of wastewater (Rush, 2003) on the more enclosed portions of the waterway. The analysis should assess current conditions and conditions under climate change scenarios. Reference should be made to the water quality modelling undertaken for the estuary as a whole • **Ensure a high standard of on-site sewage management (OSSM) –** including via license pump-out operation, septic system owner education, regular maintenance and replacement. • **Improved quality of water from wastewater discharges –** working with Sydney Water and State Government to raise standards. Upgrading Sewage Treatment Plants (STPs), increasing wet weather capacity of STPs in catchment to ensure no bypassing during wet weather. • **Increase re-use/recycle of wastewater** – implement re-use options (such as dual reticulation, drinking water or other system) for treated effluent from STPs and their reticulation systems (eg sewer mining). • **Reduce impact of maritime sewage –** provide easy access to pump-out facilities throughout the waterways and encourage boaters to follow guidelines. Require all marinas to provide accessible pump-out facilities as a component of their licence to operate in the HNRS. • **Planning controls** – including LEPs, and DCPs to incorporate best practice on-site sewage management. A focus on new dwellings or major alterations and additions to existing dwellings in the vicinity of priority oyster harvest areas to consider installation of pump-out sewage systems where feasible. • **Community and stakeholder education –** to increase awareness of boaters responsibilities with respect to the disposal of ballast, sewage and rubbish, the location of existing sewage pump-out and rubbish disposal facilities, and how to safeguard against leaks and spills, and what to do if a leak or spill occurs.	**Upper Hawkesbury CZMP actions** WQ2, LPD3, 44, 52, 55, 70 **Lower Hawkesbury CZMP actions** 7, 9, 10, 39, 87, 91, 92, 93, 96, 97, 98, 103, 105, 110, 113, 114, 116, 117 **Pittwater CZMP actions** 3c, 7c, 9d **Brisbane Water CZMP actions** E11, W02, W03, W05, W115, W120 **Gosford Beaches CZMP actions** PE1, PE3

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
Water extraction – surface and groundwater *Hydrologic Modifications* - 6.1, 6.2	• **Increased water use efficiency in the catchment –** to reduce the water footprint of development, ensuring that water savings are passed on to the estuary and not solely used to justify increased development. • **Increase re-use/recycle of wastewater** – implement re-use options (such as dual reticulation, drinking water or other system) for treated effluent from STPs and their reticulation systems (eg sewer mining). • **Improved quality of water from wastewater discharges –** working with Sydney Water and State Government to raise standards. Upgrading Sewage Treatment Plants (STPs), increasing wet weather capacity of STPs in catchment to ensure no bypassing during wet weather. • **Utilise WSUD in the catchment -** incorporating best practise sediment, erosion and stormwater controls, water reduction devices and maximal permeable surfaces, constructed wetlands, sediment, and detention basins. Regular WSUD asset maintenance is critical. • **Planning controls** – including LEPs, and DCPs and BASIX to incorporate best practice water use management. • **Prevention/minimisation of extractive industrial activities –** including coal seam gas, mining, etc. Regulate surface and ground water extraction (through licences etc) based upon assessment of required environmental flows. • **Increase environmental flows –** effective freshwater releases from storages to enhance ecological function considering timing and volume.	**Upper Hawkesbury CZMP actions** WQ2, LPD3, WQ7, WQ8, 17, 47, 62, 77, 78, 86 **Lower Hawkesbury CZMP actions** 1, 2, 7, 50, 83, 84, 85, 86, 87, 88, 107, 114, 115 **Pittwater CZMP actions** 3b **Brisbane Water CZMP actions** P04
Barriers to longitudinal and lateral connectivity *Habitat Disturbance* - 5.1, 5.2, 5.3, 5.4, 5.5 *Recreation and tourism* - 8.4	• **Remove unnecessary in stream structures –** including weirs and dams. Where removal is not feasible, alterations to improve fish passage and sediment mobilisation should be prioritised. • **Increase environmental flows –** freshwater releases from storages to enhance ecological function. These should be of sufficient volumes to temporarily inundate low lying habitats. • **Remove unnecessary foreshore structures –** such as seawalls, revetments, boat ramps, etc, Where removal is not feasible, structures should be redesigned to incorporate fish friendly habitat features including eco-friendly sea walls, deliberate placement of large woody debris, and intertidal structures.	**Upper Hawkesbury CZMP actions** ARH2, ARH3, FP1, FP3, FP4, LPD1, LPD5, RA3, SLR2, 13, 38, 42, 62, 71, 88 **Lower Hawkesbury CZMP actions** 8, 11, 13, 15, 25, 26, 27, 28, 29, 36, 43, 44, 48, 131 **Pittwater CZMP actions** 1b, 1c, 4e, 6c, 6d **Brisbane Water CZMP actions**

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
	• **Ecosystem migration facilitation** – mapping and reserving accommodation space for habitat migration and supporting land care activities to encourage establishment of desired habitat and removal of weeds. • **Maintain, enhance, and expand healthy estuarine ecosystems** – assess the habitat condition and viability of programs providing resilience to changing conditions via increased biodiversity. Where viable, encourage the planting of appropriate native species to enhance connectivity, green corridors and succession of desired adult trees. Fence existing saltmarshes and other riparian foreshore areas to prevent access by vehicles, bikes and domestic animals. • **Blue Carbon -** creation or enhancement of Blue Carbon habitat including tidal reinstatement of isolated wetlands consistent with the Blue Carbon Methodology (Lovelock et al, 2022). Scoping the possibility of Blue Carbon projects in the estuaries that might quality for carbon credits under the Commonwealth's new Blue Carbon Method (tidal reinstatement). Viability of projects is likely to be greater if they are clustered into a single portfolio, so coordination between councils would be advantageous. • **Planning controls** – including LEPs, DCPs and CMAs to incorporate conservation of biodiversity corridors, riparian buffers, and estuarine vegetation areas. Update and implement Plans of Management, ensuring maintenance of habitat mix / diversity (which may include selective removal of mangrove seedlings that have encroached onto saltmarsh areas from time to time) • **Public-Private partnerships –** provide incentives to landholders to conserve significant habitats and native vegetation identified on private land (e.g. through property vegetation plans and voluntary conservation agreements).	C14, E09, P16, P19, P20, P27, P30, P48, P49, P50, R14, R19, R22, W123, W26, W29, W43, W48, W59, W60, W66, W67, W69, W70, W71 **Gosford Beaches CZMP actions** O18, O22, O43 **Pearl Beach Lagoon CZMP actions** 2, 5, 8
Erosion and Sedimentation *Long Term Hazards* - 1.2 *Habitat Disturbance* - 5.1, 5.2, 5.3, 5.4, 5.5 *Hydrologic Modifications* -6.3	• **Undertake bank stabilisation works –** prioritising active erosion sites, and sites near seagrass beds. Various erosion drivers such as boat wake, river and tidal flows, bank saturation, and wave action will require different stabilisation approaches. • **Enhance and maintain riparian vegetation buffers –** via planting of native vegetation and fencing of riparian zone to prevent stock access. Minimise clearing of native vegetation. • **Enforce compliance with development and construction consent conditions** – (e.g. in subdivisions) to minimise sediment delivery and destruction of riparian vegetation corridors. • **Reduce sediment supply from rural landscapes** – incorporate best practise land management, stock management, fertiliser and pesticide use, erosion controls and runoff controls to reduce pollutant and sediment loads from rural lands.	**Upper Hawkesbury CZMP actions** FP6, FP7, LPD5, ME1, WQ2, LPD3, WQ3, WQ4, WQ5, 42, 45, 51, 83, 87, 90 **Lower Hawkesbury CZMP actions** 7, 8, 13, 25, 50, 52, 57, 59, 111, 124, 129, 130, 147 **Pittwater CZMP actions** 3d, 3g, 6b, 9c **Brisbane Water CZMP actions** C14, P01, P05, P07, P09, P14, P49, R04, R09, R10, R11, R16, R24, R43, W04, W06, W07, W09, W10, W14, W26,

Stressor Linked Scoping Study Stressor IDs	**Management options to address stressor**	**Key relevant existing CZMP actions**
	• **Utilise WSUD in the catchment –** incorporating best practise sediment, erosion and stormwater controls, water reduction devices and maximal permeable surfaces, constructed wetlands, sediment, and detention basins. Regular WSUD asset maintenance is critical.	W27, W34, W35, W38, W39, W41, W44, W45, W48, W49, W52, W53 **Gosford Beaches CZMP actions** O17 **Pearl Beach Lagoon CZMP actions** 9
Dredging *Water Pollution and Sediment Contamination* -4.6 *Hydrologic Modifications* - 6.4	• **Reduce impact of required dredging –** all dredging should be compliant with environmental approvals and follow best practice for reducing environmental impact. Consideration is needed for nearby benthic habitat, especially seagrass and sponges. Sediment plumes should be minimised. Contaminated dredge spoil must be removed and remediated accordingly. Beneficial dredge spoil should be used in accordance with environmental approvals. • **Design navigational channels to minimise dredging –** an understanding of sediment dynamics should be used to design and place navigational channels and signage in locations with lower sedimentation rates. Using natural processes to maintain navigable channels is preferable to intermittent dredging. • **Relocate recreational assets to reduce dredging –** assets such as pump-out stations, public jetties and boat ramps should be relocated where feasible to areas that don't require intermittent dredging. A balance is required between enabling access to facilities and selecting appropriate sites.	**Upper Hawkesbury CZMP actions** 65, 124, 125 **Pittwater CZMP actions** 2d **Brisbane Water CZMP actions** P07, P08, P39, R09, R45
Sediment contamination *Water Pollution and Sediment Contamination* -4.5, 4.6	• **Identify existing deposits of contaminated sediment –** allowing for targeted remediation, and avoidance of activities that cause disturbance and resuspension. • **Identify and mitigate sources of contaminants–** contaminant sources from the catchment or waterways including industrial estates, waste management, marinas, and agriculture can be addressed with actions that limit pollution, manage stormwater, treat and intercept pollution. • **Communication and education -** liaise directly with land owners/ managers to reduce nutrient and sediment inputs. Promote the use of oil absorbent devices for the removal of fuels and oils from bilge water.	**Upper Hawkesbury CZMP actions** RA1, WQ2, LPD3, WQ3, 44, 48, 51 **Lower Hawkesbury CZMP actions** 7, 9, 30, 54, 55, 56, 67, 69, 94, 100, 101, 102, 106, 108, 109, 119, 120, 121, 124, 125, 129 **Pittwater CZMP actions** 3d, 7a, 7b, 8b **Brisbane Water CZMP actions**

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
		C01, E02, P01, Po2, P03, P05, R04, R24, R43, R45, W01, W09, W27 **Pearl Beach Lagoon CZMP actions** 9
Invasive species *Habitat Disturbance* - 5.6, 5.7	• **Map the extent of invasive species –** weeds of concern should be periodically mapped to provide information on where weed management should be targeted. • **Monitor the presence of invasive fauna –** working with commercial and recreational fishers, exotic species can be identified to provide information on changing ecosystem structure. • **Coordinated removal of invasive species – o**n public land, this can be implemented under Plans of Management for parks and reserves. Community resources should be harnessed through activities and organisations such as local Bushcare groups. • **Promote growth of native vegetation -** well established native vegetation can diminish the spread of invasive species. • **Communication and education –** private land holders should be trained to identify and remove known invasive weeds. Citizen science applications such as Deckee - Boating App for Maps, Weather, Reports & Alerts can also support data collection and estuarine user awareness of multiple issues.	**Upper Hawkesbury CZMP actions** ARH4, ARH6, 13, 25, 37, 61, 69, 82 **Lower Hawkesbury CZMP actions** 11, 15, 27, 28, 36, 55, 127, 128, 131, 132, 133, 134, 145, 146 **Pittwater CZMP actions** 1c, 2a, 6d **Brisbane Water CZMP actions** P19, P20, P23, P27, P28, R20, R25, W66, W70, W71, W73 **Gosford Beaches CZMP actions** O18, O22, O30, O37, O46, O7, PA15, PA23, PE16 **Pearl Beach Lagoon CZMP actions** 2, 5
Commercial fishing *Commercial Fishing and Boating* - 7.1, 7.2, 7.3	• **Compliance –** ensuring compliance with existing regulations to protect fisheries and ensure sustainable and resilient populations. • **Promote sustainable fishing techniques –** such as those that limit unintended bycatch of non-utilised species, marine mammals, reptiles, seabirds and impacts on associated or dependent species using such measures as mesh or gear modifications, closed areas and bycatch reduction devices. • **Communication and education –** targeting commercial fishers to ensure they understand the immediate action required to mitigate impacts on protected or endangered species from their trawling operations	**Lower Hawkesbury CZMP actions** 19, 20, 22, 23, 35, 39, 67, 89, 91, 101, 109, 145, 146 **Brisbane Water CZMP actions** P07, R44

Stressor Linked Scoping Study Stressor IDs	**Management options to address stressor**	**Key relevant existing CZMP actions**
Recreational fishing *Recreation and tourism* - 8.1	• **Compliance –** ensuring compliance with regulations on bag limits, minimum fish sizes, and species lists, etc • **Promote sustainable fishing techniques –** such as those that limit unintended bycatch of non-utilised species, marine mammals, reptiles, seabirds and impacts on associated or dependent species using such measures as mesh or gear modifications, closed areas and bycatch reduction devices. • **Reduce the impact of foreshore access –** by restricting foreshore access in areas of high environmental sensitivity, ensuring adequate waste disposal facilities in areas of high visitation. • **Communication and education –** to promote responsible fishing practices, encourage catch and release, prevent littering, and to highlight unique values of estuary.	**Lower Hawkesbury CZMP actions** 4, 16, 19, 21, 36, 39, 41, 62, 135, 137, 144, 145 **Pittwater CZMP actions** 8f **Brisbane Water CZMP actions** C04, C15, E14, P41, R18, R31, W123 **Gosford Beaches CZMP actions** O19, O21
Active boating *Commercial Fishing and Boating* - 7.4 *Recreation and Tourism* - 8.2	• **Minimise the impact of boat generated wake –** including by creating no-wake zones in the waterways, restricting the use of ballast, and protecting foreshore with wave dissipating techniques such as floating booms, artificial reefs, or bank reprofiling and stabilisation. Closing the river to recreational boats during high water events can prevent boat wakes from impacting on higher banks. • **Minimising the number of access structures allowed** – reducing the number of access structures allowed within development approvals and ensuring public access points are designed to accommodate expected crowds. • **Prevent boats from disturbing sensitive habitats –** including preventing boats from traversing seagrass meadows, oyster harvest areas, and accessing saltmarshes. Navigational aids can be used to direct boat traffic. • **Reduce impact from moorings –** prevent the installation of additional chain moorings, and progressively replace existing moorings with environmentally friendly, seagrass safe design. • **Avoid 2 stroke motors –** due to their higher emissions and pollution generation compared to four stroke motors. • **Communication and education –** to promote responsible boating, inform about the location of waste pump out facilities, and to encourage environmentally responsible behaviours. The "River Code" can continue to be promoted.	**Upper Hawkesbury CZMP actions** FP7, 45, 67, 70, 83, 87 **Lower Hawkesbury CZMP actions** 5, 9, 16, 24, 34, 39, 60, 61, 62, 63, 64, 66, 67, 68, 91, 93, 132 **Pittwater CZMP actions** 3h, 4a, 4b, 4c, 4d, 4f, 4g, 5a, 7a, 8a, 8b, 9a, 9b, 9e **Brisbane Water CZMP actions** C08, C12, E01, E11, P03, P08, P41, R09, R31, W02, W05, W65, W87

Stressor Linked Scoping Study Stressor IDs	Management options to address stressor	Key relevant existing CZMP actions
Passive boating *Recreation and Tourism - 8.3*	• **Manage access –** by providing sufficient well designed access points throughout the estuary and discouraging informal access via ecologically sensitive areas. • **Communication and education –** to promote responsible boating, discourage littering, and maximise the public appreciation of the environmental values of the estuary.	**Upper Hawkesbury CZMP actions** LPD4, 50, 81 **Lower Hawkesbury CZMP actions** 4, 5, 16, 24, 34, 36, 39, 61, 135, 137, 144 **Pittwater CZMP actions** 5a **Brisbane Water CZMP actions** P35, P41, R31 **Gosford Beaches CZMP actions** O19, O21, O23
Swimming *Recreation and Tourism - 8.3*	• **Manage access –** by providing sufficient well designed access points throughout the estuary and discouraging informal access via ecologically sensitive areas. • **Promote the use of marine friendly sunscreen –** to avoid the introduction of harmful chemicals into waterways. • **Communication and education –** to promote responsible recreation, discourage littering, and maximise the public appreciation of the environmental values of the estuary.	**Upper Hawkesbury CZMP actions** LPD4 **Lower Hawkesbury CZMP actions** 16, 36, 41, 66, 132, 135, 137, 144 **Pittwater CZMP actions** 5a, 8a **Brisbane Water CZMP actions** P41, R31 **Gosford Beaches CZMP actions** O19, O21, O23, O27

6.3 Strategic planning as a management tool

A system wide approach to developing the HNCMP provides a vehicle for the coordinated and strategic management of the estuarine system. This approach can also foster alignment with regional and strategic planning initiatives (Water Technology, 2020). This approach provides an impetus to use available strategic planning tools to enhance the environmental values of the HNRS system while supporting legislated objectives.

Local and State governments have a variety of strategic planning tools available to achieve conservation and positive ecological outcomes. For local governments these include:

- Local Strategic Planning Statements (LSPS) – set out the 20-year vision for land use in the local area, the special character and values that are to be preserved and how change will be managed into the future. A council's LSPS guides the evolution of LEPs and DCPs over time to meet the community's needs.
- Local Environmental Plans (LEPs) - guide planning decisions for local government areas through zoning and development controls. They provide a local framework for the way land can be developed and used. LEPs are the main planning tool to shape the future of communities by ensuring local development is carried out appropriately.
- Development Control Plans (DCPs) - provides detailed planning and design guidelines to support the planning controls in the Local Environmental Plan developed by a council.

For State government these include:

- Regional Plans - State-led strategic planning documents which set the direction and establish objectives for delivering the vision for a liveable productive, and sustainable planning framework in NSW. Relevant regional plans for the HNRS are the Greater Sydney Metropolitan Regional Plan and the Central Coast Regional Plan.
- District Plans - Five district plans implement the vision and objectives of the Greater Sydney Region Plan at a district level. These 20-year plans provide a bridge between regional and local planning to inform LEPs, local strategic planning statements (LSPS), community strategic plans and the assessment of planning proposals. Relevant district plans for the HNRS are the North and Western City District Plan.
- State Environmental Planning policies (SEPPs) - instruments that address planning issues on a state-wide level. This is different to a LEP that addresses planning controls for a local government area.

Examples of planning instruments that are currently used to protect natural features and processes of the HNRS are described in Table 27.

Table 27. Examples of planning instruments currently used to protect natural features and processes of the HNRS.

Feature	Environmental Planning Instrument giving effect	Description and role in protecting HNRS
Resilience to natural hazards	Resilience and Hazards SEPP	Commencing 1 March 2022, the SEPP consolidates the *SEPP (Coastal Management) 2018,* which contain provisions for and use planning within the coastal zone, in a manner consistent with the objects of the *Coastal Management Act 2016*.
Biodiversity and conservation	Biodiversity and conservation SEPP	Commencing 1 March 2022, the new Biodiversity and Conservation SEPP consolidates, among others, the previously enacted *Sydney Regional Environmental Plan No 20 – Hawkesbury – Nepean River (No 2 – 1997), SEPP (Sydney Drinking Water*

		Catchment) 2011, SEPP No 19—Bushland in Urban Areas, SEPP (Vegetation in Non-Rural Areas) 2017.
Planned Urban Growth	SEPP (Precincts - Central River City) 2021 & SEPP (Precincts - Western Parkland City) 2021	Commencing 1 March 2022, these new SEPPs contains planning provisions for precincts identified as growth centres previously encompassed in the SEPP (Sydney Region Growth Centres) 2006.
Riparian Lands Watercourses	Various Catchment Council LEPs	Identifies land where development implications exist to reduce impacts in riparian lands and watercourses. These are recognised as a transition zone between the land and the watercourse that is important for maintaining or improving the shape, stability and ecological functions of a watercourse.
Scenic Protection	Blue Mountains LEP, Penrith LEP	Identifies the land where development implications exist to reduce visual impacts in scenic areas. This has the added benefit of protecting the landscape and ecological features in these areas which contribute to the scenic values being protected.

6.3.1 Using strategic planning to achieve positive ecological outcomes

Both the Coastal Environment Area (CEA) and the Coastal Wetlands and Littoral Rainforest Area (CWLRA) provide strong protection for vulnerable estuarine habitats. They encourage rehabilitation and restoration of degraded areas and promote the improvement of ecological resilience, including opportunities for migration due to sea level rise and other stressors. This promotes the protection and stewardship of key ecological processes in the HNRS such as primary and secondary production, nutrient dynamics and cycling, and lateral connectivity. Therefore, classifying land as these under the Resilience and Hazards SEPP is a powerful tool for achieving positive ecological outcomes. This provides an opportunity for promoting ecological values by strategically increasing the coverage of this land classification within the HNRS.

A Planning Proposal is needed to amend the mapping of these areas under the RH SEPP. A Planning Proposal involves (among other requirements) providing a statement of the objectives or intended outcomes of the proposed instrument, and the justification for those objectives. A Planning Proposal to expand the CEA and CWLRA would promote the protection and stewardship of key ecological processes in the HNRS and support the strategic objectives of local and state government including LSPS, LEPs, and the coastal management framework, and the marine estate management strategy.

Analysis of the current RH SEPP CWLRA map indicates that such an opportunity exists. A comparison of the RH SEPP CWLRA map with other available habitat maps such as the DPI Fisheries Estuarine Habitat Mapping Tool (available at Geocortex Viewer for HTML5 (nsw.gov.au)) and the NSW Wetlands spatial data (NSW Wetlands | Anzlic Dataset | SEED) (Kingsford et al., 2004) shows that some known habitats that can be classified within the definition of CWLRA exist in locations outside the current maps. The process to determine this overlap is described below.

The NSW Wetlands spatial data maps floodplain wetlands, freshwater lakes, saline lakes, reservoirs, estuarine wetlands and coastal lagoons and lakes. Features classified as estuarine wetland and floodplain wetlands within the tidal range were extracted for analysis. Mangrove and saltmarsh from the DPI Fisheries spatial data were also extracted. Seagrass habitat was not extracted because it is not classifiable as CWLRA. These two datasets were then overlayed onto the existing CWLRA map. Mapped wetlands, mangroves and saltmarsh habitat located outside of the CWLRA were identified. These identified features were then screened to determine if they were located within the National Park estate, the reason being that these would already be offered a level of protection due to their National Park status. The remaining features comprise habitat that could justifiably be included in the CWLRA.

While some of these features are located on the edge of existing CLWRA locations and are captured in the CWLRA proximity zone, this should not rule them out for consideration as CWLRA proper as such inclusion would serve to expand the proximity zone and therefore the area of protection offered by the RH SEPP. It should also be noted that this approach is based on a high-level spatial analysis and has not been quality checked in detail. It is likely that further detailed analysis would be needed to support a planning proposal that would be used to update the RH SEPP map.

Table 28 provides the area (ha) of each mapped coastal wetland habitat, within each of the Partner Council LGAs, not currently included in RH SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate. Central Coast Council acknowledges that the CWLRA mapping within its LGA is inaccurate in part and has recently produced updated mapping of wetland habitats (Eco Logical Australia, 2022). This is substantiated by the analysis described above with Central Coast Council showing approximately 240 ha of mapped coastal wetland habitat not currently included in RH SEPP, more than 4 times more than any other of the Partner Councils. Hawkesbury City Council and Hornsby Shire Council each have about 60 ha available. Maps for each of the Partner Council LGAs (except Ku-Ring-Gai) are provided in Figure 51 – 55.

Table 28. Area (ha) of mapped coastal wetland habitat not currently included in RH SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate with values for each Partner Council LGA.

Map source	Habitat	CCC	HCC	HSC	KC	NBC	THSC	Total
NSW Wetlands map	Estuarine Wetland	148.08	-	21.71	-	-	-	169.78
	Floodplain Wetland	4.19	55.48	-	-	-	6.75	66.42
DPI Fisheries map	Mangrove	66.01	-	34.97	0.05	2.45	-	103.48
	Saltmarsh	25.34	-	4.10	-	0.21	-	29.65
	Total	243.61	55.48	60.78	0.05	2.66	6.75	369.33

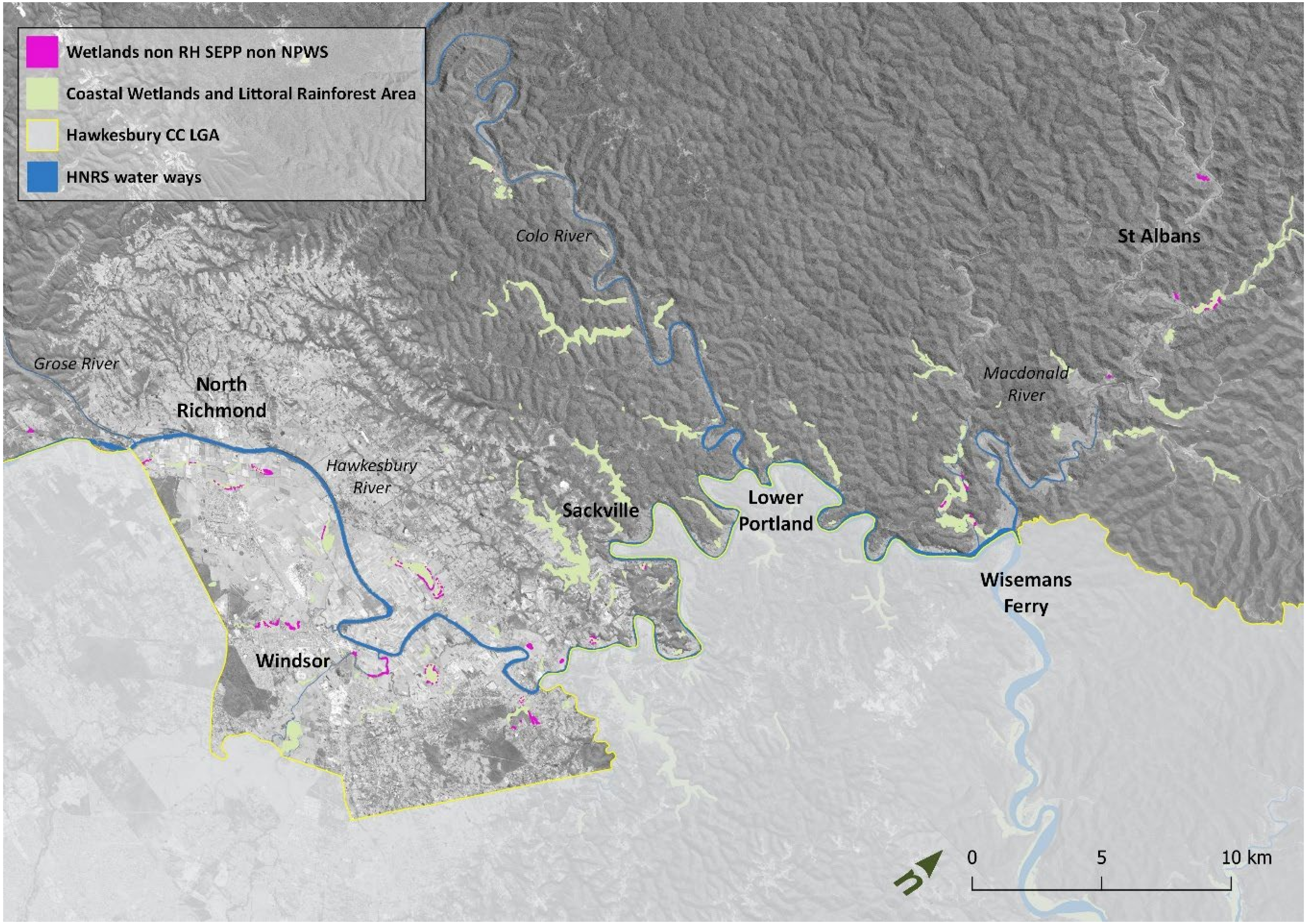


Figure 51. *Area of mapped coastal wetland habitat in Hawkesbury City Council not currently included in Resilience and Hazard SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate.*

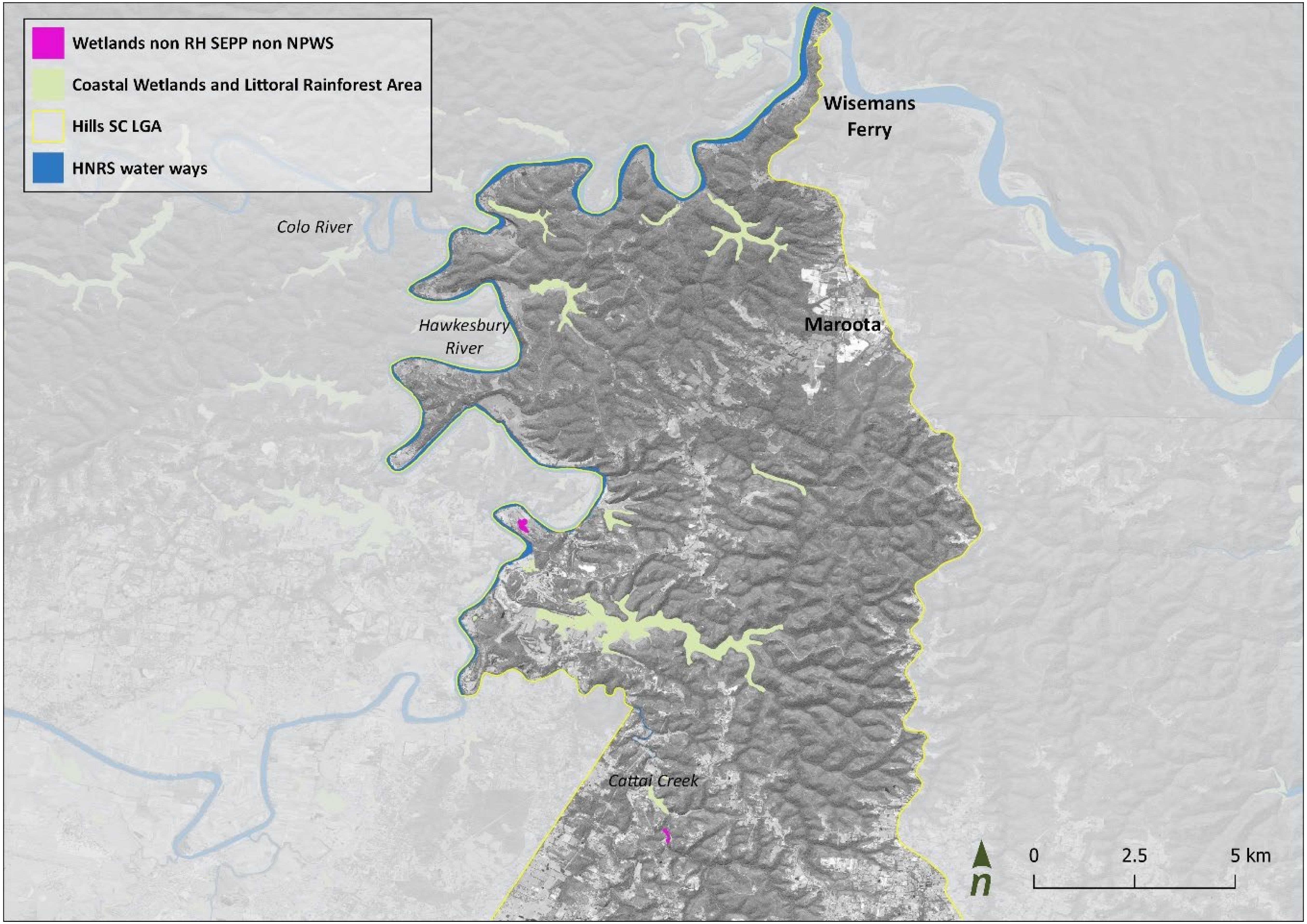


Figure 52. *Area of mapped coastal wetland habitat in The Hills Shire Council not currently included in Resilience and Hazard SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate.*

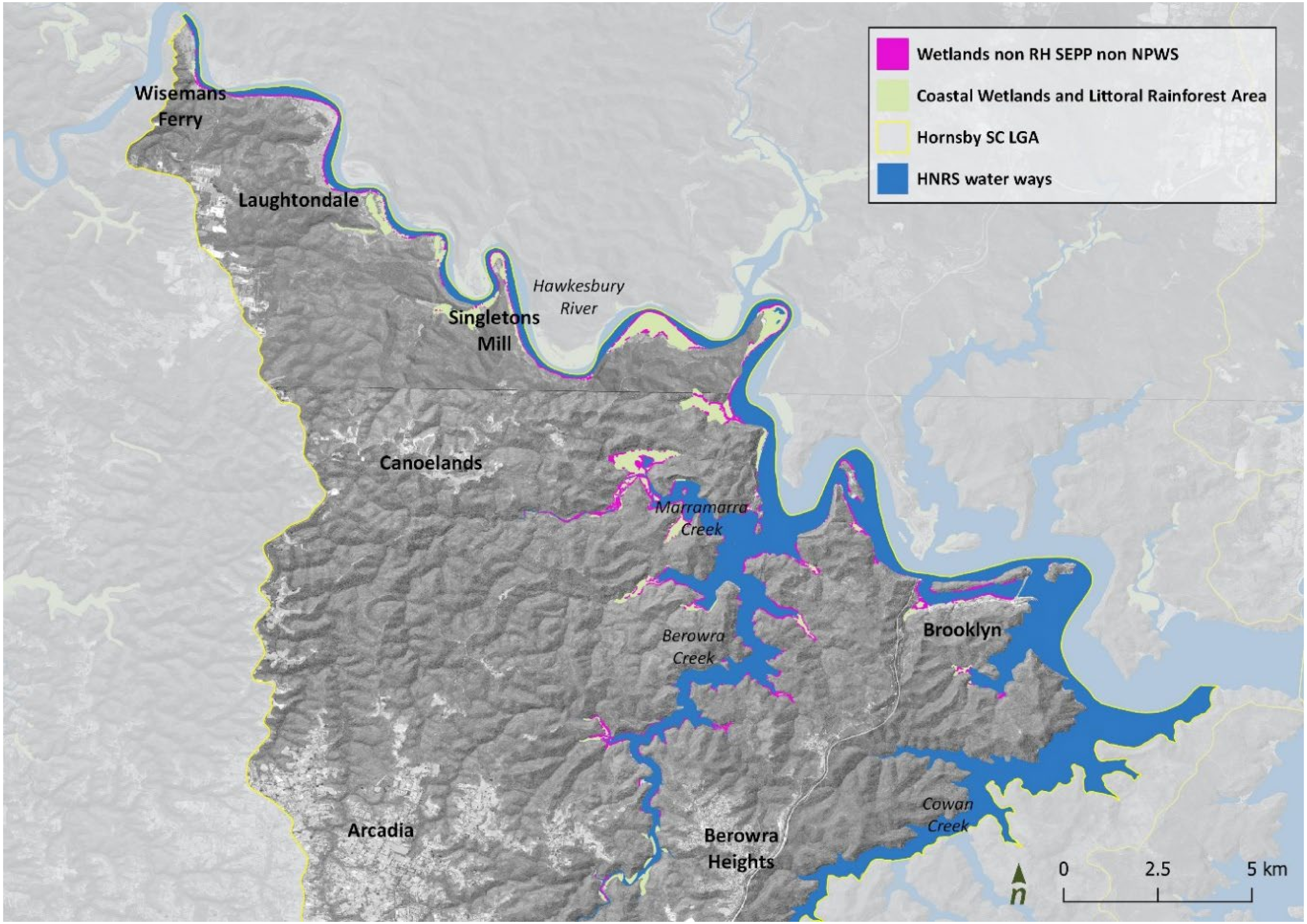


Figure 53. *Area of mapped coastal wetland habitat in Hornsby Shire Council not currently included in Resilience and Hazard SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate.*

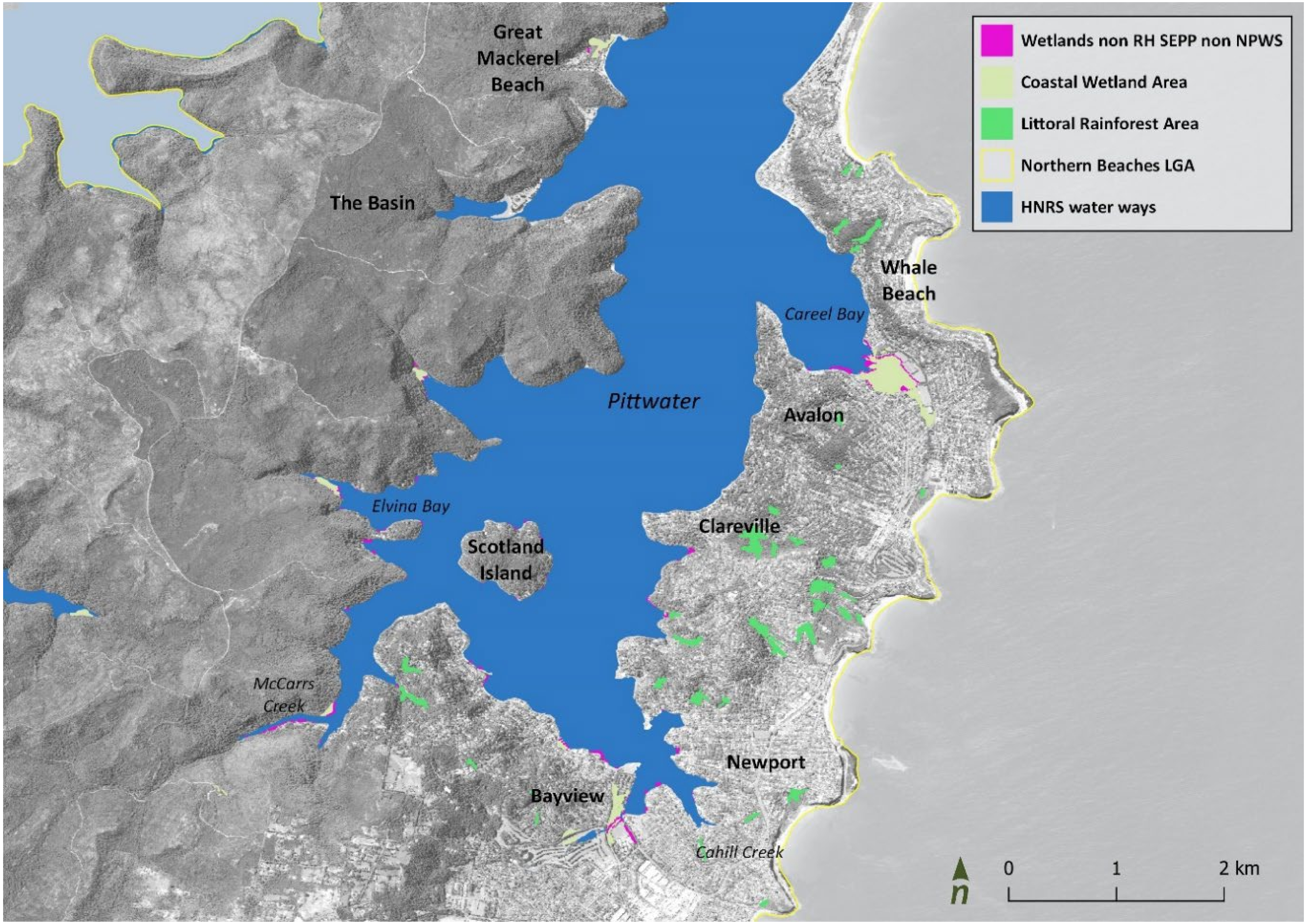


Figure 54. *Area of mapped coastal wetland habitat in Northern Beaches Council not currently included in Resilience and Hazard SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate.*

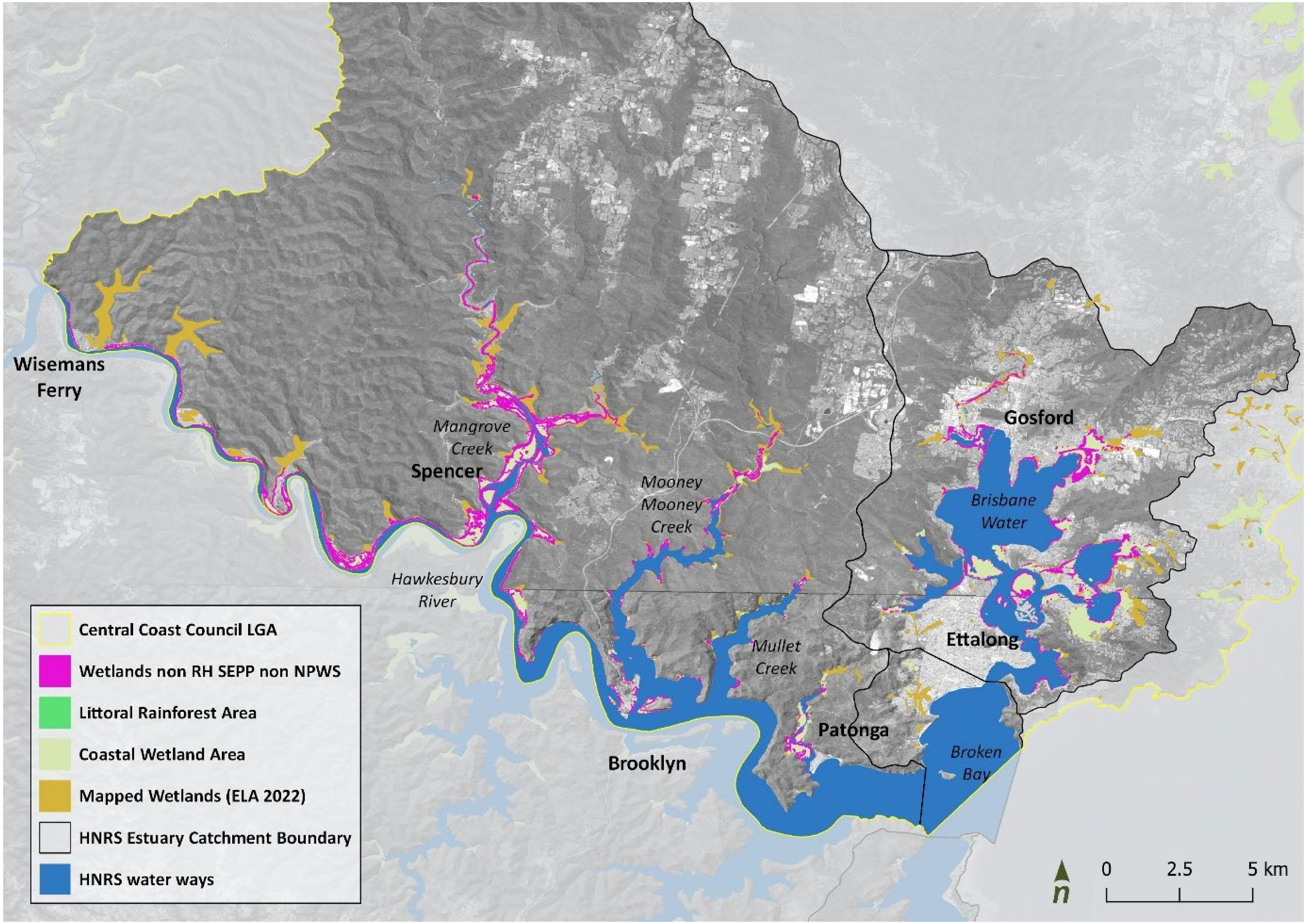


Figure 55. *Area of mapped coastal wetland habitat in Central Coast Council not currently included in Resilience and Hazard SEPP Littoral Rainforest/ Coastal Wetland nor within National Parks Estate. Recent wetland mapping from* Eco Logical Australia 2022 *is included.*

6.4 Knowledge gaps and future research areas

The literature review, synthesis of existing information, and conversations with experts and key stakeholders has led to the identification of knowledge gaps and future research areas that can be addressed to continue to improve the management and understanding of the HNRS. The identification and bridging of knowledge gaps should be done through the lens of developing conceptual and numerical models that will aid in management objectives within the HNRS. It is recommended that research and monitoring programs to address knowledge gaps be designed in close collaboration with model developers to maximise the utility of the data collected.

6.4.1 Current initiatives aiming to address knowledge gaps

Hawkesbury Nepean River and South Creek model

The Hawkesbury Nepean River and South Creek model (the HN model) is operated by Sydney Water and DPE, as is specifically designed to provide guidance on the likely quantitative differences in water quality and quantity when contrasting different catchment conditions, environmental flows, wastewater discharges and land use scenarios over time. The HN model was developed for Sydney Water by SKM (now Jacobs Pty Ltd) in partnership with BMT WBM, eWater, University of Western Australia and Yorb. It was also independently peer reviewed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for design and technical quality.

In particular, the HN model was developed to inform planning for growth and consider potential future changes to Sydney Water's Environment Protection Licences. The HN model allows users to better understand:

- the difference in receiving water quality and flow between diffuse and point source pollution
- the impact of wastewater treatment plant discharge in wet, dry and average weather conditions, and
- the complex interactions that can occur within such a large river system

The model has significantly improved our ability to evaluate management and planning scenarios, especially in terms of their relative impact on flows and water quality. Sydney Water is committed to continuously improve the model through processes of re-calibration and validation against contemporary observations and incorporating major catchment changes.

At the time of its completion in 2013, the HN Model was industry best practice. However, since 2013, notable improvements have occurred in both modelling software and the scientific understanding of the catchment and aquatic processes. Sydney Water is commencing work to revise the models to leverage these improvements to make better business and wastewater management decisions for the community and the environment.

DPE Hawkesbury Nepean River Knowledge Gap Strategy

The Department of Planning and Environment – Estuary and Coasts Science (DPE ECS) has developed a knowledge gap strategy based on a review of long-term monitoring data and the preliminary results of a recent field campaign (DPE ECS, 2021). This strategy focuses on catchment, hydrodynamic, and biogeochemical processes that represent the linkages between catchment inputs and ecosystem function and allow for scenario testing. The main knowledge gaps identified in that review are selected because they are limiting factors in the improvement of the HN model. The knowledge gaps identified in this strategy are summarised below, noting that the full strategy includes more detail and that this list should not be considered comprehensive:

- phytoplankton dynamics – including growth rates, sinking velocities, mortality/grazing rates, interaction between diffuse and point source nutrients, and controls over *Microcystis* bloom development.
- macrophyte dynamics – including improving the model's capability in accounting for macrophyte infestations as an expression of eutrophication
- nutrient and sediment dynamics – including improving understanding of diffuse and point source pollution, internal recycling and resuspension of sediments with organic matter content, and the implications of large imbalances in Nitrogen and Phosphorus for phytoplankton composition and the flow-on effects for higher food web interactions.

- **catchment model issues –** including quantifying flow-weighted measures of nutrient concentrations in runoff from key land use types throughout the catchment and improving the understanding of groundwater discharges.
- **Location specific processes –** including the unique hydrodynamic and biogeochemical characteristics of Berowra Creek and the biogeochemical and ecological function of South Creek.

6.4.2 Additional knowledge gaps regarding ecological structure and function

Several topics related to the ecological structure and function of the HNRS have been identified in addition to the biogeochemistry focused knowledge gaps included in the preliminary Hawkesbury Nepean River Knowledge Gap Strategy. These are described in Table 29:

Table 29. Additional knowledge gaps relating to ecological structure and function.

Topic	Category	Knowledge gap
Ecological structure	Flora	• Condition of main vegetation types (eg condition protocols and the subsequent on ground application to quantify condition). • Changes in major vegetation types (in terms of extent or condition) in response to population growth or climate change pressures over time (eg replacement of saltmarsh by mangroves, loss of riparian paperbark or she-oak woodlands). • Sensitivity/resilience of major vegetation types to anthropogenic stressors (e.g. sensitivity of different spp. Of seagrass to temperature increase or changes in nutrient and underwater light regimes). • Extent of infestations and quantification of the effectiveness of existing control measures for undesirable plants (introduced and native). • Responses of flora to nutrient enrichment (eg replacement of seagrasses by benthic algae; shifts in biomass retention in above- vs below-ground organs in mangroves).
	Fauna	• The abundance and recruitment success of native recreational and commercial fisheries, birds and aquatic invertebrates stocks in the estuary. • Responses of the fauna to anthropogenic pressures, in particular changes to flow regimes, of estuarine fish populations (e.g., the purported decrease in Mulloway populations; sensitivity of Yellowfin Bream populations to changes in location of tidal wedge, etc.). • Information assist in managing the impact of aquatic diseases (i.e. QX oyster disease, Pacific Oyster Mortality Syndrome, red spot disease in prawns, bass norovirus, fish deformities (i.e. Lordosis)). • Better understanding of the roles of jellyfish in the river system, and their abundance and biomass under differing environmental conditions. • Improving understanding of the HNRS influence on the productivity of adjacent nearshore shelf environments to provide regional context of the HNR and its importance to numerous nearshore and offshore ecosystems.
	Biodiversity	• A thorough understanding of the biodiversity within the HNRS, including spatial and temporal variability and responses to climate change. • Create and improve mechanisms for protecting biodiversity including biodiversity credits (which are in the initial stages of development for aquatic systems), fisheries credits, and providing guidance for navigating multiple tools and pathways.

Topic	Category	Knowledge gap
		• Understanding habitat production and availability and its link to secondary productivity. Typically done via a fisheries productivity pathway, but can include any species of note within the HNRS. • Understand trophic relay dynamics and how nutrients are being transported throughout the system by biological processes. • Determine priority locations for wetland restoration, perhaps considering (i) blue carbon potential (not only habitat creation but avoided GHG emissions, and (ii) resilience to longer-term climate change impacts, including sea-level rise. This would be best done at an estuary scale.
	Water quality	• Calculate a nutrient budget, including the identification of nutrient sources that contribute to algal growth for the Brisbane Water estuary to assess the potential for eutrophication of the more enclosed portions of the waterway and to inform a water quality improvement plan for the estuary (action previously identified in the Brisbane Water CZMP) • Full collation and analysis of existing data on spatial and temporal trends in WQ data • Improved predictive ability re the frequency, intensity, scale and taxonomic composition of algal blooms • Toxicant analysis, including of heavy metals, pesticides and emerging pollutants such as endocrine disruptors • Groundwater significance: what role does groundwater play in the supply of nutrients to the estuary? • Assessment of direct consequences of higher concentration of pyrogenic carbon in estuarine sediments to water quality, ecosystem functioning or estuarine biota.
	Geomorphology	• Rates of sediment accretion and elevation gain of estuarine wetlands and their ability to keep track with eustatic sea level rise (eg extension of Sediment Elevation Tables (SETs) across additional important wetlands, noting that SETs are already installed in Berowra Creek and Marra Marra Creek). • Detailed understanding of sedimentary processes and budgets of the major Brisbane Water tributaries (Narara, Erina, Woy Woy and Kincumber Creek) related to navigation, contamination, habitat impacts, and property protection. • Investigate the potential for increased sedimentation as a result of bushfires and prescribed burning, including using responsive monitoring to gain an understanding of the influences of sediment pulses arising from post-fire floods. • Sedimentation pulse events (flooding, runoff following bushfire), and their ecological effects (likely to be amplified under climate change). This would include potential positive effects in the provision of an elevation subsidy to coastal wetlands subject to sea level rise.
Ecological function and processes	Estuarine food-web structure and sensitivity to anthropogenic pressures	• Empirical description of important food webs and links to trophic structure. • Likely alteration pathways for food webs in response to climate change stressors. • Quantifying how much habitat loss influences the greater ecosystem viability and ability to continually provide ecosystem services. Including

Topic	Category	Knowledge gap
		an assessment of the viability of current habitats to support ecosystem processes. • Develop a set of biological indicators (eg, food chain or structural biota) which will assist in measuring climate change impacts. • Develop ecosystem health indicators and thresholds tailored to specific reaches and flow conditions. This is critical for setting nutrient and sediment load limits that maintain ecosystem health. These indicators must be underpinned by an understanding of the HNR food web in response to drivers and stressors. • Implications of reduced abundance and availability of target species for recreational and commercial fisheries. • Interactions between top-down (e.g. herbivory) and bottom-up (e.g. nutrient limitation and light availability) in controlling algal biomass accumulation. • Determine the estuary carrying capacity to accommodate future population and development within the catchment while maintaining socially, culturally and economically important ecological function. • Best practice /methods to increase marine biodiversity (plants and animals) (e.g., natural foreshores, oyster and rocky reefs, seagrass beds). • Undertake a comprehensive environmental flows investigation for all tributaries to the Lower Hawkesbury. This should include determining groundwater and surface water extraction rates/volumes, contributions from all sources (urban runoff, STPs), and ecological flow requirements. • Use System of Environmental-Economic Accounting (SEEA) to integrate economic and environmental data to provide a more comprehensive and multipurpose view of the interrelationships between the economy and the environment and the stocks and changes in stocks of environmental assets, as they bring benefits to HNRS communities. • Determine an ecosystem productivity budget using a mass balance approach, and considering ecosystem productivity benefits and fisheries habitat benefits.
	Additional biogeochemical processes in the water column and sediments	• Investigate the potential for increased algal blooms as a result of bushfires and prescribed burning. • Comparative rates of N input versus N loss via denitrification or physical export. • Cycling of critical trace elements (eg Fe, Si) and their importance as limiting factors for phytoplankton growth and biomass accumulation. • Sequestration and release of C in estuarine ecosystems, and its climate-change implications (eg C accumulation in coastal wetlands; release of greenhouse gases such as CO_2 and CH_4 from estuarine wetlands). • Determine which nutrient sources are problematic for nuisance algae including HABs. • Understand the relative contribution of pulse events relative to sustained nutrient flows and their impact on estuary productivity.

6.4.3 Hawkesbury Research Hub

A Hawkesbury Research Hub (HRH) has been identified as a potential avenue for creating the framework needed to accomplish robust research outcomes and effectively fill knowledge gaps. Addressing the wide range of problems and knowledge gaps facing sustainable development in the HNRS will require a well-coordinated multi-disciplinary program of research spanning multiple years. The scale of research should be proportionate with the values of the system and the large investments needed to protect these values. It is important that such a program also extends to the Brisbane Water and Pittwater estuaries. Due to the high profile and ecological value of the HNRS, it is likely that a coordinated research program will present many opportunities for carrying out cutting-edge science and developing innovative solutions.

The core functions of the proposed HRH include:

- **Ongoing stakeholder consultation –** The HRH must be keenly focused on carrying out science that is tailored to filling specific knowledge gaps identified for the HNR. The research themes and knowledge gap identification will be coordinated by a panel including senior scientists, Universities, relevant EPA and DPE personnel, Great Sydney Commission representatives, Sydney Water representatives, and HNRS CMP project coordinators.
- **The establishment of research partnerships with external universities –** Drawing in expertise specific to research themes is key to providing high quality, robust science and management outcomes. Research themes will be developed by the HRH, and expressions of interest from qualified university researchers will be assessed. Close supervision of research project development by the HRH will ensure that results are directly relevant to solving specific identified problems and are in a format that can be utilised and integrated into other research streams.
- **Scoping and sourcing of funding opportunities –** examples include Combination of ARC Linkage, ARC discovery, industry, Australian Postgraduate Awards, Fisheries Research and Development Corporation and contributions from Partner Councils.
- **Communication and publication of findings –** a multi-pronged communications strategy should be developed in the first instance and alongside the formation of the HRH. Examples of communication channels and media that can be used to convey research outcomes include science publications in peer reviewed journals, media releases, short film and TV series.

7 Conclusion and next steps

This abridgement report serves as a concise overview of the state of knowledge of the ecological and physical processes that operate in and impact on the Hawkesbury-Nepean River system estuary. The concepts covered at a high level provide a holistic representation of estuarine functions that that support multiple and wide ranging benefits and values to the HNRS community.

Managers in local and state government can utilise this report as a source of information regarding the relevant processes that could potentially effect their management area or focus within the Hawkesbury Nepean River system. The extensive list of references to the literature provides more detailed insights into estuarine function where further understanding is needed. The commentary on threats and stressors, and the management opportunities to address them provides a targeted analysis that can inform the development of integrated management strategies that build on and improve existing approaches.

Communication of the concepts covered in this report to the broader community is an important component in garnering support for estuarine management, supporting the CMP, and in empowering communities to contribute in a meaningful way. Several elements of the report can be used as communication tools including the conceptual diagrams that synthesise and illustrate important ecological and physical processes, and the interactive mapping platform which allows for spatial exploration of available data.

7.1 Next steps

In accordance with the NSW Coastal Management Framework, the next steps in Stage 3 will include reviewing and refining management actions from existing CZMPs and EMPs and compiling them into an updated list of actions to be implemented through the CMP. This review should also identify new opportunities and management actions that can be incorporated into the CMP (eg Blue Carbon Method projects). The preliminary assessment of existing CZMP actions for their relevance in addressing key threats and stressors undertaken in this report provides a starting point in determining where future management should be targeted. The existing CZMPs have been developed for geographically distinct areas of the Hawkesbury-Nepean River estuary. Coalescing these distinct management plans into a system wide integrated CMP should involve adherence to estuarine rehabilitation and management principles to guide action development.

A high-level list of management actions to address each stressor is provided in Table 26. In Stage 3 of CMP development, these actions should be considered alongside existing management actions and refined to accommodate both local and system wide context.

Among the system wide actions that will contribute to holistic estuarine management is the utilisation of strategic planning to influence land use and development in the contributing catchment. A recommended approach is to submit a planning proposal to expand the Coastal Wetlands and Littoral Rainforest Areas to include identified wetlands not currently included in the Resilience SEPP mapping. A second planning proposal expanding the Coastal Environment Area to include a greater proportion of the contributing catchment would also facilitate ecologically sensitive development in accordance with the objectives of the CM Act.

Effective estuarine management in the face of changing conditions also must be supported by targeted research to provide up to date understanding of important physical and ecological processes. Addressing the knowledge gaps with future research described in this report will provide information to answer important questions and guide future management of the HNRS.

8 References

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Appendix A – Threats and stressors alignment with Scoping Study

Stressor	Link to stressor IDs in Stage 1
Sea level rise	**Long term hazards** 1.1 - Tidal inundation of estuaries (i.e. “sunny day flooding”) 1.2 - Estuary foreshore erosion and bank instability 1.3 - Long term coastal shoreline recession **Climate change impacts** 3.1 - Altered ocean currents and nutrient inputs 3.6 - Sea level rise 3.7 - Long term shoreline recession due to sea level rise 3.8 - Altered salinity levels / profile 3.9 - Habitat migration and squeeze
Ocean acidification and rising temperatures	**Climate change impacts** 3.2 - Ocean temperature increase 3.3 - Ocean acidification **Habitat disturbance** 5.6 - Introduction of invasive fauna pest species (e.g. carp) and diseases (POMS etc) 5.7 - Introduction of invasive flora pest species (e.g. aquatic weeds) and diseases
Altered estuarine hydrology	**Event based hazards** 2.3 - Combined coastal and catchment flooding 2.5 - Drought **Climate change impacts** 3.4 - Altered storm frequency and severity 3.5 - Altered hydrological regimes

Stressor	Link to stressor IDs in Stage 1
Habitat migration and squeeze	**Climate change impacts** 3.9 - Habitat migration and squeeze **Habitat disturbance** 5.1 - Foreshore / urban development **Recreation and Tourism** 8.4 - Coastal infrastructure, marina expansion, modifications, upgrades and associated dredging.
Increased intensity and distribution of bushfires	**Event based hazards** 2.4 - Bushfire **Water Pollution and Sediment Contamination** 4.5 - Sediment contamination / pollution **Hydrologic Modifications** 6.3 - Sedimentation and infilling channels and changing and regulating flows
Catchment and foreshore development	**Habitat Disturbance** 5.1 - Foreshore / urban development 5.3 - Clearing / disturbance of riparian and aquatic habitat 5.4 - Clearing / disturbance of littoral rainforest habitat 5.5 - Clearing / disturbance of terrestrial habitat **Recreation and Tourism** 8.1 - Recreational fishing (boat and shore based) 8.2 - Recreational boating and boating infrastructure 8.3 - Passive Recreational Use 8.4 - Coastal infrastructure, marina expansion, modifications, upgrades and associated dredging. 8.5 - Anti-social behaviour and unsafe practices **Access and availability** 9.1 - Overcrowding / congestion of waterways and user group conflict 9.2 - Overcrowding / congestion of foreshores/beaches and user group conflict
Stormwater runoff	**Water Pollution and Sediment Contamination** 4.1 - Urban stormwater discharge 4.3 - Industrial discharges 4.5 - Sediment contamination / pollution
Agricultural runoff	**Water Pollution and Sediment Contamination** 4.2 - Agricultural runoff
Sewage and wastewater runoff	**Water Pollution and Sediment Contamination** 4.4 - Sewage effluent and septic runoff **Hydrologic Modifications** 6.2 - Modified freshwater flows, including water extraction WWTP discharges
Water extraction – surface and groundwater	**Hydrologic Modifications** 6.1 - Increasing use of groundwater 6.2 - Modified freshwater flows, including water extraction WWTP discharges

Stressor	Link to stressor IDs in Stage 1
Barriers to longitudinal and lateral connectivity	**Habitat Disturbance** 5.1 - Foreshore / urban development 5.2 - Stock grazing of riparian and marine vegetation (in estuaries) 5.3 - Clearing / disturbance of riparian and aquatic habitat 5.4 - Clearing / disturbance of littoral rainforest habitat 5.5 - Clearing / disturbance of terrestrial habitat **Recreation and Tourism** 8.4 - Coastal infrastructure, marina expansion, modifications, upgrades and associated dredging.
Erosion and Sedimentation	**Long Term Hazards** 1.2 - Estuary foreshore erosion and bank instability **Habitat Disturbance** 5.1 - Foreshore / urban development 5.2 - Stock grazing of riparian and marine vegetation (in estuaries) 5.3 - Clearing / disturbance of riparian and aquatic habitat 5.4 - Clearing / disturbance of littoral rainforest habitat 5.5 - Clearing / disturbance of terrestrial habitat **Hydrologic Modifications** 6.3- Sedimentation and infilling channels and changing and regulating flows
Dredging	**Water Pollution and Sediment Contamination** 4.6 - Disturbance of contaminated sediment on seabed (e.g. dredging) and in foreshore areas **Hydrologic Modifications** 6.4 - Navigation and entrance management and modification (such as dredging)
Sediment contamination	**Water Pollution and Sediment Contamination** 4.5 - Sediment contamination / pollution 4.6 - Disturbance of contaminated sediment on seabed (e.g. dredging) and in foreshore areas
Invasive species	**Habitat Disturbance** 5.6 - Introduction of invasive fauna pest species (e.g. carp) and diseases (POMS etc) 5.7 - Introduction of invasive flora pest species (e.g. aquatic weeds) and diseases
Commercial fishing	**Commercial Fishing and Boating** 7.1 - Commercial fishing in coastal / marine waters - ocean haul etc 7.2 - Commercial fishing in estuaries - prawn trawl etc 7.3 - Aquaculture – oyster farming etc
Recreational fishing	**Recreation and Tourism** 8.1 - Recreational fishing (boat and shore based)
Active boating	**Commercial Fishing and Boating** 7.4 - Commercial boating - small commercial vessels and charters activities etc **Recreation and Tourism** 8.2 - Recreational boating and boating infrastructure
Passive boating	**Recreation and Tourism** 8.3 - Passive Recreational Use
Swimming	**Recreation and Tourism** 8.3 - Passive Recreational Use

Stressor IDs not included	**Long term hazards** 1.4 Estuary entrance instability 1.5 Cliff and slope instability **Event Based Hazards** 2.1 Coastal storm impacts - erosion 2.2 Coastal storm impacts - inundation 2.6 Tsunami 2.7 Dam breach / break **Access and availability** 9.3 Limited or lack of foreshore and waterway access 9.4 Limited or lack of supporting infrastructure (for boating etc) 9.5 Lack of disability access **Public Health and Safety** 10.1 Water pollution/contamination affecting human health and safety – including algal blooms 10.2 Seafood contamination 10.3 Drinking water contamination 10.4 Coastal hazards (coastal erosion, cliff instability and inundation/wave overtopping) 10.5 Public safety risk from aging and/or degraded coastal/estuary infrastructure 10.6 Wildlife interactions (sharks, jellyfish etc) **Governance** 11.1 Lack of adequate coordination between estuary councils, catchment councils and state government agencies – and jurisdictional ambiguity. 11.2 Inadequate, inefficient regulation, or over-regulation (agencies) 11.3 Lack of compliance with regulations (by users) or lack of regulation effort (by agencies) 11.4 Lack of funding for investigation and action implementation 11.5 Lack of or ineffective community engagement or participation in governance **Information Gaps** 12.1 Incomplete coastal and estuary process information (including climate change impacts or hydrodynamics along the entire river system) 12.2 Incomplete ecological information (including climate change impacts) 12.3 Inadequate and/or incomplete European and Indigenous Heritage information 12.4 Inadequate social and economic information

Appendix B – Ecosystem vulnerability assessment

Ecosystem vulnerability can be defined as the potential for loss of habitat, function, or ability to contribute to important eco-physical processes (Weißhuhn et al. 2018). Understanding the relative vulnerability of different ecosystem components can help to prioritise management efforts by targeting stressors with the most severe potential impact or focusing on interventions designed to protect the most vulnerable populations. A vulnerability assessment has been undertaken to determine which key habitats within the Hawkesbury River estuary system are likely to merit the most management effort. An assessment approach based on Astles et. al 2010 has been used.

The ecosystem vulnerability assessment considers three factors as follows:

- **Sensitivity** – susceptibility of a habitat to a hazard, disturbance or stressor.
- **Scarcity –** a measure of how rare or common a type of habitat is. This considers both the presence of available habitat as well as the actual distribution within the estuarine system.
- **Adaptive capacity** – characterizes the ability of a habitat to cope with the hazard and its consequences. Contributing factors to adaptive capacity include resistance to stressors (structure, form, attachment) and resilience (regrowth, recolonisation, reproduction, replenishment of structure) (Astles et al. 2010).

The habitats considered include:

- Saltmarsh
- Mangroves
- Seagrass
- Riparian vegetation
- Forested coastal wetlands
- Mudflats
- Sandflats (intertidal / subtidal)
- Rock reef (intertidal / subtidal
- Water column - riverine
- Water column - estuarine
- Water column – marine

Stressor impact on ecosystem	
5	Catastrophic negative impact
4	Substantial negative impact
3	Moderate negative impact
2	Minimal negative impact
1	No negative impact

The *scarcity* of a habitat contributes to its vulnerability, with more abundant habitats less vulnerable to stressors. Developing a scarcity rating is highly dependent on the spatial scale under consideration. A habitat may be abundant in one tributary (meriting a low scarcity score) and absent in another (meriting a high scarcity score), with the system-wide score needing to consider all areas. Also, some habitats inherently cannot exist in some locations of the system due to the physical characteristics of the site and the requirements of the ecosystem (e.g., saltmarshes cannot exist in subtidal areas). Therefore, the potentially available habitat throughout the system has also been considered. The *scarcity* of each habitat was rated according to the scale in Table 30.

Table 30. Scale used to rate habitat scarcity

Habitat scarcity	
5	Very scarce - limited populations in limited available habitat throughout HNRS
4	Scarce - present in limited available habitat
3	Somewhat scarce - present in patches in available habitat throughout HNRS
2	Common - present throughout available habitat in HNRS
1	Very common - commonly present in widely available habitat

The *adaptive capacity* rating for each habitat was informed by two factors – resistance and resilience. The definitions and ratings for each of these factors has been adapted from Astles 2010.

Resistance of estuarine habitats (the ability of a habitat to withstand stressors) to the effects of human activities is based on three physical aspects – structure, form and attachment (Astles 2010)

Structure – the degree the structure is altered by physical stressors depends on its hardness.

- Hard – minimal to no change in shape when physical contact made
- Flexible – can change shape but returns to original condition after contact removed
- Soft – changes shape under contact and does not return to original condition after contact removed

Form – the degree to how easily physical contact can be made is related to its form.

- Vertical/erect – extends up from surface of substratum vertically or at an angle
- Flat – laying on surface of substratum without vertical parts*
- Sub-surface – laying beneath surface of substratum*

*Sub-surface and flat forms of a habitat will be susceptible if a human activity acts at or below the surface of the substratum either physically or biologically.

Attachment – the degree a habitat can be displaced.

- Permanent – fixed in place by geological means
- Sessile – attached to substratum by biological means (plant and animal)
- Loose – unattached to substratum

R*esilience* of estuarine habitats (the ability of habitats to recover from an interaction with stressors) was determined by either biological characteristics (such as regrowth / regeneration rate, recolonisation, and reproduction) or geomorphic characteristics (such as sediment accretion or structure rebuilding) for habitats like mudflats or sandflats (Astles 2010).

Regrowth/regeneration – the rate at which an organism can regrow damaged parts.

- Fast – within 1 week
- Moderate – within 1 month
- Slow – greater than a month

Recolonisation – ability to occupy new patches or space.

- Dispersal range
  - wide (anywhere within the estuary),
  - narrow (within 100m of parent habitat)

Reproduction – ability to replace itself.

- Propagule output
    - large (>50)
    - small (<50)
- Cycle
    - seasonal
    - aseasonal

Replenishment/rebuilding – the rate at which its processes can rebuild its physical or biochemical structure.

- Accretion of sediment
    - fast (< 1 month)
    - slow (> 1 month)
- Reformation of structure
    - fast (< 1 year)
    - slow (> 1 year)

Astles (2010) uses these criteria to assign a resistance and resilience rating of low, medium, or high to each habitat. This was done systematically – assigning a value for each of the above criteria and accounting for the number of susceptible characteristics for each habitat type. For the purposes of the vulnerability assessment for this report, these ratings have been adapted to a 5-point scale described in Table 31.

Table 31. Scale used to rate habitat adaptive capacity with consideration for resistance and resilience (based on method used in Astles 2010)

Adaptive capacity			
	Resistance		Resilience
5	Very low	5	Very low
4	Low	4	Low
3	Average	3	Average
2	Above average	2	Above average
1	High	1	High

The ratings that each habitat received from the above factors were considered together to produce and overall vulnerability rating. The vulnerability rating for each habitat type was determined by taking the sum of:

- the average habitat sensitivity rating (for all stressors)
- scarcity rating
- average of the adaptive capacity resistance and resilience ratings.

Therefore, the maximum score possible, indicating the most vulnerable habitat, is 15. The formula used to determine the vulnerability rating for each habitat is illustrated in Figure 56. Results are summarised in Table 32.

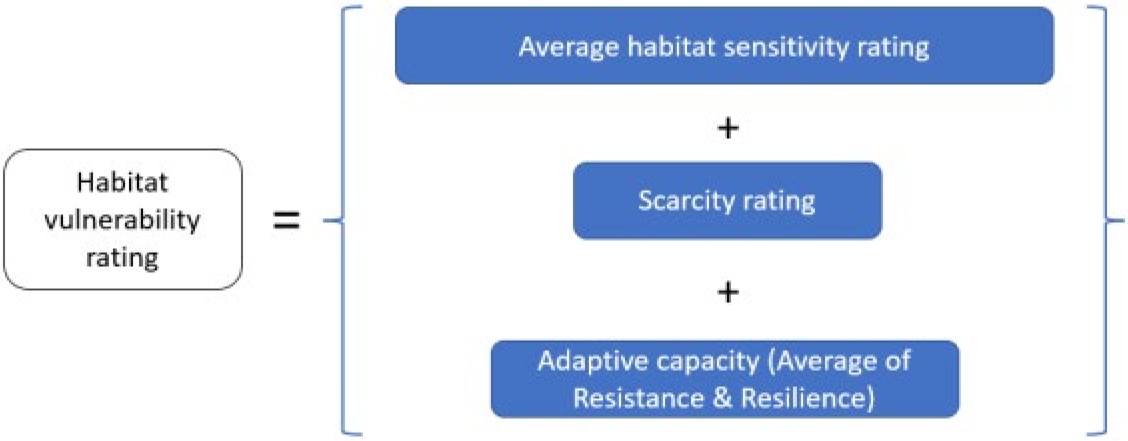

Figure 56. *Formula used to calculate habitat vulnerability rating.*

Table 32. Summary of habitat vulnerability assessment results

Ecosystem	Stressors																				Sensitivity score	Adaptive capacity			Vulnerability rating
	Sea level rise	*Ocean acidification and rising temperatures*	*Altered estuarine hydrology*	*Habitat migration and squeeze*	*Bushfire*	*Foreshore development*	*Urban stormwater runoff*	*Agricultural runoff*	*Sewage and wastewater runoff*	*Water extraction – surface and groundwater*	*Barriers to longitudinal and lateral connectivity*	*Erosion and sedimentation*	*Dredging*	*Invasive species*	*Sediment contamination*	*Commercial fishing*	*Recreational fishing*	*Active boating*	*Passive boating*	*Swimming*		**Scarcity**	**Resistance**	**Resilience**	
Saltmarsh	5	4	4	5	4	4	4	4	4	4	5	4	2	4	3	3	2	2	2	2	71	5	5	5	86
Seagrass	3	4	4	3	3	4	4	4	4	3	2	5	5	3	5	4	3	4	3	3	73	4	4	4	85
Water column - riverine	1	2	5	2	3	2	5	5	5	4	4	4	4	3	4	4	3	4	1	1	66	3	3	4	76
Water column - estuarine	1	4	4	2	3	2	4	5	4	5	4	3	4	3	4	4	4	4	1	1	66	2	5	3	76
Riparian vegetation	3	3	3	4	3	4	4	3	3	3	4	4	3	3	3	2	2	4	3	3	64	4	5	3	76
Mangroves	4	2	3	4	2	4	3	3	3	3	4	3	2	3	3	3	3	4	2	3	61	3	5	5	74
Mudflats	3	4	3	3	2	3	2	3	3	3	2	4	4	3	5	3	3	3	1	3	60	3	5	3	71
Forested coastal wetlands	4	3	4	4	5	5	3	3	3	4	3	3	2	3	2	1	1	1	1	1	56	4	4	4	68
Sandflats (intertidal / subtidal)	2	4	2	3	2	3	2	2	3	3	2	4	4	3	4	3	3	3	2	3	57	3	5	2	67
Rock reef (intertidal / subtidal)	3	3	3	3	2	4	3	2	3	2	2	2	3	3	2	2	4	2	3	3	54	3	3	4	64
Water column - marine	1	4	2	2	2	2	3	3	3	3	3	3	4	3	2	4	4	4	1	1	54	2	3	2	61
Stressor impact rating	2.7	3.4	3.4	3.2	2.8	3.4	3.4	3.4	3.5	3.4	3.2	3.5	3.4	3.1	3.4	3.0	2.9	3.2	1.8	2.2					

Appendix C – List of key management actions from CZMPs

Stressor	Action ID	Description	Status (where available)
Sea level rise	**Upper Hawkesbury CZMP**		
Sea level rise	SLR1	Incorporate sea level rise considerations into infrastructure asset management and planning processes	
Sea level rise	SLR2	Map estuarine vegetation and assess vulnerabilities to future sea level rise	
Sea level rise	43	Identify wetland species and communities that will be impacted by sea level rise and prioritise opportunities for landward migration.	
Sea level rise	**Lower Hawkesbury CZMP**		
Sea level rise	13	Define and map minimum buffer widths for riparian/foreshore vegetation in relevant planning documents (LEPs, DCPs etc) to protect estuary assets and account for landward migration of habitat due to sea level rise.	**In progress / Incomplete**
Sea level rise	26	Undertake comprehensive of mapping of the extent and condition of riparian habitats (including mangroves, saltmarsh and wetland species) in the Lower Hawkesbury and review periodically	**Implemented and Ongoing**
Sea level rise	43	Undertake periodic mapping of aquatic habitats (including the extent and condition of benthic, intertidal zone, water column and water surface habitats) throughout the Lower Hawkesbury	**Completed**
Sea level rise	80	Improve the understanding of local impacts which may arise from climate change (eg produce vulnerability maps) and the management responses to such impacts (changes to infrastructure, planning provisions etc)	**In progress / Incomplete**
Sea level rise	**Pittwater CZMP**		
Sea level rise	1b	Update and implement Plan of Management for Careel Bay wetlands, ensuring maintenance of habitat mix / diversity (which may include selective removal of mangrove seedlings that have encroached onto saltmarsh areas from time to time)	**Not Commenced / Outstanding**
Sea level rise	3a	Climate change impacts for development are to be considered and addressed, with the development of relevant risk management plans for adoption into Council's DCP	**Implemented and Ongoing**
Sea level rise	**Brisbane Water CZMP**		
Sea level rise	E08	Give consideration to methods of detecting and informing the community of changes to sea levels and other potential climate change impacts. These methods should not result in a sense of panic or alarm, instead they should empower the community to act in a well-considered and informed manner and where possible, encourage the community to become engaged in Council's decision making processes. The information provided to the public should be supported by research presented by the IPCC and the State/Federal government, as well as observed trends in local sea levels.	
Sea level rise	P16	Investigate opportunities to purchase saltmarsh areas for incorporation into Council's reserve system in accordance with Policy *R0.15 - Acquisition of Wetlands.*	
Sea level rise	P43	Prepare a Climate Change Adaptation Plan that will deliver land use zoning and development controls for the Estuary that are based on the current IPCC projections of 0.9m sea level rise by 2100. The preparation of this study should be closely linked to the *Brisbane Water Foreshore Coastal Floodplain Risk Inundation Management Study and Plan* , anticipated to be drafted by 2011.	
Sea level rise	P46	Review existing *DCP 119 - Wharves and Jettie*s with a view to ensuring the policy is in accordance with the goals and objectives of the Estuary Management Study and Plan. In addition, sea level rise projections should also be considered where facilities are to be upgraded.	
Sea level rise	P60	Ensure that climate change considerations are incorporated into all relevant Plans of Management for locations around the Estuary.	
Sea level rise	R19	Investigate options for the landward migration of intertidal habitats such as saltmarsh under climate change scenarios.	
Sea level rise	R40	Provide for ongoing monitoring of estuarine water levels to provide a continuous long term data set. This is key for monitoring the potential impacts of climate change and initiating appropriate adaptive management responses. The need to install additional water level gauges should be considered.	
Sea level rise	R42	Undertake an estuarine shoreline vulnerability assessment (based on shoreline geomorphology) to assist in planning for sea level rise.	

Stressor	Action ID	Description	Status (where available)
Sea level rise	W60	Where possible, provide for managed retreat of infrastructure from foreshore areas likely to be affected by sea level rise on a regular basis.	
Sea level rise	W71	Where appropriate, rehabilitate saltmarsh habitats on an Estuary-wide basis. Rehabilitation works should be prioritised with due consideration of habitat connectivity, and the potential for ongoing conservation in both the medium-term and long-term (i.e. under a climate change scenario).	
Sea level rise	**Gosford Beaches CZMP**		
Sea level rise	PA5	Future relocation of carpark and associated infrastructure to an area landward of the coastal hazard area	**Not Commenced / Outstanding**
Sea level rise	PE18	Long term removal and relocation of playground should erosion escarpment move landward in future	**Not Commenced / Outstanding**
Sea level rise	PE21	Landward relocation of water supply and electricity should it be damaged by future erosion	**Not Commenced / Outstanding**
Ocean acidification and rising temperatures	**Upper Hawkesbury CZMP**		
Ocean acidification and rising temperatures	ME2	MOU between agencies regarding sharing of environmental health data	
Ocean acidification and rising temperatures	WQ8	Develop a monitoring strategy for key water quality parameters (implement an estuary health monitoring program and issue biennial report cards)	
Ocean acidification and rising temperatures	**Lower Hawkesbury CZMP**		
Ocean acidification and rising temperatures	26	Undertake comprehensive of mapping of the extent and condition of riparian habitats (including mangroves, saltmarsh and wetland species) in the Lower Hawkesbury and review periodically	**Implemented and Ongoing**
Ocean acidification and rising temperatures	43	Undertake periodic mapping of aquatic habitats (including the extent and condition of benthic, intertidal zone, water column and water surface habitats) throughout the Lower Hawkesbury	**Completed**
Ocean acidification and rising temperatures	44	Develop key biological indicators and establish a biological monitoring program for aquatic and riparian habitats	**Implemented and Ongoing**
Ocean acidification and rising temperatures	45	Develop a comprehensive ecosystem health water quality monitoring program across the Lower Hawkesbury	**Completed**
Ocean acidification and rising temperatures	73	Establish an MOU for data sharing (e.g. between SWC, NSW Food Authority, HSC, HNCMA, GSC, PC etc). Compile and manage a supporting database for the MOU for all monitoring data for the Lower Hawkesbury.	**Completed**
Ocean acidification and rising temperatures	80	Improve the understanding of local impacts which may arise from climate change (eg produce vulnerability maps) and the management responses to such impacts (changes to infrastructure, planning provisions etc)	**In progress / Incomplete**
Ocean acidification and rising temperatures	82	Develop a set of biological indicators (eg, food chain or structural biota) which will assist in measuring climate change impacts	**Not Commenced / Outstanding**
Ocean acidification and rising temperatures	**Pittwater CZMP**		
Ocean acidification and rising temperatures	6c	Re-vegetation along estuary foreshores and along riparian zones within catchment (on both public and private lands) to connect habitats, provide shade and enhance ecological communities (esp. EECs)	**Implemented and Ongoing**
Ocean acidification and rising temperatures	**Brisbane Water CZMP**		

Stressor	Action ID	Description	Status (where available)
Ocean acidification and rising temperatures	P19	Develop a strategy for the conservation of areas important for the biodiversity of invertebrates. Particular attention should be paid to priority sites that represent the greatest proportion of species, including Ettalong, Narara Creek, Koolewong, and Woy Woy Bay-Pelican Island.	
Ocean acidification and rising temperatures	R20	Investigate opportunities to monitor indicator organisms within the Estuary to assess effectiveness of management measures to protect biodiversity and maintain the ecological health of the Estuary.	
Ocean acidification and rising temperatures	R22	Monitor the extent of riparian, foreshore and aquatic vegetation around the Brisbane Water Estuary. Trends in vegetation condition and extent should be reported every five years. Reference should be made to the NSW Government's NSW Monitoring, Evaluation and Reporting Strategy for estuaries to assess extent of mangrove, saltmarsh and seagrass (the latter to species).	
Ocean acidification and rising temperatures	W123	Investigate the feasibility of utilising artificial reef structures to provide habitat diversity and/or minimise foreshore erosion/recession.	
Altered estuarine hydrology	**Upper Hawkesbury CZMP**		
Altered estuarine hydrology	WQ7	Utilise hydraulics and WQ modelling insights coming out of present study for Sydney Water to understand processes and impacts.	
Altered estuarine hydrology	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Altered estuarine hydrology	47	Lobby for an increase in environmental flows	
Altered estuarine hydrology	64	Keep abreast of research on the relationship between environmental flow regime and estuary health	
Altered estuarine hydrology	**Lower Hawkesbury CZMP**		
Altered estuarine hydrology	83	Continue to lobby for reuse of water from STPs, to reduce freshwater demands in catchment	**In progress / Incomplete**
Altered estuarine hydrology	85	Develop and implement a plan of management to maintain sustainable environmental flows as a component of total water cycle management (based upon studies and modelling of sustainable flows).	**In progress / Incomplete**
Altered estuarine hydrology	88	Undertake a comprehensive environmental flows investigation for all tributaries to the Lower Hawkesbury. This should include determining groundwater and surface water extraction rates/volumes, contributions from all sources (urban runoff, STPs), and ecological flow requirements.	**Not Commenced / Outstanding**
Altered estuarine hydrology	115	Provide education to increase community acceptance of recycled water from STPs, and collection and re-use of stormwater, etc as per the Sustainable Total Water Cycle Management strategy	**Not Commenced / Outstanding**
Altered estuarine hydrology	122	Undertake remote and real time environmental monitoring for the Lower Hawkesbury (e.g. chlorophyll-a probes, wind speed probes, salinity, flow meters, satellite data), and make data available to the public.	**Implemented and Ongoing**
Altered estuarine hydrology	**Pittwater CZMP**		
Altered estuarine hydrology	3b	WSUD principles to be added to all development controls (draft DECC DCP)	**Implemented and Ongoing**
Altered estuarine hydrology	**Brisbane Water CZMP**		
Altered estuarine hydrology	P04	Review the Water *Cycle Management Guidelines* (2007) and ensure that they reflect best practice WSUD and appropriately support the new DCP.	

Stressor	Action ID	Description	Status (where available)
Altered estuarine hydrology	P30	Develop a DCP for Wetlands aimed at maintaining and restoring natural biological and physical processes of wetland function by minimising changes to wetland hydrology from land uses in the catchment. This should be undertaken in line with DECCW's *NSW Wetlands Policy* (2010b).	
Altered estuarine hydrology	R24	Investigate the use of constructed wetlands, sediment, and detention basins and other WSUD options to minimise the effect of freshwater and sediment inflows, with particular reference to areas of high biodiversity value around entrances to creeks. Consideration should be given to both current and future meteorological conditions.	
Altered estuarine hydrology	W01	Investigate options for implementing catchment based WSUD features in the catchment in order to manage stormwater quality and quantity, with a priority focus on the Narara and Erina Creek catchments, followed by Kincumber Creek catchment.	
Altered estuarine hydrology	**Pearl Beach Lagoon CZMP**		
Altered estuarine hydrology	8	Investigate options to modify the weir	In progress / Incomplete
Habitat migration and squeeze	**Upper Hawkesbury CZMP**		
Habitat migration and squeeze	ARH2	Prepare a species planting fact sheet for applicants and Council officers for use in development assessment of foreshore works	
Habitat migration and squeeze	ARH3	Work from relevant priorities determined by the HNCAP 2013-23 (In accordance with the HNCAP 2013-2023, identify locations for and undertake targeted rehabilitation, creation and enhancement of estuarine and floodplain wetland communities and adjacent riparian vegetation)	
Habitat migration and squeeze	SLR2	Map estuarine vegetation and assess vulnerabilities to future sea level rise	
Habitat migration and squeeze	13	Encourage the planting of appropriate species to enhance connectivity, green corridors and succession of desired adult trees	
Habitat migration and squeeze	43	Identify wetland species and communities that will be impacted by sea level rise and prioritise opportunities for landward migration.	
Habitat migration and squeeze	63	Capitalise on any opportunities to acquire privately owned foreshore lands, bringing them into public ownership to improve and enhance public access and ecological values.	
Habitat migration and squeeze	**Lower Hawkesbury CZMP**		
Habitat migration and squeeze	13	Define and map minimum buffer widths for riparian/foreshore vegetation in relevant planning documents (LEPs, DCPs etc) to protect estuary assets and account for landward migration of habitat due to sea level rise.	**In progress / Incomplete**
Habitat migration and squeeze	25	Riparian zones in priority agricultural areas fenced to prevent access of livestock to estuary, protect and encourage rehabilitation of riparian vegetation.	**In progress / Incomplete**
Habitat migration and squeeze	26	Undertake comprehensive of mapping of the extent and condition of riparian habitats (including mangroves, saltmarsh and wetland species) in the Lower Hawkesbury and review periodically	**Implemented and Ongoing**
Habitat migration and squeeze	27	Improve native vegetation condition through revegetation of priority areas (based on habitat mapping)	**Implemented and Ongoing**
Habitat migration and squeeze	43	Undertake periodic mapping of aquatic habitats (including the extent and condition of benthic, intertidal zone, water column and water surface habitats) throughout the Lower Hawkesbury	**Completed**
Habitat migration and squeeze	**Pittwater CZMP**		
Habitat migration and squeeze	1b	Update and implement Plan of Management for Careel Bay wetlands, ensuring maintenance of habitat mix / diversity (which may include selective removal of mangrove seedlings that have encroached onto saltmarsh areas from time to time)	**Not Commenced / Outstanding**
Habitat migration and squeeze	1c	Prepare and implement Plans of Management for areas of significant habitat (eg EECs) on public land and DCPs for private lands ensuring preservation and enhancement of key environmental values	**In progress / Incomplete**

Stressor	Action ID	Description	Status (where available)
Habitat migration and squeeze	6c	Re-vegetation along estuary foreshores and along riparian zones within catchment (on both public and private lands) to connect habitats, provide shade and enhance ecological communities (esp. EECs)	**Implemented and Ongoing**
Habitat migration and squeeze	**Brisbane Water CZMP**		
Habitat migration and squeeze	P16	Investigate opportunities to purchase saltmarsh areas for incorporation into Council's reserve system in accordance with Policy *R0.15 - Acquisition of Wetlands* .	
Habitat migration and squeeze	P20	Develop a conservation and education strategy for seagrass beds, as identified in the *Estuary Processes Study* (CLT, 2008), that: - Support the highest abundance and diversity of fish, - Are known to be important for sponges and ascidians, and - Are known to be important for biological connectivity.	
Habitat migration and squeeze	P28	Provide adequate resources within Council to provide for ongoing management of Bushcare volunteers.	
Habitat migration and squeeze	P30	Develop a DCP for Wetlands aimed at maintaining and restoring natural biological and physical processes of wetland function by minimising changes to wetland hydrology from land uses in the catchment. This should be undertaken in line with DECCW's *NSW Wetlands Policy* (2010b).	
Habitat migration and squeeze	P43	Prepare a Climate Change Adaptation Plan that will deliver land use zoning and development controls for the Estuary that are based on the current IPCC projections of 0.9m sea level rise by 2100. The preparation of this study should be closely linked to the *Brisbane Water Foreshore Coastal Floodplain Risk Inundation Management Study and Plan* , anticipated to be drafted by 2011.	
Habitat migration and squeeze	P48	Develop environmentally friendly design and construction guidelines for foreshore infrastructure such as jetties, boat ramps, seawalls/retaining walls and foreshore protection works. This should include advice on retro-fitting existing structures to be more environmentally friendly. The guidelines should be made publicly available and distributed to all foreshore property owners. (Note: Seawalls addressed in DECC's Environmentally Friendly Seawalls guidelines (2009)).	
Habitat migration and squeeze	P49	Develop guidelines (or compile existing guidelines where available) for foreshore stabilisation via the establishment of locally native estuarine plant species. The guidelines should provide details of the benefits of soft stabilisation works, advice on the species to be used and how to establish plantings. Seedlings may be cultivated at Council's nursery for supply to interested parties.	
Habitat migration and squeeze	P50	Review *D6.47 - Setback Policy: Creeks, Rivers and Lagoon* s. The review should in the first instance widen the definition of applicable waterbodies to incorporate 'estuaries', and in the second instance be re-assessed to incorporate the likely impacts of climate change. In particular, the setbacks applied should be re-assessed to take into account processes relating to both catchment flooding and foreshore inundation.	
Habitat migration and squeeze	R19	Investigate options for the landward migration of intertidal habitats such as saltmarsh under climate change scenarios.	
Habitat migration and squeeze	R22	Monitor the extent of riparian, foreshore and aquatic vegetation around the Brisbane Water Estuary. Trends in vegetation condition and extent should be reported every five years. Reference should be made to the NSW Government's NSW Monitoring, Evaluation and Reporting Strategy for estuaries to assess extent of mangrove, saltmarsh and seagrass (the latter to species).	
Habitat migration and squeeze	R42	Undertake an estuarine shoreline vulnerability assessment (based on shoreline geomorphology) to assist in planning for sea level rise.	
Habitat migration and squeeze	W60	Where possible, provide for managed retreat of infrastructure from foreshore areas likely to be affected by sea level rise on a regular basis.	
Habitat migration and squeeze	W70	Fence existing saltmarshes to prevent access by vehicles, bikes and domestic animals and provide information on the importance of saltmarsh habitat to estuary health.	

Stressor	Action ID	Description	Status (where available)
Habitat migration and squeeze	W71	Where appropriate, rehabilitate saltmarsh habitats on an Estuary-wide basis. Rehabilitation works should be prioritised with due consideration of habitat connectivity, and the potential for ongoing conservation in both the medium-term and long-term (i.e. under a climate change scenario).	
Habitat migration and squeeze	**Gosford Beaches CZMP**		
Habitat migration and squeeze	O43	Collapse steep eroded escarpment and revegetate following erosion events	**Implemented and Ongoing**
Habitat migration and squeeze	PA5	Future relocation of carpark and associated infrastructure to an area landward of the coastal hazard area	**Not Commenced / Outstanding**
Habitat migration and squeeze	PE18	Long term removal and relocation of playground should erosion escarpment move landward in future	**Not Commenced / Outstanding**
Habitat migration and squeeze	**Pearl Beach Lagoon CZMP**		
Habitat migration and squeeze	5	Rehabilitate habitats within creek lines of the catchment	**Implemented and Ongoing**
Increased intensity and distribution of bushfires	**Upper Hawkesbury CZMP**		
Increased intensity and distribution of bushfires	38	When prioritising areas for rehabilitation, seek out opportunities to compliment riparian and biodiversity corridors.	
Increased intensity and distribution of bushfires	42	Have a compulsory riparian buffer of 100-200 metre	
Increased intensity and distribution of bushfires	**Lower Hawkesbury CZMP**		
Increased intensity and distribution of bushfires	15	During the review of plans of management for all parks and reserves (both national and council managed), ensure estuary assets are preserved (including habitat values for native animals, animals listed under the TSC Act 1995, prescribed burning and bushfire suppression undertaken according to park/reserve fire management plan, etc).	**Implemented and Ongoing**
Increased intensity and distribution of bushfires	57	Undertake soil conservation works such as fencing, gully control structures, track/trail, fire trails and rural road stabilisation and revegetation to reduce soil erosion	**In progress / Incomplete**
Increased intensity and distribution of bushfires	129	Investigate the potential for increased sedimentation as a result of bushfires and prescribed burning	**In progress / Incomplete**
Increased intensity and distribution of bushfires	131	Prepare and implement creek rehabilitation plans to restore and maintain native vegetation in the riparian zone	**Implemented and Ongoing**
Increased intensity and distribution of bushfires	143	Develop a catchment and estuarine model to illustrate the interactions between the estuary and catchment influences	**In progress / Incomplete**
Increased intensity and distribution of bushfires	**Pittwater CZMP**		
Increased intensity and distribution of bushfires	R22	Monitor the extent of riparian, foreshore and aquatic vegetation around the Brisbane Water Estuary. Trends in vegetation condition and extent should be reported every five years. Reference should be made to the NSW Government's NSW Monitoring, Evaluation and Reporting Strategy for estuaries to assess extent of mangrove, saltmarsh and seagrass (the latter to species).	

Stressor	Action ID	Description	Status (where available)
Increased intensity and distribution of bushfires	R24	Investigate the use of constructed wetlands, sediment, and detention basins and other WSUD options to minimise the effect of freshwater and sediment inflows, with particular reference to areas of high biodiversity value around entrances to creeks. Consideration should be given to both current and future meteorological conditions.	
Increased intensity and distribution of bushfires	W06	Install and maintain as required sediment traps targeting stormwater flows draining from the escarpment at Hardys Bay.	
Increased intensity and distribution of bushfires	W07	Provide ongoing maintenance of existing sediment traps in the catchment draining to Horsfield Bay.	
Increased intensity and distribution of bushfires	W14	Develop and implement measures to address stormwater quality issues associated with runoff from the access road and fire trails near Fisherman's Parade.	
Catchment and foreshore development	**Upper Hawkesbury CZMP**		
Catchment and foreshore development	ARH5	Council led program to identify when riparian land changes ownership and to contact new owners making them aware of opportunities for grants to improve the condition of riparian lands. (related to 30)	
Catchment and foreshore development	FP1	Prepare fact sheet on appropriate structures on river corridor.	
Catchment and foreshore development	FP3	Review and update Hawkesbury DCP to include a new chapter on foreshore management	
Catchment and foreshore development	FP4	Prepare a site specific guideline for environmentally friendly seawalls in the Upper Hawkesbury River.	
Catchment and foreshore development	LPD5	Provide development assessment guidelines for subdivisions to maximise riparian corridors and reduce fragmented private frontages.	
Catchment and foreshore development	WQ1	Write a specific WSUD chapter in the Hawkesbury DCP	
Catchment and foreshore development	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Catchment and foreshore development	WQ5	Enforce implementation and maintenance of effective sediment controls during the subdivision and building phases of all developments (including infrastructure projects) by undertaking regular audits of developments during construction	
Catchment and foreshore development	21	Update development control plan to inform water based structure construction.	
Catchment and foreshore development	72	When determining DAs question why proponent needs a particular structure i.e. a boat ramp versus a pontoon. Boat ramp and associated works have a higher impact	
Catchment and foreshore development	78	Update LEP zonings to reflect the limits to population growth and development (as based on the findings of land capability and ecological assessments) and to protect significant habitats requiring protection (as based on ecological assessments)	
Catchment and foreshore development	**Lower Hawkesbury CZMP**		
Catchment and foreshore development	1	Conduct assessments to determine the carrying capacity of land areas (based on water, air, biodiversity and land capabilities) and limits for sustainable development within the entire catchment.	**Completed**

Stressor	Action ID	Description	Status (where available)
Catchment and foreshore development	2	Collect information to inform amendments to planning controls based on the assessment of land capability, estuary carrying capacity (future population and development within the catchment) and ecological assessments.	**Implemented and Ongoing**
Catchment and foreshore development	4	Determine sustainable limits for recreational activities (types, numbers and locations) and the requirements for existing/new facilities and access to achieve sustainable limits on foreshores and waterways of the estuary (i.e., suitable locations, unsustainable locations requiring removal, locations requiring restoration, new sustainable locations).	**Implemented and Ongoing**
Catchment and foreshore development	6	Develop and implement an Estuary Processes and Issues Checklist (EPIC) and integrate the checklist into councils planning controls. (The checklist is required to be completed and submitted with DA documentation. The checklist will require applicants and council planners to assess the likely impacts of DAs upon the natural processes, estuary values and sustainability of the Lower Hawkesbury Estuary).	**Completed**
Catchment and foreshore development	7	Ensure planning instruments incorporate best practise: sediment, erosion and stormwater controls (eg construction controls plans and WSUD); use of water reduction devices and maximal permeable surfaces, landscaped area calculations: protection of native vegetation; sewage management (eg low risk OSSMs); restriction of landscaping and gardens to endemic species; energy efficient design and ESD.	**Implemented and Ongoing**
Catchment and foreshore development	8	Ensure suitable controls are contained within planning instruments for the design of foreshore development including recreational facilities to maintain the estuary shoreline in as natural state as possible and minimises potential for bank erosion.	**Implemented and Ongoing**
Catchment and foreshore development	9	Incorporate appropriate provision in planning instruments to require all Marinas to provide accessible pump out facilities as a component of their licence to operate in the Lower Hawkesbury.	**Unknown**
Catchment and foreshore development	12	Undertake an audit of planning compliance to review the effectiveness of development consent conditions to protect estuary assets and achieve sustainability. (eg an audit of the types of development being approved for consistency with sustainable growth limits and estuary asset protection goals).	**In progress / Incomplete**
Catchment and foreshore development	14	In all Development Control Plans, information on the existing environmental context and desired future character is to be included in order to provide a more complete strategic approach.	**Implemented and Ongoing**
Catchment and foreshore development	50	Enhance compliance with development consent conditions (sediment erosion controls, stormwater controls, permeable surface area, water reduction devices, urban design, vegetation removal etc). Increase and enforce penalties for non-compliance and unauthorised development (including renovations etc)	**Implemented and Ongoing**
Catchment and foreshore development	143	Develop a catchment and estuarine model to illustrate the interactions between the estuary and catchment influences	**In progress / Incomplete**
Catchment and foreshore development	144	Undertake periodic surveys of the types, numbers and locations of various recreational activities on all foreshores and waterways of the Lower Hawkesbury.	**Implemented and Ongoing**
Catchment and foreshore development	**Pittwater CZMP**		
Catchment and foreshore development	1c	Prepare and implement Plans of Management for areas of significant habitat (eg EECs) on public land and DCPs for private lands ensuring preservation and enhancement of key environmental values	**In progress / Incomplete**
Catchment and foreshore development	2a	Significant environmental values are to be identified and are adequately protected within appropriate planning instruments (including foreshore areas, EECs, vegetation stands). Eg, modify SEPP-14 wetland boundaries, TPOs.	**In progress / Incomplete**
Catchment and foreshore development	3e	Developments not to degrade scenic amenity of the Pittwater estuary and surrounds	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Catchment and foreshore development	3f	Public amenity and existing foreshore values to be retained / improved for foreshore developments	**Implemented and Ongoing**
Catchment and foreshore development	3h	Require all new marina developments (> 9 berths) to have pump-out services	**In progress / Incomplete**
Catchment and foreshore development	4f	Encourage all existing large marinas (> 30 berths) to install pump-out services	**Implemented and Ongoing**
Catchment and foreshore development	7a	Targeted measures for reducing marina operations waste	**Implemented and Ongoing**
Catchment and foreshore development	7b	Targeted catchment management measures, following catchment-wide urban pollution and sediment runoff audit (esp. areas discharging to poorly flushed embayments)	**Implemented and Ongoing**
Catchment and foreshore development	**Brisbane Water CZMP**		
Catchment and foreshore development	C01	Continue program of auditing to ensure best management practices for marinas around Brisbane Water Estuary. DECC's brochure *Environmental Action for Marinas, Boatsheds and Slipways* (2007) should be provided to marine operators.	
Catchment and foreshore development	C05	Ensure the ongoing enforcement of Council's *Tree Vandalism Policy.* Reference should also be made to *D6.44 Landscape and Vegetation Management Policy* .	
Catchment and foreshore development	C13	Provide additional resources for enforcement of compliance with foreshore development controls.	
Catchment and foreshore development	C14	Audit existing foreshore development (including property boundaries, fences and other structures, boat houses, boat ramps, jetties, etc.) and identify illegal or non-conforming development for retrospective enforcement of development controls. This should be undertaken in accordance with the Conditions of Consent and relevant policy in force at the time of Development Approval. Where foreshore structures are negatively impacting on estuarine processes (e.g. causing erosion or accretion on adjacent lands), investigate opportunities to mitigate these issues. This may be achieved through the Crown lands lease/licensing mechanism (where relevant).	
Catchment and foreshore development	E07	Establish a 'Clean Up Brisbane Water Day' with the dual objectives of removing rubbish from the Estuary foreshores and waterways, and of educating the public about the Estuary.	
Catchment and foreshore development	E09	Provide foreshore property owners with information/guidelines about what constitutes good and bad practice with respect to foreshore management (e.g. limits of mowing, stabilisation works, etc.). This should include information on environmentally friendly seawall options to both the community and those individuals assessing development applications for these structures. Reference should be made to DECC's *Environmentally Friendly Seawalls: A Guide to Improving the Environmental Value of Seawalls and Seawall-lined Foreshores in Estuaries* (2009).	
Catchment and foreshore development	P35	Finalise Council's Dinghy Storage Policy and progress through implementation of the Foreshore Reserves Dinghy Storage Implementation Plan.	
Catchment and foreshore development	P45	Undertake a review of the existing foreshore development policies and plans for the Gosford LGA and assess the need to amend development controls to provide for controlled, sustainable development of the foreshore.	
Catchment and foreshore development	P46	Review existing *DCP 119 - Wharves and Jettied* s with a view to ensuring the policy is in accordance with the goals and objectives of the Estuary Management Study and Plan. In addition, sea level rise projections should also be considered where facilities are to be upgraded.	

Stressor	Action ID	Description	Status (where available)
Catchment and foreshore development	P47	Encourage jetty sharing arrangements via the leasing mechanism such that each jetty services 2-3 properties. This will involve review of applications for new leases as well as license/lease renewals.	
Catchment and foreshore development	P48	Develop environmentally friendly design and construction guidelines for foreshore infrastructure such as jetties, boat ramps, seawalls/retaining walls and foreshore protection works. This should include advice on retro-fitting existing structures to be more environmentally friendly. The guidelines should be made publicly available and distributed to all foreshore property owners. (Note: Seawalls addressed in DECC's Environmentally Friendly Seawalls guidelines (2009)).	
Catchment and foreshore development	R05	Keep a log of the volumes and types of material removed from GPTs during routine maintenance and incorporate this information into the water quality monitoring program.	
Catchment and foreshore development	R14	Investigate options for upgrading the seawall along Masons Parade and Dane Drive, Gosford, in line with the Gosford Challenge/City Centre Redevelopment to consider environmentally friendly design.	
Catchment and foreshore development	R24	Investigate the use of constructed wetlands, sediment, and detention basins and other WSUD options to minimise the effect of freshwater and sediment inflows, with particular reference to areas of high biodiversity value around entrances to creeks. Consideration should be given to both current and future meteorological conditions.	
Catchment and foreshore development	R31	Conduct an audit of existing land-based and water-based infrastructure for boating (e.g. picnic tables, playgrounds, BBQs, jetties, boat ramps, dinghy storage areas, moorings, trailer parking areas, car parking, garbage bins, toilets, shared pathways, etc.) focusing on: - Patterns in patronage/usage, - Condition and maintenance requirements, - Characterisation of neighbouring land uses, - Proximity to key habitat, heritage items and other environmentally sensitive areas, - Proximity to key locations (e.g. pump out stations, marinas, popular fishing spots, etc.), and - Safety. Based on the outcome of the audit, assess the need to upgrade, maintain or de-commission existing infrastructure. The purpose of this audit is primarily to rationalise recreational access and amenity. The findings may be used to inform Action P41, the Users Plan.	
Catchment and foreshore development	W01	Investigate options for implementing catchment based WSUD features in the catchment in order to manage stormwater quality and quantity, with a priority focus on the Narara and Erina Creek catchments, followed by Kincumber Creek catchment.	
Catchment and foreshore development	W69	Review condition of existing sea walls in Council's foreshore parks to investigate possibility of returning natural foreshore and/or use of alternative materials in line with DECC's Environmentally Friendly Seawalls guidelines (2009).	
Catchment and foreshore development	W77	Investigate alternative dinghy storage options/locations to provide suitable storage facilities located near the Scout Hall on Mason Parade, Gosford.	
Catchment and foreshore development	W85	Enforce the replacement of fixed public jetties with floating pontoons (where feasible) with transparent or mesh deck materials to permit light penetration in areas containing seagrass habitat.	
Catchment and foreshore development	W91	Provide bins and bags for the disposal of animal faeces by dog walkers.	
Catchment and foreshore development	W93	Provide additional rubbish and recycling bins along the foreshore, focusing on access points and targeting heavily utilised foreshore reserves as a priority.	

Stressor	Action ID	Description	Status (where available)
Catchment and foreshore development	**Gosford Beaches CZMP**		
Catchment and foreshore development	6	Improved compliance for construction activities	**Implemented and Ongoing**
Stormwater runoff	**Upper Hawkesbury CZMP**		
Stormwater runoff	ARH1	Support the implementation of the River Health Strategy implementation of actions to benefit the estuary (fencing, riparian revegetation etc.).	
Stormwater runoff	RA1	Increase compliance activity on the river for pollution / dumping. Increase public promotion of implications for offenders	
Stormwater runoff	WQ1	Write a specific WSUD chapter in the Hawkesbury DCP	
Stormwater runoff	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Stormwater runoff	WQ6	Undertake adequate and appropriate maintenance of existing WSUD devices to maintain their effectiveness, in particular GPTs, nutrient filters and other stormwater quality improvement devices.	
Stormwater runoff	WQ7	Utilise hydraulics and WQ modelling insights coming out of present study for Sydney Water to understand processes and impacts.	
Stormwater runoff	WQ8	Develop a monitoring strategy for key water quality parameters (implement an estuary health monitoring program and issue biennial report cards)	
Stormwater runoff	17	Council to adopt a policy of no CSG mining in the catchment	
Stormwater runoff	48	Identify potential sources of pollutants (e.g. Golf course, sedimentation hotspots and agricultural lands) and liaise directly with land owners/ managers to reduce nutrient and sediment inputs	
Stormwater runoff	51	Retrofit appropriate WSUD in existing urban areas including measures such as artificial wetlands, vegetated swales	
Stormwater runoff	56	No sand mining in the catchment	
Stormwater runoff	89	Algae/Weeds - reduce nutrient levels (e.g. Urban runoff); increased (env) river flow.	
Stormwater runoff	**Lower Hawkesbury CZMP**		
Stormwater runoff	1	Conduct assessments to determine the carrying capacity of land areas (based on water, air, biodiversity and land capabilities) and limits for sustainable development within the entire catchment.	**Completed**
Stormwater runoff	7	Ensure planning instruments incorporate best practise: sediment, erosion and stormwater controls (eg construction controls plans and WSUD); use of water reduction devices and maximal permeable surfaces, landscaped area calculations: protection of native vegetation; sewage management (eg low risk OSSMs); restriction of landscaping and gardens to endemic species; energy efficient design and ESD.	**Implemented and Ongoing**
Stormwater runoff	30	Initiate a program for the removal of rubbish (including derelict boats) from riparian areas. The clean-up program should focus on larger items such as derelict boats and dumped construction materials, with input and assistance from industry groups and volunteers.	**Implemented and Ongoing**
Stormwater runoff	42	Establish and implement one recreational water quality monitoring program (such as Beach/Streamwatch by EPA) for the entire Lower Hawkesbury.	**Completed**
Stormwater runoff	45	Develop a comprehensive ecosystem health water quality monitoring program across the Lower Hawkesbury	**Completed**
Stormwater runoff	50	Enhance compliance with development consent conditions (sediment erosion controls, stormwater controls, permeable surface area, water reduction devices, urban design, vegetation removal etc). Increase and enforce penalties for non-compliance and unauthorised development (including renovations etc)	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Stormwater runoff	51	Increase compliance with development consent conditions (such as for maintenance of stormwater devices, permeable surface area, water reduction devices, urban design, vegetation removal etc) over the long term (i.e., in the years after completion of a development) to ensure such conditions continue to be met	**In progress / Incomplete**
Stormwater runoff	54	Implement education strategy for commercial and industrial sectors of the catchment to increase awareness of their impact on estuarine environment, and provide solutions to mitigate such impacts	**Implemented and Ongoing**
Stormwater runoff	83	Continue to lobby for reuse of water from STPs, to reduce freshwater demands in catchment	**In progress / Incomplete**
Stormwater runoff	85	Develop and implement a plan of management to maintain sustainable environmental flows as a component of total water cycle management (based upon studies and modelling of sustainable flows).	**In progress / Incomplete**
Stormwater runoff	94	Provide incentives to install oil absorbent devices within bilge water holding tanks for all moored and berthed vessels.	**Not Commenced / Outstanding**
Stormwater runoff	101	Ensure all boating facilities (marinas, slipways, private boat sheds, ferries, boat ramps etc) have containment areas for boat operation and maintenance (especially anti-foul paints, fuel storage tanks) and use best practise methods for mitigating environmental impacts. Perform follow-up audits to ensure recommendations are completed.	**Unknown**
Stormwater runoff	106	Reconsider licence conditions upon EPA licence renewals to reduce load of pollutant discharged	**In progress / Incomplete**
Stormwater runoff	108	Audit commercial and industrial areas with regard to mitigating impacts on estuarine assets.	**Implemented and Ongoing**
Stormwater runoff	111	Apply best practise stormwater management and asset management for stormwater infrastructure through preparation, implementation and regular review of stormwater management plans across the Lower Hawkesbury catchment.	**Implemented and Ongoing**
Stormwater runoff	112	Consider end of pipe treatment for all direct stormwater outlets to the estuary	**Implemented and Ongoing**
Stormwater runoff	116	Investigate increasing wet weather capacity of STPs in catchment to ensure no bypassing during wet weather	**In progress / Incomplete**
Stormwater runoff	119	Ensure that all state-owned road and rail infrastructure within the catchment has adequate stormwater management for water quality and flows	**Unknown**
Stormwater runoff	121	Improve management of leachate and runoff from waste disposal sites	**Implemented and Ongoing**
Stormwater runoff	133	Encourage vigilance in reporting noncompliance with regulations and environmental conditions/degradation (eg, sediment erosion controls, OSSMs, vegetation removal/destruction, stormwater control and maintenance, recreational activities etc) and pollution incidents (e.g. algal blooms, oils spills, chemical spills etc) to appropriate authorities (e.g., "river hood watch program")	**Implemented and Ongoing**
Stormwater runoff	143	Develop a catchment and estuarine model to illustrate the interactions between the estuary and catchment influences	**In progress / Incomplete**
Stormwater runoff	148	Determine physical processes (hydrodynamics) of the estuary using in stream flow gauges, bathymetric survey etc	**Implemented and Ongoing**
Stormwater runoff	**Pittwater CZMP**		
Stormwater runoff	3b	WSUD principles to be added to all development controls (draft DECC DCP)	**Implemented and Ongoing**
Stormwater runoff	3c	Appropriate on-site sewage systems to be adopted, suitable for soils, topography etc	**Implemented and Ongoing**
Stormwater runoff	3d	Developments not to incorporate pollution and/or sediment discharges to the waterways	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Stormwater runoff	7b	Targeted catchment management measures, following catchment-wide urban pollution and sediment runoff audit (esp. areas discharging to poorly flushed embayments)	**Implemented and Ongoing**
Stormwater runoff	**Brisbane Water CZMP**		
Stormwater runoff	C02	Provide additional resources for Council officers to undertake audits of properties to ensure enforcement of policies and conditions of consent relating to water quality during both the construction and operational phases.	
Stormwater runoff	C03	Work with private land holders / tenants to improve stormwater management practices in the industrial estate near Hawk Street.	
Stormwater runoff	C10	Enforce on-leash dog walking in restricted areas in line with Council's Dog Policy Review.	
Stormwater runoff	C15	Enforce littering restrictions and undertake parallel education programs about littering.	
Stormwater runoff	E02	Label stormwater drain inlets in problematic areas "This drains to ……".	
Stormwater runoff	E18	Undertake a stormwater education program highlighting impacts of human activities on ecological values.	
Stormwater runoff	P01	Provide for the development, implementation and regular re- assessment of Riparian Zone and Bank Management Plans for the major tributaries draining into the Estuary, including Narara Creek River care Plan, Erina Rivercare Plan, Kincumber Creek Riparian Plan, Woy Woy Creek, Currumbine Creek and Ettalong Creek.	
Stormwater runoff	P02	Develop and implement a pollution response strategy to address major pollution events. *Policy D1.02 - Oil Spillages in Navigable Waters should* be updated accordingly.	
Stormwater runoff	P04	Review the *Water Cycle Management Guidelines* (2007) and ensure that they reflect best practice WSUD and appropriately support the new DCP.	
Stormwater runoff	P05	Investigate the need for sediment traps and other stormwater management measures to control any erosion and sedimentation from sloping lands draining to the stormwater outlet opposite Byalla Lane.	
Stormwater runoff	R01	Conduct a review of the design and methodology employed in the existing water quality monitoring program. Ideally the program should be a comprehensive, scientifically rigorous and ongoing program of water and sediment quality monitoring for the Brisbane Water Estuary, incorporating dry weather and event monitoring of both the tributary mouths and main waterbody. Sampling in the main waterbodies should incorporate vertical profiling.	
Stormwater runoff	R03	Calculate a nutrient budget for the Estuary to assess the potential for eutrophication of the more enclosed portions of the waterway. The analysis should assess current conditions and conditions under climate change scenarios. Reference should be made to the water quality modelling undertaken for the Estuary as a whole, as outlined in Appendix E of the *Estuary Processes Study* (CLT, 2008).	
Stormwater runoff	R04	Audit the performance of existing stormwater quality improvement devices and assess the need for modifications.	
Stormwater runoff	R05	Keep a log of the volumes and types of material removed from GPTs during routine maintenance and incorporate this information into the water quality monitoring program.	
Stormwater runoff	R06	Undertake ongoing monitoring and maintenance of Council owned stormwater quality improvement devices.	
Stormwater runoff	R10	Conduct a condition assessment of existing stormwater outlets draining into the Estuary focusing on assessing impacts on natural sedimentary processes (e.g. erosion, accretion) and adjacent habitats.	
Stormwater runoff	R24	Investigate the use of constructed wetlands, sediment, and detention basins and other WSUD options to minimise the effect of freshwater and sediment inflows, with particular reference to areas of high biodiversity value around entrances to creeks. Consideration should be given to both current and future meteorological conditions.	

Stressor	Action ID	Description	Status (where available)
Stormwater runoff	R44	Work with Oyster Growers to develop an Environmental Management Strategy, along with improved water quality monitoring and project collaboration.	
Stormwater runoff	W01	Investigate options for implementing catchment based WSUD features in the catchment in order to manage stormwater quality and quantity, with a priority focus on the Narara and Erina Creek catchments, followed by Kincumber Creek catchment.	
Stormwater runoff	W04	Investigate appropriate stormwater treatment and control measures to reduce sedimentation into Correa Bay.	
Stormwater runoff	W06	Install and maintain as required sediment traps targeting stormwater flows draining from the escarpment at Hardys Bay.	
Stormwater runoff	W07	Provide ongoing maintenance of existing sediment traps in the catchment draining to Horsfield Bay.	
Stormwater runoff	W09	Investigate appropriate WSUD features for those roads that are currently unsealed/unfinished in order to reduce the impact of erosion and sedimentation from these roadways.	
Stormwater runoff	W10	Remediate (or pipe) open drains and install sediment traps for those drains running from Wilkie King and Mundoora Avenues.	
Stormwater runoff	W122	Investigate the feasibility of increasing the capacity of the culvert under the rail line at Fagans Bay to enhance flushing and thereby improve water quality. This investigation should also consider the influence of any historic sedimentation that may have occurred.	
Stormwater runoff	W14	Develop and implement measures to address stormwater quality issues associated with runoff from the access road and fire trails near Fisherman's Parade.	
Stormwater runoff	W44	Replace the collapsed stormwater drain running between the two ovals in Austin Butler Reserve and remove accreted sediments. There is a preference for the use of a natural vegetated swale and/or small wetland.	
Stormwater runoff	W51	Implement measures to dissipate the energy of stormwater flows and prevent scour associated with the stormwater outlet near the corner of Jirramba and Mimosa Avenues.	
Stormwater runoff	W91	Provide bins and bags for the disposal of animal faeces by dog walkers.	
Stormwater runoff	**Gosford Beaches CZMP**		
Stormwater runoff	O31	Investigate installation of stormwater energy dissipation to reduce discharge velocities at outlet	**In progress / Incomplete**
Stormwater runoff	O47	Investigate installation of stormwater energy dissipation to reduce discharge velocities at stormwater outlets	**In progress / Incomplete**
Stormwater runoff	PA21	Investigate installation of stormwater energy dissipation to reduce discharge velocities at outlet	**Not Commenced / Outstanding**
Stormwater runoff	**Pearl Beach Lagoon CZMP**		
Stormwater runoff	4	Retrofit stormwater quality improvement measures	**In progress / Incomplete**
Stormwater runoff	5	Rehabilitate habitats within creek lines of the catchment	**Implemented and Ongoing**
Stormwater runoff	6	Improved compliance for construction activities	**Implemented and Ongoing**
Agricultural runoff	**Upper Hawkesbury CZMP**		
Agricultural runoff	ARH1	Support the implementation of the River Health Strategy implementation of actions to benefit the estuary (fencing, riparian revegetation etc.).	
Agricultural runoff	ARH3	Work from relevant priorities determined by the HNCAP 2013-23 (In accordance with the HNCAP 2013-2023, identify locations for and undertake targeted rehabilitation, creation and enhancement of estuarine and floodplain wetland communities and adjacent riparian vegetation)	
Agricultural runoff	ARH5	Council led program to identify when riparian land changes ownership and to contact new owners making them aware of opportunities for grants to improve the condition of riparian lands. (related to 30)	

Stressor	Action ID	Description	Status (where available)
Agricultural runoff	WQ3	Review and update relevant DCPs in relation to rural lands to incorporate best practise land management, stock management, fertiliser and pesticide use, erosion controls and runoff controls to reduce pollutant and sediment loads from rural lands.	
Agricultural runoff	WQ8	Develop a monitoring strategy for key water quality parameters (implement an estuary health monitoring program and issue biennial report cards)	
Agricultural runoff	35	Pilot projects to showcase best practice riparian vegetation.	
Agricultural runoff	42	Have a compulsory riparian buffer of 100-200 metre	
Agricultural runoff	48	Identify potential sources of pollutants (e.g. Golf course, sedimentation hotspots and agricultural lands) and liaise directly with land owners/ managers to reduce nutrient and sediment inputs	
Agricultural runoff	49	Provide targeted education for landowners within the catchment	
Agricultural runoff	57	Encourage the installation of filtration systems for runoff from farms (artificial wetlands) - refer to later option	
Agricultural runoff	76	Support Smart Farming initiatives.	
Agricultural runoff	**Lower Hawkesbury CZMP**		
Agricultural runoff	11	Encourage conservation of native vegetation on private land	**Implemented and Ongoing**
Agricultural runoff	13	Define and map minimum buffer widths for riparian/foreshore vegetation in relevant planning documents (LEPs, DCPs etc) to protect estuary assets and account for landward migration of habitat due to sea level rise.	**In progress / Incomplete**
Agricultural runoff	25	Riparian zones in priority agricultural areas fenced to prevent access of livestock to estuary, protect and encourage rehabilitation of riparian vegetation.	**In progress / Incomplete**
Agricultural runoff	27	Improve native vegetation condition through revegetation of priority areas (based on habitat mapping)	**Implemented and Ongoing**
Agricultural runoff	29	Provide incentives to landholders to conserve significant habitats and native vegetation identified on private land (e.g. through property vegetation plans and voluntary conservation agreements)	**Implemented and Ongoing**
Agricultural runoff	48	Minimise clearing of vegetation on privately owned land via new LEP template (eg Clause 5.9) and existing biodiversity strategy	**Implemented and Ongoing**
Agricultural runoff	52	Increase the number of rural residential and smaller area landholders (less than 100 ha) attending management training for rural residential block and small farm management. The education should increase awareness of rural impacts on the estuarine environment and provide solutions to manage such impacts.	**Implemented and Ongoing**
Agricultural runoff	55	Educate residents as to best practise catchment management (fertilisers, chemicals, pesticides, threat of weeds to bushland, and encourage the removal of exotic species and replacement with suitable indigenous plants, domestic animals)	**Implemented and Ongoing**
Agricultural runoff	56	Provide incentives for the establishment of riparian filters to treat run-off from areas which may generate potentially high pollutant loads in runoff (eg, livestock, turf farms etc)	**In progress / Incomplete**
Agricultural runoff	57	Undertake soil conservation works such as fencing, gully control structures, track/trail, fire trails and rural road stabilisation and revegetation to reduce soil erosion	**In progress / Incomplete**
Agricultural runoff	120	Ensure use of low residue herbicides and adopt practices to minimise input to the waterway	**In progress / Incomplete**
Agricultural runoff	124	Determine sources of sediment contamination and impacts of contaminants on estuarine health, through sediment and water quality testing across the Lower Hawkesbury	**Implemented and Ongoing**
Agricultural runoff	143	Develop a catchment and estuarine model to illustrate the interactions between the estuary and catchment influences	**In progress / Incomplete**
Sewage and wastewater runoff	**Upper Hawkesbury CZMP**		

Stressor	Action ID	Description	Status (where available)
Sewage and wastewater runoff	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Sewage and wastewater runoff	44	Lobbying state government by community and council regarding higher quality of water from discharges by Sydney Water.	
Sewage and wastewater runoff	52	Reduce potential sewage contamination to the river, through identifying sources, increased auditing of onsite systems and where possible, connect rural residential residences up to the sewer network	
Sewage and wastewater runoff	55	Upgrade STPs	
Sewage and wastewater runoff	70	Direct the community to appropriate waste facilities.	
Sewage and wastewater runoff	**Lower Hawkesbury CZMP**		
Sewage and wastewater runoff	7	Ensure planning instruments incorporate best practise: sediment, erosion and stormwater controls (eg construction controls plans and WSUD); use of water reduction devices and maximal permeable surfaces, landscaped area calculations: protection of native vegetation; sewage management (eg low risk OSSMs); restriction of landscaping and gardens to endemic species; energy efficient design and ESD.	**Implemented and Ongoing**
Sewage and wastewater runoff	9	Incorporate appropriate provision in planning instruments to require all Marinas to provide accessible pump out facilities as a component of their licence to operate in the Lower Hawkesbury.	**Unknown**
Sewage and wastewater runoff	10	Incorporate provisions within planning controls to require all new dwellings or major alterations and additions to existing dwellings in the vicinity of priority oyster harvest areas to consider installation of pump out sewage systems where feasible.	**Implemented and Ongoing**
Sewage and wastewater runoff	39	Ensure adequate waste disposal facilities for people aboard boats and recreational fishers on land. This includes installation/provision of approved bins on hire boats, commercial fishing boats, moored boats and trailable boats, and supporting waste services on land.	**Implemented and Ongoing**
Sewage and wastewater runoff	87	Implement re-use options (such as dual reticulation, drinking water or other system) for treated effluent from STPs and their reticulation systems (eg sewer mining)	**Implemented and Ongoing**
Sewage and wastewater runoff	91	Extend regulations for holding tanks to both grey and black water for recreational and commercial vessels.	**Not Commenced / Outstanding**
Sewage and wastewater runoff	92	Lobby State government to increase deterrents for effluent discharges and other forms of pollution from vessels using the waterways.	**Not Commenced / Outstanding**
Sewage and wastewater runoff	93	Prepare and implement a strategy for pump outs across the Lower Hawkesbury Estuary (eg public use of commercial pump outs, installation of additional public pump outs etc)	**In progress / Incomplete**
Sewage and wastewater runoff	96	Provide incentives (eg grants or services) for a routine pump out service to riverside settlements	**Implemented and Ongoing**
Sewage and wastewater runoff	97	Develop a sewage management strategy for riverside settlements as part of the 'Sanitary Surveys' undertaken by NSW Food Authority with consideration given to eliminating sewage leaching to the estuary.	**Implemented and Ongoing**
Sewage and wastewater runoff	98	Encourage Sydney Water to consider an assessment of alternatives for management of sewage at Brooklyn, including effluent reuse.	**Implemented and Ongoing**
Sewage and wastewater runoff	103	Ensure all onsite septic systems throughout the catchment are audited for efficient operation and recommendations of audits enacted. Enforce penalties where correct operation and outcomes of audit are not enacted.	**In progress / Incomplete**
Sewage and wastewater runoff	105	Implement a program to audit private sewer connections (such as NSW Government's former "pipe checks" program) and ensure audit recommendations are enacted	**In progress / Incomplete**
Sewage and wastewater runoff	110	Provide information to residents to improve management of on-site sewage disposal, particularly in proximity to oyster harvesting areas, and on alternative disposal methods.	**In progress / Incomplete**

Stressor	Action ID	Description	Status (where available)
Sewage and wastewater runoff	113	Eliminate all sources of sewer overflows (including pumping stations, mushrooms, sewer chokes) in both dry and wet weather throughout the Lower Hawkesbury catchment.	**Implemented and Ongoing**
Sewage and wastewater runoff	114	Continue to upgrade STP effluent quality to minimise pollutant loads and enable greater re-use	**Implemented and Ongoing**
Sewage and wastewater runoff	116	Investigate increasing wet weather capacity of STPs in catchment to ensure no bypassing during wet weather	**In progress / Incomplete**
Sewage and wastewater runoff	117	Install appropriate sewage disposal at public facilities located near waterways in the parks, reserves and foreshore recreational areas	**Implemented and Ongoing**
Sewage and wastewater runoff	**Pittwater CZMP**		
Sewage and wastewater runoff	3c	Appropriate on-site sewage systems to be adopted, suitable for soils, topography etc	**Implemented and Ongoing**
Sewage and wastewater runoff	7c	Minimise overflows from the reticulated sewerage system (through Sydney Water consultation)	**In progress / Incomplete**
Sewage and wastewater runoff	9d	Compliance: On-site sewage systems operation	**Implemented and Ongoing**
Sewage and wastewater runoff	**Brisbane Water CZMP**		
Sewage and wastewater runoff	E11	Conduct an education program for the boating community on: - Their responsibilities with respect to the disposal of ballast, sewage and rubbish, - The location of existing sewage pump-out and rubbish disposal facilities, and - How to safeguard against leaks and spills, and what to do if a leak or spill occurs. This should include a distribution of a copy of NSW Maritime's Don't Make Waves (2006) brochure.	
Sewage and wastewater runoff	W02	Install additional sewage pump-out facilities to reduce water pollution. These should be situated at locations accessible by a range of vessels.	
Sewage and wastewater runoff	W03	Provide for continued implementation of Council's Sewerage Enhancement Program and associated capital investments.	
Sewage and wastewater runoff	W05	Advertise and provide signage for boat pump-out facilities.	
Sewage and wastewater runoff	W115	Dredge to improve access to the boat pump-out and other facilities in Gosford Harbour. The dredging should be sufficient to permit access over the full tidal cycle.	
Sewage and wastewater runoff	W120	Dredge to improve access to the boat pump-out and other facilities in Hardys Bay. The dredging should be sufficient to permit access over the full tidal cycle.	
Sewage and wastewater runoff	**Gosford Beaches CZMP**		
Sewage and wastewater runoff	PE1	Erosion Protection works to be allowed for four properties south of Green Point Creek entrance as well as for sewage pumping station and sewer line at end of Gem Road and south from Gem Road extending to protect infrastructure	**Not Commenced / Outstanding**
Sewage and wastewater runoff	PE3	Relocate sewer infrastructure and pumping station further landward	**Not Commenced / Outstanding**
Water extraction – surface and groundwater	**Upper Hawkesbury CZMP**		
Water extraction – surface and groundwater	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Water extraction – surface and groundwater	WQ7	Utilise hydraulics and WQ modelling insights coming out of present study for Sydney Water to understand processes and impacts.	

Stressor	Action ID	Description	Status (where available)
Water extraction – surface and groundwater	17	Council to adopt a policy of no CSG mining in the catchment	
Water extraction – surface and groundwater	47	Lobby for an increase environmental flows	
Water extraction – surface and groundwater	62	Council to Lobby for an increase freshwater flows	
Water extraction – surface and groundwater	77	Review catchment population/development based on the assessment of estuary carrying capacity and ecological assessments	
Water extraction – surface and groundwater	78	Update LEP zonings to reflect the limits to population growth and development (as based on the findings of land capability and ecological assessments) and to protect significant habitats requiring protection (as based on ecological assessments)	
Water extraction – surface and groundwater	86	Release water from warmer section of dam	
Water extraction – surface and groundwater	**Lower Hawkesbury CZMP**		
Water extraction – surface and groundwater	1	Conduct assessments to determine the carrying capacity of land areas (based on water, air, biodiversity and land capabilities) and limits for sustainable development within the entire catchment.	**Completed**
Water extraction – surface and groundwater	2	Collect information to inform amendments to planning controls based on the assessment of land capability, estuary carrying capacity (future population and development within the catchment) and ecological assessments.	**Implemented and Ongoing**
Water extraction – surface and groundwater	7	Ensure planning instruments incorporate best practise: sediment, erosion and stormwater controls (eg construction controls plans and WSUD); use of water reduction devices and maximal permeable surfaces, landscaped area calculations: protection of native vegetation; sewage management (eg low risk OSSMs); restriction of landscaping and gardens to endemic species; energy efficient design and ESD.	**Implemented and Ongoing**
Water extraction – surface and groundwater	50	Enhance compliance with development consent conditions (sediment erosion controls, stormwater controls, permeable surface area, water reduction devices, urban design, vegetation removal etc). Increase and enforce penalties for non-compliance and unauthorised development (including renovations etc)	**Implemented and Ongoing**
Water extraction – surface and groundwater	83	Continue to lobby for reuse of water from STPs, to reduce freshwater demands in catchment	**In progress / Incomplete**
Water extraction – surface and groundwater	84	Regulate surface and ground water extraction (through licences etc) based upon assessment of required environmental flows.	**Unknown**
Water extraction – surface and groundwater	85	Develop and implement a plan of management to maintain sustainable environmental flows as a component of total water cycle management (based upon studies and modelling of sustainable flows).	**In progress / Incomplete**
Water extraction – surface and groundwater	86	Increase the uptake of water and energy reduction devices through greater planning controls, incentives, free water reduction audits for homes/businesses etc	**Implemented and Ongoing**
Water extraction – surface and groundwater	87	Implement re-use options (such as dual reticulation, drinking water or other system) for treated effluent from STPs and their reticulation systems (eg sewer mining)	**Implemented and Ongoing**
Water extraction – surface and groundwater	88	Undertake a comprehensive environmental flows investigation for all tributaries to the Lower Hawkesbury. This should include determining groundwater and surface water extraction rates/volumes, contributions from all sources (urban runoff, STPs), and ecological flow requirements.	**Not Commenced / Outstanding**

Stressor	Action ID	Description	Status (where available)
Water extraction – surface and groundwater	107	Ensure compliance with greywater reuse policy (i.e. DWE and Council Policies)	**Implemented and Ongoing**
Water extraction – surface and groundwater	114	Continue to upgrade STP effluent quality to minimise pollutant loads and enable greater re-use	**Implemented and Ongoing**
Water extraction – surface and groundwater	115	Provide education to increase community acceptance of recycled water from STPs, and collection and re-use of stormwater, etc as per the Sustainable Total Water Cycle Management strategy	**Not Commenced / Outstanding**
Water extraction – surface and groundwater	**Pittwater CZMP**		
Water extraction – surface and groundwater	3b	WSUD principles to be added to all development controls (draft DECC DCP)	**Implemented and Ongoing**
Water extraction – surface and groundwater	**Brisbane Water CZMP**		
Water extraction – surface and groundwater	P04	Review the Water *Cycle Management Guidelines* (2007) and ensure that they reflect best practice WSUD and appropriately support the new DCP.	
Barriers to longitudinal and lateral connectivity	**Upper Hawkesbury CZMP**		
Barriers to longitudinal and lateral connectivity	ARH2	Prepare a species planting fact sheet for applicants and Council officers for use in development assessment of foreshore works	
Barriers to longitudinal and lateral connectivity	ARH3	Work from relevant priorities determined by the HNCAP 2013-23 (In accordance with the HNCAP 2013-2023, identify locations for and undertake targeted rehabilitation, creation and enhancement of estuarine and floodplain wetland communities and adjacent riparian vegetation)	
Barriers to longitudinal and lateral connectivity	FP1	Prepare fact sheet on appropriate structures on river corridor.	
Barriers to longitudinal and lateral connectivity	FP3	Review and update Hawkesbury DCP to include a new chapter on foreshore management	
Barriers to longitudinal and lateral connectivity	FP4	Prepare a site specific guideline for environmentally friendly seawalls in the Upper Hawkesbury River.	
Barriers to longitudinal and lateral connectivity	LPD1	Develop a method checklist which enables local council planners to continually assess the likely impacts of DAs upon the natural processes, estuary values and sustainability of the Upper Hawkesbury Estuary	
Barriers to longitudinal and lateral connectivity	LPD5	Provide development assessment guidelines for subdivisions to maximise riparian corridors and reduce fragmented private frontages.	
Barriers to longitudinal and lateral connectivity	RA3	Undertake compliance on unauthorised use and development on riparian and estuarine vegetation areas	

Stressor	Action ID	Description	Status (where available)
Barriers to longitudinal and lateral connectivity	SLR2	Map estuarine vegetation and assess vulnerabilities to future sea level rise	
Barriers to longitudinal and lateral connectivity	13	Encourage the planting of appropriate species to enhance connectivity, green corridors and succession of desired adult trees	
Barriers to longitudinal and lateral connectivity	38	When prioritising areas for rehabilitation, seek out opportunities to compliment riparian and biodiversity corridors.	
Barriers to longitudinal and lateral connectivity	42	Have a compulsory riparian buffer of 100-200 metre	
Barriers to longitudinal and lateral connectivity	62	Council to lobby for an increase freshwater flows	
Barriers to longitudinal and lateral connectivity	71	Rehabilitation of barriers to fish passage.	
Barriers to longitudinal and lateral connectivity	88	Eel slide at dam wall - refer to later option not relevant because no dam in area	
Barriers to longitudinal and lateral connectivity	**Lower Hawkesbury CZMP**		
Barriers to longitudinal and lateral connectivity	8	Ensure suitable controls are contained within planning instruments for the design of foreshore development including recreational facilities to maintain the estuary shoreline in as natural state as possible and minimises potential for bank erosion.	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	11	Encourage conservation of native vegetation on private land	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	13	Define and map minimum buffer widths for riparian/foreshore vegetation in relevant planning documents (LEPs, DCPs etc) to protect estuary assets and account for landward migration of habitat due to sea level rise.	**In progress / Incomplete**
Barriers to longitudinal and lateral connectivity	15	During the review of plans of management for all parks and reserves (both national and council managed), ensure estuary assets are preserved (including habitat values for native animals, animals listed under the TSC Act 1995, prescribed burning and bushfire suppression undertaken according to park/reserve fire management plan, etc).	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	25	Riparian zones in priority agricultural areas fenced to prevent access of livestock to estuary, protect and encourage rehabilitation of riparian vegetation.	**In progress / Incomplete**
Barriers to longitudinal and lateral connectivity	26	Undertake comprehensive of mapping of the extent and condition of riparian habitats (including mangroves, saltmarsh and wetland species) in the Lower Hawkesbury and review periodically	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Barriers to longitudinal and lateral connectivity	27	Improve native vegetation condition through revegetation of priority areas (based on habitat mapping)	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	28	Expand bush regeneration programs and conservation programs for specific priority species	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	29	Provide incentives to landholders to conserve significant habitats and native vegetation identified on private land (e.g. through property vegetation plans and voluntary conservation agreements)	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	36	Restrict foreshore access in areas of high environmental sensitivity	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	43	Undertake periodic mapping of aquatic habitats (including the extent and condition of benthic, intertidal zone, water column and water surface habitats) throughout the Lower Hawkesbury	**Completed**
Barriers to longitudinal and lateral connectivity	44	Develop key biological indicators and establish a biological monitoring program for aquatic and riparian habitats	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	48	Minimise clearing of vegetation on privately owned land via new LEP template (eg Clause 5.9) and existing biodiversity strategy	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	131	Prepare and implement creek rehabilitation plans to restore and maintain native vegetation in the riparian zone	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	**Pittwater CZMP**		
Barriers to longitudinal and lateral connectivity	1b	Update and implement Plan of Management for Careel Bay wetlands, ensuring maintenance of habitat mix / diversity (which may include selective removal of mangrove seedlings that have encroached onto saltmarsh areas from time to time)	**Not Commenced / Outstanding**
Barriers to longitudinal and lateral connectivity	1c	Prepare and implement Plans of Management for areas of significant habitat (eg EECs) on public land and DCPs for private lands ensuring preservation and enhancement of key environmental values	**In progress / Incomplete**
Barriers to longitudinal and lateral connectivity	4e	Remove significant impediments to fish passage	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	6c	Re-vegetation along estuary foreshores and along riparian zones within catchment (on both public and private lands) to connect habitats, provide shade and enhance ecological communities (esp. EECs)	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	6d	Weed and exotic species control, including Caulerpa taxifolia.	**In progress / Incomplete**

Stressor	Action ID	Description	Status (where available)
Barriers to longitudinal and lateral connectivity	**Brisbane Water CZMP**		
Barriers to longitudinal and lateral connectivity	C14	Audit existing foreshore development (including property boundaries, fences and other structures, boat houses, boat ramps, jetties, etc.) and identify illegal or non-conforming development for retrospective enforcement of development controls. This should be undertaken in accordance with the Conditions of Consent and relevant policy in force at the time of Development Approval. Where foreshore structures are negatively impacting on estuarine processes (e.g. causing erosion or accretion on adjacent lands), investigate opportunities to mitigate these issues. This may be achieved through the Crown lands lease/licensing mechanism (where relevant).	
Barriers to longitudinal and lateral connectivity	E09	Provide foreshore property owners with information/guidelines about what constitutes good and bad practice with respect to foreshore management (e.g. limits of mowing, stabilisation works, etc.). This should include information on environmentally friendly seawall options to both the community and those individuals assessing development applications for these structures. Reference should be made to DECC's *Environmentally Friendly Seawalls: A Guide to Improving the Environmental Value of Seawalls and Seawall-lined Foreshores in Estuaries* (2009).	
Barriers to longitudinal and lateral connectivity	P16	Investigate opportunities to purchase saltmarsh areas for incorporation into Council's reserve system in accordance with Policy *R0.15 - Acquisition of Wetlands* .	
Barriers to longitudinal and lateral connectivity	P19	Develop a strategy for the conservation of areas important for the biodiversity of invertebrates. Particular attention should be paid to priority sites that represent the greatest proportion of species, including Ettalong, Narara Creek, Koolewong, and Woy Woy Bay-Pelican Island.	
Barriers to longitudinal and lateral connectivity	P20	Develop a conservation and education strategy for seagrass beds, as identified in the *Estuary Processes Study* (CLT, 2008), that: - Support the highest abundance and diversity of fish, - Are known to be important for sponges and ascidians, and - Are known to be important for biological connectivity.	
Barriers to longitudinal and lateral connectivity	P27	Develop a Plan of Management to provide protection for the Bush Stone Curlew populations occurring around the Estuary. In addition, provide for ongoing implementation of the Plan of Management for Green and Golden Bell Frogs.	
Barriers to longitudinal and lateral connectivity	P30	Develop a DCP for Wetlands aimed at maintaining and restoring natural biological and physical processes of wetland function by minimising changes to wetland hydrology from land uses in the catchment. This should be undertaken in line with DECCW's *NSW Wetlands Policy (*2010b).	
Barriers to longitudinal and lateral connectivity	P48	Develop environmentally friendly design and construction guidelines for foreshore infrastructure such as jetties, boat ramps, seawalls/retaining walls and foreshore protection works. This should include advice on retro-fitting existing structures to be more environmentally friendly. The guidelines should be made publicly available and distributed to all foreshore property owners. (Note: Seawalls addressed in DECC's Environmentally Friendly Seawalls guidelines (2009)).	
Barriers to longitudinal and lateral connectivity	P49	Develop guidelines (or compile existing guidelines where available) for foreshore stabilisation via the establishment of locally native estuarine plant species. The guidelines should provide details of the benefits of soft stabilisation works, advice on the species to be used and how to establish plantings. Seedlings may be cultivated at Council's nursery for supply to interested parties.	

Stressor	Action ID	Description	Status (where available)
Barriers to longitudinal and lateral connectivity	P50	Review *D6.47 - Setback Policy: Creeks, Rivers and Lagoon* s. The review should in the first instance widen the definition of applicable waterbodies to incorporate 'estuaries', and in the second instance be re-assessed to incorporate the likely impacts of climate change. In particular, the setbacks applied should be re-assessed to take into account processes relating to both catchment flooding and foreshore inundation.	
Barriers to longitudinal and lateral connectivity	R14	Investigate options for upgrading the seawall along Masons Parade and Dane Drive, Gosford, in line with the Gosford Challenge/City Centre Redevelopment to consider environmentally friendly design.	
Barriers to longitudinal and lateral connectivity	R19	Investigate options for the landward migration of intertidal habitats such as saltmarsh under climate change scenarios.	
Barriers to longitudinal and lateral connectivity	R22	Monitor the extent of riparian, foreshore and aquatic vegetation around the Brisbane Water Estuary. Trends in vegetation condition and extent should be reported every five years. Reference should be made to the NSW Government's NSW Monitoring, Evaluation and Reporting Strategy for estuaries to assess extent of mangrove, saltmarsh and seagrass (the latter to species).	
Barriers to longitudinal and lateral connectivity	W123	Investigate the feasibility of utilising artificial reef structures to provide habitat diversity and/or minimise foreshore erosion/recession.	
Barriers to longitudinal and lateral connectivity	W26	Rehabilitate the eroding foreshores on the eastern shores of Hardys Bay with natural vegetation typical of that naturally occurring in the area. Where this is not feasible, investigate environmentally friendly seawall options.	
Barriers to longitudinal and lateral connectivity	W29	Implement shoreline protection works which incorporate environmentally friendly design features.	
Barriers to longitudinal and lateral connectivity	W43	Develop and implement a long term solution to replace the currently failing seawall in Memorial Park on Brick Wharf Road. Any option identified should wherever possible incorporate environmentally friendly features.	
Barriers to longitudinal and lateral connectivity	W48	Enhance foreshore vegetation to prevent further erosion of Illoura Reserve between Lintern Street and Malinya Road, Davistown, and along the western/northern foreshore of Kincumber Broadwater.	
Barriers to longitudinal and lateral connectivity	W59	Investigate the benefits of decommissioning the Woy Woy Creek dam at former abattoir site.	
Barriers to longitudinal and lateral connectivity	W60	Where possible, provide for managed retreat of infrastructure from foreshore areas likely to be affected by sea level rise on a regular basis.	
Barriers to longitudinal and lateral connectivity	W66	Provide fish friendly structures where new instream structures are being constructed.	
Barriers to longitudinal and lateral connectivity	W67	Identify existing instream infrastructure (e.g. weirs and culverts) for replacement or retrofitting to fish friendly status.	

Stressor	Action ID	Description	Status (where available)
Barriers to longitudinal and lateral connectivity	W69	Review condition of existing sea walls in Council's foreshore parks to investigate possibility of returning natural foreshore and/or use of alternative materials in line with DECC's Environmentally Friendly Seawalls guidelines (2009).	
Barriers to longitudinal and lateral connectivity	W70	Fence existing saltmarshes to prevent access by vehicles, bikes and domestic animals and provide information on the importance of saltmarsh habitat to estuary health.	
Barriers to longitudinal and lateral connectivity	W71	Where appropriate, rehabilitate saltmarsh habitats on an Estuary-wide basis. Rehabilitation works should be prioritised with due consideration of habitat connectivity, and the potential for ongoing conservation in both the medium-term and long-term (i.e. under a climate change scenario).	
Barriers to longitudinal and lateral connectivity	**Gosford Beaches CZMP**		
Barriers to longitudinal and lateral connectivity	O18	Complete a vegetation profile for Umina and Ocean Beach and support the natural vegetation profile.	**Completed**
Barriers to longitudinal and lateral connectivity	O22	Encourage and assist DuneCare group to maintain and revegetate dune after a storm using appropriate endemic vegetation	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	O43	Collapse steep eroded escarpment and revegetate following erosion events	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	**Pearl Beach Lagoon CZMP**		
Barriers to longitudinal and lateral connectivity	2	Prepare a vegetation and access master plan	**Not Commenced / Outstanding**
Barriers to longitudinal and lateral connectivity	5	Rehabilitate habitats within creek lines of the catchment	**Implemented and Ongoing**
Barriers to longitudinal and lateral connectivity	8	Investigate options to modify the weir	**In progress / Incomplete**
Erosion and Sedimentation	**Upper Hawkesbury CZMP**		
Erosion and Sedimentation	FP6	Undertake bank erosion works in areas currently experiencing bank erosion and instability and areas vulnerable to this in the future. Council to undertake works on publicly owned land and to support works on privately owned land	
Erosion and Sedimentation	FP7	Investigate potential causes of bank erosion along the River including the impact of boating activities in partnership with landowners, boat users and relevant agencies.	
Erosion and Sedimentation	LPD5	Provide development assessment guidelines for subdivisions to maximise riparian corridors and reduce fragmented private frontages.	
Erosion and Sedimentation	ME1	Erosion Monitoring	

Stressor	Action ID	Description	Status (where available)
Erosion and Sedimentation	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Erosion and Sedimentation	WQ3	Review and update relevant DCPs in relation to rural lands to incorporate best practise land management, stock management, fertiliser and pesticide use, erosion controls and runoff controls to reduce pollutant and sediment loads from rural lands.	
Erosion and Sedimentation	WQ4	Undertake an education program for works staff involved in sediment and erosion control within the catchments to raise the profile of best practice erosion and sediment control, assist staff with new policies and procedures and track improvements in performance.	
Erosion and Sedimentation	WQ5	Enforce implementation and maintenance of effective sediment controls during the subdivision and building phases of all developments (including infrastructure projects) by undertaking regular audits of developments during construction	
Erosion and Sedimentation	42	Have a compulsory riparian buffer of 100-200 metre	
Erosion and Sedimentation	45	Lobby for stricter regulations for wakeboarding, for example restricting the use of ballast	
Erosion and Sedimentation	51	Retrofit appropriate WSUD in existing urban areas including measures such as artificial wetlands, vegetated swales	
Erosion and Sedimentation	83	Ensure latest research on boat wake, speed limits, boat type and erosion are considered in recreational zoning of the estuary.	
Erosion and Sedimentation	87	Close river to all but emergency boats during very high water (floods/ King Tides) to reduce bank erosion during these conditions.	
Erosion and Sedimentation	90	Extent of bank erosion - controlled use of waterway; bank revegetation/stabilisation; manage points of access - people, stock.	
Erosion and Sedimentation	**Lower Hawkesbury CZMP**		
Erosion and Sedimentation	7	Ensure planning instruments incorporate best practise: sediment, erosion and stormwater controls (eg construction controls plans and WSUD); use of water reduction devices and maximal permeable surfaces, landscaped area calculations: protection of native vegetation; sewage management (eg low risk OSSMs); restriction of landscaping and gardens to endemic species; energy efficient design and ESD.	**Implemented and Ongoing**
Erosion and Sedimentation	8	Ensure suitable controls are contained within planning instruments for the design of foreshore development including recreational facilities to maintain the estuary shoreline in as natural state as possible and minimises potential for bank erosion.	**Implemented and Ongoing**
Erosion and Sedimentation	13	Define and map minimum buffer widths for riparian/foreshore vegetation in relevant planning documents (LEPs, DCPs etc) to protect estuary assets and account for landward migration of habitat due to sea level rise.	**In progress / Incomplete**
Erosion and Sedimentation	25	Riparian zones in priority agricultural areas fenced to prevent access of livestock to estuary, protect and encourage rehabilitation of riparian vegetation.	**In progress / Incomplete**
Erosion and Sedimentation	50	Enhance compliance with development consent conditions (sediment erosion controls, stormwater controls, permeable surface area, water reduction devices, urban design, vegetation removal etc). Increase and enforce penalties for non-compliance and unauthorised development (including renovations etc)	**Implemented and Ongoing**
Erosion and Sedimentation	52	Increase the number of rural residential and smaller area landholders (less than 100 ha) attending management training for rural residential block and small farm management. The education should increase awareness of rural impacts on the estuarine environment and provide solutions to manage such impacts.	**Implemented and Ongoing**
Erosion and Sedimentation	57	Undertake soil conservation works such as fencing, gully control structures, track/trail, fire trails and rural road stabilisation and revegetation to reduce soil erosion	**In progress / Incomplete**
Erosion and Sedimentation	59	Use recommendations made in the Hornsby Shire Waterways Review (SJB, 2006) to inform waterway zoning in new LEP for the Lower Hawkesbury	**Completed**
Erosion and Sedimentation	111	Apply best practise stormwater management and asset management for stormwater infrastructure through preparation, implementation and regular review of stormwater management plans across the Lower Hawkesbury catchment.	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Erosion and Sedimentation	124	Determine sources of sediment contamination and impacts of contaminants on estuarine health, through sediment and water quality testing across the Lower Hawkesbury	**Implemented and Ongoing**
Erosion and Sedimentation	129	Investigate the potential for increased sedimentation as a result of bushfires and prescribed burning	**In progress / Incomplete**
Erosion and Sedimentation	130	Determine sedimentation rates for the estuary as required.	**Implemented and Ongoing**
Erosion and Sedimentation	147	Undertake a study to identify locations of bank erosion in the estuary and determine the causes of such erosion (e.g., wind waves, boat wake) and remediate as required	**Implemented and Ongoing**
Erosion and Sedimentation	**Pittwater CZMP**		
Erosion and Sedimentation	3d	Developments not to incorporate pollution and/or sediment discharges to the waterways	**Implemented and Ongoing**
Erosion and Sedimentation	3g	Make stricter sediment & erosion controls for developments	**Implemented and Ongoing**
Erosion and Sedimentation	6b	Redress erosion along Pittwater foreshores and along catchment streams / tributaries	**Implemented and Ongoing**
Erosion and Sedimentation	9c	Compliance: Sediment and erosion controls, as well as other development controls / conditions	**Implemented and Ongoing**
Erosion and Sedimentation	**Brisbane Water CZMP**		
Erosion and Sedimentation	C14	Audit existing foreshore development (including property boundaries, fences and other structures, boat houses, boat ramps, jetties, etc.) and identify illegal or non-conforming development for retrospective enforcement of development controls. This should be undertaken in accordance with the Conditions of Consent and relevant policy in force at the time of Development Approval. Where foreshore structures are negatively impacting on estuarine processes (e.g. causing erosion or accretion on adjacent lands), investigate opportunities to mitigate these issues. This may be achieved through the Crown lands lease/licensing mechanism (where relevant).	
Erosion and Sedimentation	P01	Provide for the development, implementation and regular re- assessment of Riparian Zone and Bank Management Plans for the major tributaries draining into the Estuary, including Narara Creek River care Plan, Erina Rivercare Plan, Kincumber Creek Riparian Plan, Woy Woy Creek, Currumbine Creek and Ettalong Creek.	
Erosion and Sedimentation	P05	Investigate the need for sediment traps and other stormwater management measures to control any erosion and sedimentation from sloping lands draining to the stormwater outlet opposite Byalla Lane.	
Erosion and Sedimentation	P07	Develop formal standard designs for key navigational channels in Brisbane Water that identify the desired channel profile and likely maintenance dredging requirements to maintain these configurations for the purposes of recreational and commercial boating. The purpose of this action is to provide clear information to users of Brisbane Water and manage community expectations in relation to maintenance of navigation channels, while acknowledging natural rates of sediment transport in these locations and likely environmental impacts. This process should be informed by the Sediment Management Plan provided in the *Brisbane Water Estuary Management Study* (CLT, 2010) and the findings of the *Brisbane Water Estuary Processes Study* (CLT, 2008). It is acknowledged that additional investigations may be required to develop the standard designs.	
Erosion and Sedimentation	P09	Implement tighter erosion and sedimentation controls to minimise risks to seagrass, with a priority for catchments adjacent to areas of seagrass of high value for species.	

Stressor	Action ID	Description	Status (where available)
Erosion and Sedimentation	P14	Continue to enforce prohibition of mowing to the water's edge in both public and private foreshore areas in order to minimise foreshore erosion and impacts on estuarine vegetation and Endangered Ecological Communities.	
Erosion and Sedimentation	P49	Develop guidelines (or compile existing guidelines where available) for foreshore stabilisation via the establishment of locally native estuarine plant species. The guidelines should provide details of the benefits of soft stabilisation works, advice on the species to be used and how to establish plantings. Seedlings may be cultivated at Council's nursery for supply to interested parties.	
Erosion and Sedimentation	R04	Audit the performance of existing stormwater quality improvement devices and assess the need for modifications.	
Erosion and Sedimentation	R09	Conduct ongoing monitoring (by survey) of key navigation channels, including: - Entrance Channel, - Paddy's Channel, - Lintern Channel, - Woy Woy Channel, - Wagstaffe Channel, - Cockle Channel, and - Saratoga Channel.	
Erosion and Sedimentation	R10	Conduct a condition assessment of existing stormwater outlets draining into the Estuary focusing on assessing impacts on natural sedimentary processes (e.g. erosion, accretion) and adjacent habitats.	
Erosion and Sedimentation	R11	Investigate sedimentary processes to determine appropriate long term management strategies to maintain property protection and public access along the foreshore between Ferry Road, Ettalong and the eastern most point of Booker Bay foreshore.	
Erosion and Sedimentation	R16	Identify the cause of erosion under the bridge near Lara Street and outline measures to address this issue.	
Erosion and Sedimentation	R24	Investigate the use of constructed wetlands, sediment, and detention basins and other WSUD options to minimise the effect of freshwater and sediment inflows, with particular reference to areas of high biodiversity value around entrances to creeks. Consideration should be given to both current and future meteorological conditions.	
Erosion and Sedimentation	R43	Undertake a comprehensive geomorphological study of historic and current sedimentation rates at the estuarine outlet areas of the major creeks (Narara, Erina, Kincumber and Woy Woy Creeks).	
Erosion and Sedimentation	W04	Investigate appropriate stormwater treatment and control measures to reduce sedimentation into Correa Bay.	
Erosion and Sedimentation	W06	Install and maintain as required sediment traps targeting stormwater flows draining from the escarpment at Hardys Bay.	
Erosion and Sedimentation	W07	Provide ongoing maintenance of existing sediment traps in the catchment draining to Horsfield Bay.	
Erosion and Sedimentation	W09	Investigate appropriate WSUD features for those roads that are currently unsealed/unfinished in order to reduce the impact of erosion and sedimentation from these roadways.	
Erosion and Sedimentation	W10	Remediate (or pipe) open drains and install sediment traps for those drains running from Wilkie King and Mundoora Avenues.	
Erosion and Sedimentation	W14	Develop and implement measures to address stormwater quality issues associated with runoff from the access road and fire trails near Fisherman's Parade.	
Erosion and Sedimentation	W26	Rehabilitate the eroding foreshores on the eastern shores of Hardys Bay with natural vegetation typical of that naturally occurring in the area. Where this is not feasible, investigate environmentally friendly seawall options.	
Erosion and Sedimentation	W27	Undertake regular maintenance to remove sediments from the outlets of stormwater drains.	

Stressor	Action ID	Description	Status (where available)
Erosion and Sedimentation	W34	Identify locations of bank erosion along creek line corridors and the Estuary foreshore. Design and implement remediation measures to address these issues, with re-establishment of native vegetation being the preferred option where feasible. Reference should be made to the shoreline assessment provided in Appendix H of the *Estuary Processes Study* (CLT, 2008) along with the Narara Creek and Erina Rivercare Plans.	
Erosion and Sedimentation	W35	Investigate appropriate sediment control works to address sediment accretion issues at St Huberts Island.	
Erosion and Sedimentation	W38	Implement shoreline protection works (to include plantings) to address the erosion and foreshore inundation along the foreshore at Yattalunga Reserve.	
Erosion and Sedimentation	W39	Rehabilitate eroded foreshore near 29 Araluen Drive, Killcare.	
Erosion and Sedimentation	W41	Undertake foreshore stabilisation works in the Punt Bridge area incorporating revegetation to address erosion issues.	
Erosion and Sedimentation	W44	Replace the collapsed stormwater drain running between the two ovals in Austin Butler Reserve and remove accreted sediments. There is a preference for the use of a natural vegetated swale and/or small wetland.	
Erosion and Sedimentation	W45	Undertake foreshore stabilisation works to address erosion currently occurring in Palermo Reserve, Empire Bay Drive.	
Erosion and Sedimentation	W48	Enhance foreshore vegetation to prevent further erosion of Illoura Reserve between Lintern Street and Malinya Road, Davistown, and along the western/northern foreshore of Kincumber Broadwater.	
Erosion and Sedimentation	W49	Implement foreshore stabilisation works to prevent further erosion of the shoreline near Rip Road Reserve.	
Erosion and Sedimentation	W52	Investigate and implement measures to address siltation currently occurring in the open drain along the foreshore between Mundoora Access and Wilkie King Avenue. Both removal of the accreted sediments and measures to address sediment sources should be considered. There is a preference for the use of a natural vegetated swale and/or small wetland.	
Erosion and Sedimentation	W53	Undertake bank stabilisation works to address the erosion occurring in the creek in the region of Avoca and Sun Valley Drives.	
Erosion and Sedimentation	**Gosford Beaches CZMP**		
Erosion and Sedimentation	O17	Install sand trapping fencing or other appropriate controls in beach access points where sand blowout occurs and in the vicinity of the SLSCs.	**Implemented and Ongoing**
Erosion and Sedimentation	**Pearl Beach Lagoon CZMP**		
Erosion and Sedimentation	9	Investigate options for removing material from lagoon bed	**In progress / Incomplete**
Dredging	**Upper Hawkesbury CZMP**		
Dredging	65	Dredging of existing navigation channels is supported subject to appropriate environmental approvals	**Implemented and Ongoing**
Dredging	124	Determine sources of sediment contamination and impacts of contaminants on estuarine health, through sediment and water quality testing across the Lower Hawkesbury	**Implemented and Ongoing**
Dredging	125	Establish an ongoing sediment monitoring program for the estuary concentrating on areas of known heavy metal contamination or boat maintenance services.	**Implemented and Ongoing**
Dredging	**Pittwater CZMP**		
Dredging	2d	Allow small scale maintenance dredging for navigational safety, providing it does not conflict with or compromise existing or future environmental values.	**Implemented and Ongoing**
Dredging	**Brisbane Water CZMP**		

Stressor	Action ID	Description	Status (where available)
Dredging	P07	Develop formal standard designs for key navigational channels in Brisbane Water that identify the desired channel profile and likely maintenance dredging requirements to maintain these configurations for the purposes of recreational and commercial boating. The purpose of this action is to provide clear information to users of Brisbane Water and manage community expectations in relation to maintenance of navigation channels, while acknowledging natural rates of sediment transport in these locations and likely environmental impacts. This process should be informed by the Sediment Management Plan provided in the *Brisbane Water Estuary Management Stud* y (CLT, 2010) and the findings of the *Brisbane Water Estuary Processes Study* (CLT, 2008). It is acknowledged that additional investigations may be required to develop the standard designs.	
Dredging	P08	Review and revise *DCP 145 Boating Facilities in St Huberts Island Canals* to ensure consistency with the goals and objectives of the Estuary Management Study and Plan. In particular, explicit consideration of sedimentary processes should form part of the assessment process for all development applications.	
Dredging	P39	Assess options for relocation of the Pretty Beach pool such that it will be suitable for swimming under all tidal conditions and is not subject to sediment build-up.	
Dredging	R09	Conduct ongoing monitoring (by survey) of key navigation channels, including: - Entrance Channel, - Paddy's Channel, - Lintern Channel, - Woy Woy Channel, - Wagstaffe Channel, - Cockle Channel, and - Saratoga Channel.	
Dredging	R45	To identify primary sources of contamination, especially in the Narara Creek catchment, consider remedial strategies and undertake follow up investigations of sediment in the northern part of the estuary to improve assessment of possible sediment toxicity.	
Sediment contamination	**Upper Hawkesbury CZMP**		
Sediment contamination	RA1	Increase compliance activity on the river for pollution / dumping. Increase public promotion of implications for offenders	
Sediment contamination	WQ2, LPD3	Review and update the Hawkesbury and Hills DCPs to give greater protection to estuary assets. Ensure DCPs incorporate best practise: sediment, erosion and stormwater controls (WSUD); use of water reduction devices and maximal permeable surfaces: protection of native vegetation; sewage (i.e. low risk OSSM) management; restriction of landscapes and gardens to endemic species; bank protection works etc. (refer also to 2)	
Sediment contamination	WQ3	Review and update relevant DCPs in relation to rural lands to incorporate best practise land management, stock management, fertiliser and pesticide use, erosion controls and runoff controls to reduce pollutant and sediment loads from rural lands.	
Sediment contamination	44	Lobbying state government by community and council regarding higher quality of water from discharges by Sydney Water.	
Sediment contamination	48	Identify potential sources of pollutants (e.g. Golf course, sedimentation hotspots and agricultural lands) and liaise directly with land owners/ managers to reduce nutrient and sediment inputs	
Sediment contamination	51	Retrofit appropriate WSUD in existing urban areas including measures such as artificial wetlands, vegetated swales	
Sediment contamination	**Lower Hawkesbury CZMP**		

Stressor	Action ID	Description	Status (where available)
Sediment contamination	7	Ensure planning instruments incorporate best practise: sediment, erosion and stormwater controls (eg construction controls plans and WSUD); use of water reduction devices and maximal permeable surfaces, landscaped area calculations: protection of native vegetation; sewage management (eg low risk OSSMs); restriction of landscaping and gardens to endemic species; energy efficient design and ESD.	**Implemented and Ongoing**
Sediment contamination	9	Incorporate appropriate provision in planning instruments to require all Marinas to provide accessible pump out facilities as a component of their licence to operate in the Lower Hawkesbury.	**Unknown**
Sediment contamination	30	Initiate a program for the removal of rubbish (including derelict boats) from riparian areas. The clean-up program should focus on larger items such as derelict boats and dumped construction materials, with input and assistance from industry groups and volunteers.	**Implemented and Ongoing**
Sediment contamination	54	Implement education strategy for commercial and industrial sectors of the catchment to increased awareness of their impact on estuarine environment, and provide solutions to mitigate such impacts	**Implemented and Ongoing**
Sediment contamination	55	Educate residents as to best practise catchment management (fertilisers, chemicals, pesticides, threat of weeds to bushland, and encourage the removal of exotic species and replacement with suitable indigenous plants, domestic animals)	**Implemented and Ongoing**
Sediment contamination	56	Provide incentives for the establishment of riparian filters to treat run-off from areas which may generate potentially high pollutant loads in runoff (eg, livestock, turf farms etc)	**In progress / Incomplete**
Sediment contamination	67	Develop and implement a program for auditing boats for methods used to contain waste from boat maintenance, effluent discharge practises, rubbish disposal, oil discharge from bilge pumps and all other environmental issues associated with boat usage. This could reasonably be combined with NSW Maritime audits of moorings.	**In progress / Incomplete**
Sediment contamination	69	Transfer the management of Kangaroo Point pump out to an appropriate State government agency	**In progress / Incomplete**
Sediment contamination	94	Provide incentives to install oil absorbent devices within bilge water holding tanks for all moored and berthed vessels.	**Not Commenced / Outstanding**
Sediment contamination	100	Ensure compliance of correct waste disposal from Marinas and vessels	**In progress / Incomplete**
Sediment contamination	101	Ensure all boating facilities (marinas, slipways, private boat sheds, ferries, boat ramps etc) have containment areas for boat operation and maintenance (especially anti-foul paints, fuel storage tanks) and use best practise methods for mitigating environmental impacts. Perform follow-up audits to ensure recommendations are completed.	**Unknown**
Sediment contamination	102	All Councils within the Lower Hawkesbury are to conduct Emergency spill management as per relevant Emergency Action Plan.	**Not Commenced / Outstanding**
Sediment contamination	106	Reconsider licence conditions upon EPA licence renewals to reduce load of pollutant discharged	**In progress / Incomplete**
Sediment contamination	108	Audit commercial and industrial areas with regard to mitigating impacts on estuarine assets.	**Implemented and Ongoing**
Sediment contamination	109	Promote the use of oil absorbent devices for the removal of fuels and oils from bilge water	**Not Commenced / Outstanding**
Sediment contamination	119	Ensure that all state-owned road and rail infrastructure within the catchment has adequate stormwater management for water quality and flows	**Unknown**
Sediment contamination	120	Ensure use of low residue herbicides and adopt practices to minimise input to the waterway	**In progress / Incomplete**
Sediment contamination	121	Improve management of leachate and runoff from waste disposal sites	**Implemented and Ongoing**
Sediment contamination	124	Determine sources of sediment contamination and impacts of contaminants on estuarine health, through sediment and water quality testing across the Lower Hawkesbury	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Sediment contamination	125	Establish an ongoing sediment monitoring program for the estuary concentrating on areas of known heavy metal contamination or boat maintenance services.	**Implemented and Ongoing**
Sediment contamination	129	Investigate the potential for increased sedimentation as a result of bushfires and prescribed burning	**In progress / Incomplete**
Sediment contamination	**Pittwater CZMP**		
Sediment contamination	3d	Developments not to incorporate pollution and/or sediment discharges to the waterways	**Implemented and Ongoing**
Sediment contamination	7a	Targeted measures for reducing marina operations waste	**Implemented and Ongoing**
Sediment contamination	7b	Targeted catchment management measures, following catchment-wide urban pollution and sediment runoff audit (esp. areas discharging to poorly flushed embayments)	**Implemented and Ongoing**
Sediment contamination	8b	Community Education - Discouragement of use of high-pollution older- style 2 stroke outboard motors	**Not Commenced / Outstanding**
Sediment contamination	**Brisbane Water CZMP**		
Sediment contamination	C01	Continue program of auditing to ensure best management practices for marinas around Brisbane Water Estuary. DECC's brochure Environmental *Action for Marinas, Boatsheds and Slipways* (2007) should be provided to marine operators.	
Sediment contamination	E02	Label stormwater drain inlets in problematic areas "These drains to ……".	
Sediment contamination	P01	Provide for the development, implementation and regular re- assessment of Riparian Zone and Bank Management Plans for the major tributaries draining into the Estuary, including Narara Creek River care Plan, Erina Rivercare Plan, Kincumber Creek Riparian Plan, Woy Woy Creek, Currumbine Creek and Ettalong Creek.	
Sediment contamination	P02	Develop and implement a pollution response strategy to address major pollution events. *Policy D1.02 - Oil Spillages in Navigable Waters* should be updated accordingly.	
Sediment contamination	P03	Support State government proposal to prohibit 2 strokes outboard motors.	
Sediment contamination	P05	Investigate the need for sediment traps and other stormwater management measures to control any erosion and sedimentation from sloping lands draining to the stormwater outlet opposite Byalla Lane.	
Sediment contamination	R04	Audit the performance of existing stormwater quality improvement devices and assess the need for modifications.	
Sediment contamination	R24	Investigate the use of constructed wetlands, sediment, and detention basins and other WSUD options to minimise the effect of freshwater and sediment inflows, with particular reference to areas of high biodiversity value around entrances to creeks. Consideration should be given to both current and future meteorological conditions.	
Sediment contamination	R43	Undertake a comprehensive geomorphological study of historic and current sedimentation rates at the estuarine outlet areas of the major creeks (Narara, Erina, Kincumber and Woy Woy Creeks).	
Sediment contamination	R45	To identify primary sources of contamination, especially in the Narara Creek catchment, consider remedial strategies and undertake follow up investigations of sediment in the northern part of the estuary to improve assessment of possible sediment toxicity.	
Sediment contamination	W01	Investigate options for implementing catchment based WSUD features in the catchment in order to manage stormwater quality and quantity, with a priority focus on the Narara and Erina Creek catchments, followed by Kincumber Creek catchment.	

Stressor	Action ID	Description	Status (where available)
Sediment contamination	W09	Investigate appropriate WSUD features for those roads that are currently unsealed/unfinished in order to reduce the impact of erosion and sedimentation from these roadways.	
Sediment contamination	W27	Undertake regular maintenance to remove sediments from the outlets of stormwater drains.	
Sediment contamination	**Pearl Beach Lagoon CZMP**		
Sediment contamination	9	Investigate options for removing material from lagoon bed	**In progress / Incomplete**
Invasive species	**Upper Hawkesbury CZMP**		
Invasive species	ARH4	Actively support the continuation of Bush care to assist with revegetation works on Public and Private Lands	
Invasive species	ARH6	Coordinating weed management efforts between the County Council, Bushcare and Landcare (including Willow Warriors) and the LALC to maximise benefits for the estuary.	
Invasive species	13	Encourage the planting of appropriate species to enhance connectivity, green corridors and succession of desired adult trees	
Invasive species	25	Repeat erosion, foreshore structure and weed mapping undertaken for this project in 5 years' time to assess changes	
Invasive species	37	Undertake bird and fauna surveys along the river to assess conservation value and inform future management	
Invasive species	61	Lantana and other weed removal and subsequent rehabilitation of Half Moon Farm for public use.	
Invasive species	69	Field days designed to remove carp from lagoons. Reintroduction of native species.	
Invasive species	82	Provide centralised up to date weed mapping. (will help facilitate 47??)	
Invasive species	**Lower Hawkesbury CZMP**		
Invasive species	11	Encourage conservation of native vegetation on private land	**Implemented and Ongoing**
Invasive species	15	During the review of plans of management for all parks and reserves (both national and council managed), ensure estuary assets are preserved (including habitat values for native animals, animals listed under the TSC Act 1995, prescribed burning and bushfire suppression undertaken according to park/reserve fire management plan, etc).	**Implemented and Ongoing**
Invasive species	27	Improve native vegetation condition through revegetation of priority areas (based on habitat mapping)	**Implemented and Ongoing**
Invasive species	28	Expand bush regeneration programs and conservation programs for specific priority species	**Implemented and Ongoing**
Invasive species	36	Restrict foreshore access in areas of high environmental sensitivity	**Implemented and Ongoing**
Invasive species	55	Educate residents as to best practise catchment management (fertilisers, chemicals, pesticides, threat of weeds to bushland, and encourage the removal of exotic species and replacement with suitable indigenous plants, domestic animals)	**Implemented and Ongoing**
Invasive species	127	Enhance weed management programs across catchment, particularly in estuarine vegetation	**Implemented and Ongoing**
Invasive species	128	Enhance existing pest eradication programs, particularly in estuarine habitats	**In progress / Incomplete**
Invasive species	131	Prepare and implement creek rehabilitation plans to restore and maintain native vegetation in the riparian zone	**Implemented and Ongoing**
Invasive species	132	Consider a "Residents Pack" which outlines the estuary values, regional significance, ways to preserve such values, and includes existing brochures (from Councils, DPI Fisheries, NSW Maritime, NPWS etc) on stormwater, endemic plantings, bushcare, boating maps, seagrass maps, aquatic weeds, etc	**Implemented and Ongoing**
Invasive species	133	Encourage vigilance in reporting noncompliance with regulations and environmental conditions/degradation (eg, sediment erosion controls, OSSMs, vegetation removal/destruction, stormwater control and maintenance, recreational activities etc) and pollution incidents (e.g. algal blooms, oils spills, chemical spills etc) to appropriate authorities (e.g., "river hood watch program")	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Invasive species	134	Encourage local residents to participate in conservation and bush regeneration schemes	**Implemented and Ongoing**
Invasive species	145	Undertake periodic survey of recreational and commercial fishers to determine volumes, species and locations of fish caught across the entire Hawkesbury Estuary	**Implemented and Ongoing**
Invasive species	146	Undertake research into the impact of catch numbers, trawl methods (such as otter boards) and other influences on the long term sustainability of all fish species (target and non-target) in the Hawkesbury Estuary	**Implemented and Ongoing**
Invasive species	**Pittwater CZMP**		
Invasive species	1c	Prepare and implement Plans of Management for areas of significant habitat (eg EECs) on public land and DCPs for private lands ensuring preservation and enhancement of key environmental values	**In progress / Incomplete**
Invasive species	2a	Significant environmental values are to be identified and are adequately protected within appropriate planning instruments (including foreshore areas, EECs, vegetation stands). Eg, modify SEPP-14 wetland boundaries, TPOs.	**In progress / Incomplete**
Invasive species	6d	Weed and exotic species control, including Caulerpa taxifolia.	**In progress / Incomplete**
Invasive species	**Brisbane Water CZMP**		
Invasive species	P19	Develop a strategy for the conservation of areas important for the biodiversity of invertebrates. Particular attention should be paid to priority sites that represent the greatest proportion of species, including Ettalong, Narara Creek, Koolewong, and Woy Woy Bay-Pelican Island.	
Invasive species	P20	Develop a conservation and education strategy for seagrass beds, as identified in the *Estuary Processes Study* (CLT, 2008), that: - Support the highest abundance and diversity of fish, - Are known to be important for sponges and ascidians, and - Are known to be important for biological connectivity.	
Invasive species	P23	Develop a conservation strategy for the birds of Brisbane Water Estuary that addresses the main issues of disturbance by pedestrians, dog-walkers and watercraft, predation by feral and domestic animals, and habitat loss/degradation. This should include consideration of threatened and protected species, such as the Bush Stone Curlew, and the habitats that support them.	
Invasive species	P27	Develop a Plan of Management to provide protection for the Bush Stone Curlew populations occurring around the Estuary. In addition, provide for ongoing implementation of the Plan of Management for Green and Golden Bell Frogs.	
Invasive species	P28	Provide adequate resources within Council to provide for ongoing management of Bushcare volunteers.	
Invasive species	R20	Investigate opportunities to monitor indicator organisms within the Estuary to assess effectiveness of management measures to protect biodiversity and maintain the ecological health of the Estuary.	
Invasive species	R25	Manage Caulerpa taxifolia in accordance with I&I NSW's *NSW Control Plan for the Noxious Marine Alga Caulerpa taxifolia* (2009).	
Invasive species	W66	Provide fish friendly structures where new instream structures are being constructed.	
Invasive species	W70	Fence existing saltmarshes to prevent access by vehicles, bikes and domestic animals and provide information on the importance of saltmarsh habitat to estuary health.	
Invasive species	W71	Where appropriate, rehabilitate saltmarsh habitats on an Estuary-wide basis. Rehabilitation works should be prioritised with due consideration of habitat connectivity, and the potential for ongoing conservation in both the medium-term and long-term (i.e. under a climate change scenario).	
Invasive species	W73	Continue weed control activities in Council's foreshore reserves.	

Stressor	Action ID	Description	Status (where available)
Invasive species	**Gosford Beaches CZMP**		
Invasive species	O18	Complete a vegetation profile for Umina and Ocean Beach and support the natural vegetation profile.	**Completed**
Invasive species	O22	Encourage and assist DuneCare group to maintain and revegetate dune after a storm using appropriate endemic vegetation	**Implemented and Ongoing**
Invasive species	O30	Encourage and assist DuneCare group to improve dune vegetation management using appropriate endemic vegetation and consolidation of beach access	**Implemented and Ongoing**
Invasive species	O37	Encourage and assist DuneCare group to maintain and revegetate dune after a storm using appropriate endemic vegetation	**Implemented and Ongoing**
Invasive species	O46	Encourage and assist DuneCare group to improve dune vegetation management using appropriate endemic vegetation and consolidation of beach access	**Implemented and Ongoing**
Invasive species	O7	Encourage and assist DuneCare group to improve dune vegetation management using appropriate endemic vegetation and consolidation of beach access at southern end of beach	**Implemented and Ongoing**
Invasive species	PA15	Continue and enhance dune vegetation management - Assist/encourage community groups with dune management actions including DuneCare/Bushcare	**Not Commenced / Outstanding**
Invasive species	PA23	Complete a vegetation profile for Patonga Beach and support the natural vegetation profile.	**Completed**
Invasive species	PE16	Continue dune vegetation management - Assist/encourage community groups with dune management actions including DuneCare/Bushcare	**Implemented and Ongoing**
Invasive species	**Pearl Beach Lagoon CZMP**		
Invasive species	2	Prepare a vegetation and access master plan	**Not Commenced / Outstanding**
Invasive species	5	Rehabilitate habitats within creek lines of the catchment	**Implemented and Ongoing**
Commercial fishing	**Lower Hawkesbury CZMP**		
Commercial fishing	19	Prepare management plans for commercial and recreational fishing (based upon the findings of commercial and recreational fishing surveys and research into fishing impacts) which outline fishing parameters to sustain fish stocks and aquatic habitats (including zones appropriate to various fishing amounts (bag limits) and practices, use of bycatch devices and non-target species avoidance techniques). The plan needs also to address potential issues with visiting commercial fishers.	**Implemented and Ongoing**
Commercial fishing	20	Ensure commercial fishers minimise the catch of non-target species, the incidental catch of non-utilised species, marine mammals, reptiles, seabirds and impacts on associated or dependent species using such measures as mesh or gear modifications, closed areas and bycatch reduction devices.	**Completed**
Commercial fishing	22	Educate all commercial fishers on methods to minimise the catch of non-target species, the incidental catch of non-utilised species, marine mammals, reptiles, seabirds and impacts on associated or dependent species. Such methods include mesh or gear modifications, closed areas and bycatch reduction devices.	**Completed**
Commercial fishing	23	Educate commercial fishers to ensure they understand the immediate action required to mitigate impacts on protected or endangered species from their trawling operations	**Implemented and Ongoing**
Commercial fishing	35	Encourage the development and implementation of selective fishing gear, trawl practises/equipment and by-catch reduction devices amongst commercial fishers and researchers	**Implemented and Ongoing**
Commercial fishing	39	Ensure adequate waste disposal facilities for people aboard boats and recreational fishers on land. This includes installation/provision of approved bins on hire boats, commercial fishing boats, moored boats and trailable boats, and supporting waste services on land.	**Implemented and Ongoing**
Commercial fishing	67	Develop and implement a program for auditing boats for methods used to contain waste from boat maintenance, effluent discharge practises, rubbish disposal, oil discharge from bilge pumps and all other environmental issues associated with boat usage. This could reasonably be combined with NSW Maritime audits of moorings.	**In progress / Incomplete**
Commercial fishing	89	Ensure fishing practises and oyster growing practises avoid artificially attracting large numbers of birds into oyster harvest zones	**Completed**

Stressor	Action ID	Description	Status (where available)
Commercial fishing	91	Extend regulations for holding tanks to both grey and black water for recreational and commercial vessels.	Not Commenced / Outstanding
Commercial fishing	101	Ensure all boating facilities (marinas, slipways, private boat sheds, ferries, boat ramps etc) have containment areas for boat operation and maintenance (especially anti-foul paints, fuel storage tanks) and use best practise methods for mitigating environmental impacts. Perform follow-up audits to ensure recommendations are completed.	Unknown
Commercial fishing	109	Promote the use of oil absorbent devices for the removal of fuels and oils from bilge water	Not Commenced / Outstanding
Commercial fishing	145	Undertake periodic survey of recreational and commercial fishers to determine volumes, species and locations of fish caught across the entire Hawkesbury Estuary	Implemented and Ongoing
Commercial fishing	146	Undertake research into the impact of catch numbers, trawl methods (such as otter boards) and other influences on the long term sustainability of all fish species (target and non-target) in the Hawkesbury Estuary	Implemented and Ongoing
Commercial fishing	**Brisbane Water CZMP**		
Commercial fishing	P07	Develop formal standard designs for key navigational channels in Brisbane Water that identify the desired channel profile and likely maintenance dredging requirements to maintain these configurations for the purposes of recreational and commercial boating. The purpose of this action is to provide clear information to users of Brisbane Water and manage community expectations in relation to maintenance of navigation channels, while acknowledging natural rates of sediment transport in these locations and likely environmental impacts. This process should be informed by the Sediment Management Plan provided in the *Brisbane Water Estuary Management Stud* y (CLT, 2010) and the findings of the *Brisbane Water Estuary Processes Study* (CLT, 2008). It is acknowledged that additional investigations may be required to develop the standard designs.	
Commercial fishing	R44	Work with Oyster Growers to develop an Environmental Management Strategy, along with improved water quality monitoring and project collaboration.	
Recreational fishing	**Lower Hawkesbury CZMP**		
Recreational fishing	4	Determine sustainable limits for recreational activities (types, numbers and locations) and the requirements for existing/new facilities and access to achieve sustainable limits on foreshores and waterways of the estuary (i.e., suitable locations, unsustainable locations requiring removal, locations requiring restoration, new sustainable locations).	Implemented and Ongoing
Recreational fishing	16	Develop a strategy for sustainable recreation across the Lower Hawkesbury, which states the sustainability of locations, facilities and access based upon recreational survey and other data.	Implemented and Ongoing
Recreational fishing	19	Prepare management plans for commercial and recreational fishing (based upon the findings of commercial and recreational fishing surveys and research into fishing impacts) which outline fishing parameters to sustain fish stocks and aquatic habitats (including zones appropriate to various fishing amounts (bag limits) and practices, use of bycatch devices and non-target species avoidance techniques). The plan needs also to address potential issues with visiting commercial fishers.	Implemented and Ongoing
Recreational fishing	21	Enforce compliance of recreational fishers with regulations on bag limits, minimum fish sizes etc	Implemented and Ongoing
Recreational fishing	36	Restrict foreshore access in areas of high environmental sensitivity	Implemented and Ongoing

Stressor	Action ID	Description	Status (where available)
Recreational fishing	39	Ensure adequate waste disposal facilities for people aboard boats and recreational fishers on land. This includes installation/provision of approved bins on hire boats, commercial fishing boats, moored boats and trailable boats, and supporting waste services on land.	**Implemented and Ongoing**
Recreational fishing	41	Establish a regular monitoring program to monitor the impacts of recreation at various locations and times of year (such as peak periods), to ensure ongoing sustainability of such locations.	**In progress / Incomplete**
Recreational fishing	62	Investigate innovative methods to restrict the numbers of boats or the size of vessels in areas of high environmental sensitivity/significance.	**Not Commenced / Outstanding**
Recreational fishing	135	Educate recreational users/general visitors about estuary values and the estuarine system, recreational impacts, and actions they may take to reduce impacts on priority areas (seagrass, harvest areas, recreational swimming) in the estuary (e.g. signage, boating stickers, brochures etc)	**Implemented and Ongoing**
Recreational fishing	137	Participate in community events to highlight unique values of estuary and promote estuary management program	**Implemented and Ongoing**
Recreational fishing	144	Undertake periodic surveys of the types, numbers and locations of various recreational activities on all foreshores and waterways of the Lower Hawkesbury.	**Implemented and Ongoing**
Recreational fishing	145	Undertake periodic survey of recreational and commercial fishers to determine volumes, species and locations of fish caught across the entire Hawkesbury Estuary	**Implemented and Ongoing**
Recreational fishing	**Pittwater CZMP**		
Recreational fishing	8f	Community Education - General environmental values of estuary	**Implemented and Ongoing**
Recreational fishing	**Brisbane Water CZMP**		
Recreational fishing	C04	Ensure ongoing enforcement of fishing regulations.	
Recreational fishing	C15	Enforce littering restrictions and undertake parallel education programs about littering.	
Recreational fishing	E14	Distribute I&I NSW's *NSW Recreational Saltwater Fishing Guide 2011* (2010), which provide advice about fishing regulations, responsible fishing and safety tips.	
Recreational fishing	P41	Prepare a Brisbane Water Estuary Users Plan which addresses such issues as equity of access, boat storage, conflicts of usage, mooring types and caps, number and type of public access points (wharves and jetties), coverage and consistency of foreshore Plans of Management with priority areas identified for new Plans of Management, estimation of an estuary carrying capacity with respect to development intensity, fishing/fisheries and boating. Reference should be made to the *Brisbane Water Estuary Processes Study* (CLT, 2008), particularly Appendix N, for further details on existing recreational patterns, conflicts and future opportunities, as well as details of where recreation may be impacting on other estuarine processes (e.g. on ecological processes). It is noted that implementation of this action is also dependent upon the provision of supporting information via the implementation of other management actions (as indicated).	
Recreational fishing	R18	Conduct a survey of recreational fishing catches and analyse recreational fishing trends to characterise both the impact on the fish populations of Brisbane Water Estuary and the value of recreational fishing as a local industry.	

Stressor	Action ID	Description	Status (where available)
Recreational fishing	R31	Conduct an audit of existing land-based and water-based infrastructure for boating (e.g. picnic tables, playgrounds, BBQs, jetties, boat ramps, dinghy storage areas, moorings, trailer parking areas, car parking, garbage bins, toilets, shared pathways, etc.) focusing on: - Patterns in patronage/usage, - Condition and maintenance requirements, - Characterisation of neighbouring land uses, - Proximity to key habitat, heritage items and other environmentally sensitive areas, - Proximity to key locations (e.g. pump out stations, marinas, popular fishing spots, etc.), and - Safety. Based on the outcome of the audit, assess the need to upgrade, maintain or de-commission existing infrastructure. The purpose of this audit is primarily to rationalise recreational access and amenity. The findings may be used to inform Action P41, the Users Plan.	
Recreational fishing	W123	Investigate the feasibility of utilising artificial reef structures to provide habitat diversity and/or minimise foreshore erosion/recession.	
Recreational fishing	**Gosford Beaches CZMP**		
Recreational fishing	O19	Increase information signage near surf clubs on the ecology and history of Umina/Ocean Beach	**Completed**
Recreational fishing	O21	Maintain current signage and facilities on a regular basis	**Implemented and Ongoing**
Active boating	**Upper Hawkesbury CZMP**		
Active boating	FP7	Investigate potential causes of bank erosion along the River including the impact of boating activities in partnership with landowners, boat users and relevant agencies.	
Active boating	45	Lobby for stricter regulations for wakeboarding, for example restricting the use of ballast	
Active boating	67	Minimise the number of structures in a DA - i.e. not multiple access points evident at the caravan parks	
Active boating	70	Direct the community to appropriate waste facilities.	
Active boating	un	Increase fines for dumping / pollution	
Active boating	83	Ensure latest research on boat wake, speed limits, boat type and erosion are considered in recreational zoning of the estuary.	
Active boating	87	Close river to all but emergency boats during very high water (floods/ King Tides) to reduce bank erosion during these conditions.	
Active boating	**Lower Hawkesbury CZMP**		
Active boating	5	Review waterway access locations and requirements to consider all stakeholder needs with recommendations from the review informing appropriate Planning and Works Programs.	**Implemented and Ongoing**
Active boating	9	Incorporate appropriate provision in planning instruments to require all Marinas to provide accessible pump out facilities as a component of their licence to operate in the Lower Hawkesbury.	**Unknown**
Active boating	16	Develop a strategy for sustainable recreation across the Lower Hawkesbury, which states the sustainability of locations, facilities and access based upon recreational survey and other data.	**Implemented and Ongoing**
Active boating	24	Identify significant seagrass beds on NSW Maritime boat charts and stickers and undertake education program to promote protection of seagrass	**Completed**
Active boating	34	Install marker buoys and warnings around seagrass habitats to deter boaters from accessing and damaging these habitats	**Completed**
Active boating	39	Ensure adequate waste disposal facilities for people aboard boats and recreational fishers on land. This includes installation/provision of approved bins on hire boats, commercial fishing boats, moored boats and trailable boats, and supporting waste services on land.	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Active boating	60	Update existing boating maps (boat and PWC speeds, access, and vessel size limits in various zones) for the entire Lower Hawkesbury to reflect findings of bank erosion studies, significant aquatic and riparian habitats, priority harvest area requirements, and other relevant environmental studies	**In progress / Incomplete**
Active boating	61	Implement exclusion zones for recreational/private boating in specific oyster harvest area to protect sanitary water quality, using appropriate methods	**In progress / Incomplete**
Active boating	62	Investigate innovative methods to restrict the numbers of boats or the size of vessels in areas of high environmental sensitivity/significance.	**Not Commenced / Outstanding**
Active boating	63	Ensure no net increase in existing moorings/berthings is permitted throughout the Lower Hawkesbury. Only permit additional berthings in marinas where they replace existing swing moorings.	**In progress / Incomplete**
Active boating	64	Progressively relocate or modify moorings considered to have a high environmental impact or are located in areas of high environmental significance or sensitivity.	**Implemented and Ongoing**
Active boating	66	Enhance compliance activities and enforcement of penalties for all waterway regulations and consider increasing deterrents for noncompliance with regulations (boat speed zones, effluent discharges, seagrass protection, littering, permanent occupation of boats, illegal overnight mooring of boats etc)	**Implemented and Ongoing**
Active boating	67	Develop and implement a program for auditing boats for methods used to contain waste from boat maintenance, effluent discharge practises, rubbish disposal, oil discharge from bilge pumps and all other environmental issues associated with boat usage. This could reasonably be combined with NSW Maritime audits of moorings.	**In progress / Incomplete**
Active boating	68	Develop a "River Code" which outlines acceptable boating activities/behaviour (focussing on environmental impacts) and includes updated boating maps. The "River Code" could incorporate existing NSW Maritime and other brochures relating to the environment and appropriate behaviour (boat speeds etc). Options for distribution of "River Code" should be considered (eg, stickers, with licence applications, broad advertising etc)	**Implemented and Ongoing**
Active boating	91	Extend regulations for holding tanks to both grey and black water for recreational and commercial vessels.	**Not Commenced / Outstanding**
Active boating	93	Prepare and implement a strategy for pump outs across the Lower Hawkesbury Estuary (eg public use of commercial pump outs, installation of additional public pump outs etc)	**In progress / Incomplete**
Active boating	132	Consider a "Residents Pack" which outlines the estuary values, regional significance, ways to preserve such values, and includes existing brochures (from Councils, DPI Fisheries, NSW Maritime, NPWS etc) on stormwater, endemic plantings, bushcare, boating maps, seagrass maps, aquatic weeds, etc	**Implemented and Ongoing**
Active boating	**Pittwater CZMP**		
Active boating	3h	Require all new marina developments (> 9 berths) to have pump-out services	**In progress / Incomplete**
Active boating	4a	Limit proximity of boating activities to environmentally significant areas and other sensitive areas (eg infested areas), incl. no anchoring	**Not Commenced / Outstanding**
Active boating	4b	Replace existing moorings with seagrass friendly moorings in areas close to existing seagrass beds	**Implemented and Ongoing**
Active boating	4c	If necessary, reduce boating speed limits in areas of high waterway use / traffic (eg western side of Scotland Island)	**Not Commenced / Outstanding**
Active boating	4d	If necessary, relocate existing moorings away from areas of high environment significance and/or high vessel traffic	**Not Commenced / Outstanding**
Active boating	4f	Encourage all existing large marinas (> 30 berths) to install pump-out services	**Implemented and Ongoing**
Active boating	4g	If necessary, reduce the total number of moorings within Pittwater to a more appropriate capacity / mooring limit, through opportunistic relinquishment and offsets through new marina developments.	**Implemented and Ongoing**
Active boating	5a	Install new and/or upgrade and repair existing waterway access locations / points, and foreshore access and facilities, considering the environment	**Implemented and Ongoing**
Active boating	7a	Targeted measures for reducing marina operations waste	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Active boating	8b	Community Education - Discouragement of use of high-pollution older- style 2 stroke outboard motors	Not Commenced / Outstanding
Active boating	9a	Compliance: Permanent occupancies on boats	Implemented and Ongoing
Active boating	9b	Compliance: Boating regulations, i.e. speeds, dangerous behaviour, Caulerpa controls / washdown	Implemented and Ongoing
Active boating	9e	Compliance: Water pollution from boats and waterway businesses (e.g. marinas)	Implemented and Ongoing
Active boating	**Brisbane Water CZMP**		
Active boating	C08	Enforce boating regulations (particularly speed restrictions and zoning of activities) within Brisbane Water.	
Active boating	C12	Investigate options for either banning or further limiting the use of jet skis in Brisbane Water Estuary.	
Active boating	E01	Distribute NSW Maritime's Brisbane Water Boating Map to ensure waterway users are aware of the regulations relating to navigational safety, permissible activities and their responsibilities as boat users.	
Active boating	E11	Conduct an education program for the boating community on: - Their responsibilities with respect to the disposal of ballast, sewage and rubbish, - The location of existing sewage pump-out and rubbish disposal facilities, and - How to safeguard against leaks and spills, and what to do if a leak or spill occurs. This should include a distribution of a copy of NSW Maritime's Don't Make Waves (2006) brochure.	
Active boating	P03	Support State government proposal to prohibit 2 stroke outboard motors.	
Active boating	P08	Review and revise *DCP 145 Boating Facilities in St Huberts Island Canals* to ensure consistency with the goals and objectives of the Estuary Management Study and Plan. In particular, explicit consideration of sedimentary processes should form part of the assessment process for all development applications.	
Active boating	P41	Prepare a Brisbane Water Estuary Users Plan which addresses such issues as equity of access, boat storage, conflicts of usage, mooring types and caps, number and type of public access points (wharves and jetties), coverage and consistency of foreshore Plans of Management with priority areas identified for new Plans of Management, estimation of an estuary carrying capacity with respect to development intensity, fishing/fisheries and boating. Reference should be made to the *Brisbane Water Estuary Processes Study* (CLT, 2008), particularly Appendix N, for further details on existing recreational patterns, conflicts and future opportunities, as well as details of where recreation may be impacting on other estuarine processes (e.g. on ecological processes). It is noted that implementation of this action is also dependent upon the provision of supporting information via the implementation of other management actions (as indicated).	
Active boating	R09	Conduct ongoing monitoring (by survey) of key navigation channels, including: - Entrance Channel, - Paddy's Channel, - Lintern Channel, - Woy Woy Channel, - Wagstaffe Channel, - Cockle Channel, and - Saratoga Channel.	

Stressor	Action ID	Description	Status (where available)
Active boating	R31	Conduct an audit of existing land-based and water-based infrastructure for boating (e.g. picnic tables, playgrounds, BBQs, jetties, boat ramps, dinghy storage areas, moorings, trailer parking areas, car parking, garbage bins, toilets, shared pathways, etc.) focusing on: - Patterns in patronage/usage, - Condition and maintenance requirements, - Characterisation of neighbouring land uses, - Proximity to key habitat, heritage items and other environmentally sensitive areas, - Proximity to key locations (e.g. pump out stations, marinas, popular fishing spots, etc.), and - Safety. Based on the outcome of the audit, assess the need to upgrade, maintain or de-commission existing infrastructure. The purpose of this audit is primarily to rationalise recreational access and amenity. The findings may be used to inform Action P41, the Users Plan.	
Active boating	W02	Install additional sewage pump-out facilities to reduce water pollution. These should be situated at locations accessible by a range of vessels.	
Active boating	W05	Advertise and provide signage for boat pump-out facilities.	
Active boating	W65	Replace existing swing moorings within the Estuary with more appropriate, seagrass friendly moorings.	
Active boating	W87	Ensure that the navigation markers are moved, or new markers put in place as required, in accordance with movement of the associated shoals.	
Passive boating	**Upper Hawkesbury CZMP**		
Passive boating	LPD4	Map caravan park locations - clearly defining regulations regarding caravan parks and identifying opportunities to reduce impacts/prevent further proliferation.	
Passive boating	50	Implement specific POMs that have been prepared for key parks. Prepare and implement a Natural Habitat Restoration Strategy that identifies priority locations, how to restore land and increase access.	
Passive boating	81	Provision of access points, toilets and facilities for passive boating away from powerboat ramps.	
Passive boating	**Lower Hawkesbury CZMP**		
Passive boating	4	Determine sustainable limits for recreational activities (types, numbers and locations) and the requirements for existing/new facilities and access to achieve sustainable limits on foreshores and waterways of the estuary (i.e., suitable locations, unsustainable locations requiring removal, locations requiring restoration, new sustainable locations).	**Implemented and Ongoing**
Passive boating	5	Review waterway access locations and requirements to consider all stakeholder needs with recommendations from the review informing appropriate Planning and Works Programs.	**Implemented and Ongoing**
Passive boating	16	Develop a strategy for sustainable recreation across the Lower Hawkesbury, which states the sustainability of locations, facilities and access based upon recreational survey and other data.	**Implemented and Ongoing**
Passive boating	24	Identify significant seagrass beds on NSW Maritime boat charts and stickers and undertake education program to promote protection of seagrass	**Completed**
Passive boating	34	Install marker buoys and warnings around seagrass habitats to deter boaters from accessing and damaging these habitats	**Completed**
Passive boating	36	Restrict foreshore access in areas of high environmental sensitivity	**Implemented and Ongoing**
Passive boating	39	Ensure adequate waste disposal facilities for people aboard boats and recreational fishers on land. This includes installation/provision of approved bins on hire boats, commercial fishing boats, moored boats and trailable boats, and supporting waste services on land.	**Implemented and Ongoing**
Passive boating	61	Implement exclusion zones for recreational/private boating in specific oyster harvest area to protect sanitary water quality, using appropriate methods	**In progress / Incomplete**

Stressor	Action ID	Description	Status (where available)
Passive boating	135	Educate recreational users/general visitors about estuary values and the estuarine system, recreational impacts, and actions they may take to reduce impacts on priority areas (seagrass, harvest areas, recreational swimming) in the estuary (e.g. signage, boating stickers, brochures etc)	**Implemented and Ongoing**
Passive boating	137	Participate in community events to highlight unique values of estuary and promote estuary management program	**Implemented and Ongoing**
Passive boating	144	Undertake periodic surveys of the types, numbers and locations of various recreational activities on all foreshores and waterways of the Lower Hawkesbury.	**Implemented and Ongoing**
Passive boating	**Pittwater CZMP**		
Passive boating	5a	Install new and/or upgrade and repair existing waterway access locations / points, and foreshore access and facilities, giving consideration to the environment	**Implemented and Ongoing**
Passive boating	**Brisbane Water CZMP**		
Passive boating	P35	Finalise Council's Dinghy Storage Policy and progress through implementation of the Foreshore Reserves Dinghy Storage Implementation Plan.	
Passive boating	P41	Prepare a Brisbane Water Estuary Users Plan which addresses such issues as equity of access, boat storage, conflicts of usage, mooring types and caps, number and type of public access points (wharves and jetties), coverage and consistency of foreshore Plans of Management with priority areas identified for new Plans of Management, estimation of an estuary carrying capacity with respect to development intensity, fishing/fisheries and boating. Reference should be made to the *Brisbane Water Estuary Processes Study* (CLT, 2008), particularly Appendix N, for further details on existing recreational patterns, conflicts and future opportunities, as well as details of where recreation may be impacting on other estuarine processes (e.g. on ecological processes). It is noted that implementation of this action is also dependent upon the provision of supporting information via the implementation of other management actions (as indicated).	
Passive boating	R31	Conduct an audit of existing land-based and water-based infrastructure for boating (e.g. picnic tables, playgrounds, BBQs, jetties, boat ramps, dinghy storage areas, moorings, trailer parking areas, car parking, garbage bins, toilets, shared pathways, etc.) focusing on: - Patterns in patronage/usage, - Condition and maintenance requirements, - Characterisation of neighbouring land uses, - Proximity to key habitat, heritage items and other environmentally sensitive areas, - Proximity to key locations (e.g. pump out stations, marinas, popular fishing spots, etc.), and - Safety. Based on the outcome of the audit, assess the need to upgrade, maintain or de-commission existing infrastructure. The purpose of this audit is primarily to rationalise recreational access and amenity. The findings may be used to inform Action P41, the Users Plan.	
Passive boating	**Gosford Beaches CZMP**		
Passive boating	O19	Increase information signage near surf clubs on the ecology and history of Umina/Ocean Beach	**Completed**
Passive boating	O21	Maintain current signage and facilities on a regular basis	**Implemented and Ongoing**
Passive boating	O23	Development of local area (Umina/Ocean Beach) online fact sheets and encourage local educational programs in schools regarding the dunes	**Not Commenced / Outstanding**
Swimming	**Upper Hawkesbury CZMP**		
Swimming	LPD4	Map caravan park locations - clearly defining regulations regarding caravan parks and identifying opportunities to reduce impacts/prevent further proliferation.	
Swimming	**Lower Hawkesbury CZMP**		
Swimming	16	Develop a strategy for sustainable recreation across the Lower Hawkesbury, which states the sustainability of locations, facilities and access based upon recreational survey and other data.	**Implemented and Ongoing**

Stressor	Action ID	Description	Status (where available)
Swimming	36	Restrict foreshore access in areas of high environmental sensitivity	Implemented and Ongoing
Swimming	41	Establish a regular monitoring program to monitor the impacts of recreation at various locations and times of year (such as peak periods), to ensure ongoing sustainability of such locations.	In progress / Incomplete
Swimming	66	Enhance compliance activities and enforcement of penalties for all waterway regulations and consider increasing deterrents for noncompliance with regulations (boat speed zones, effluent discharges, seagrass protection, littering, permanent occupation of boats, illegal overnight mooring of boats etc)	Implemented and Ongoing
Swimming	132	Consider a "Residents Pack" which outlines the estuary values, regional significance, ways to preserve such values, and includes existing brochures (from Councils, DPI Fisheries, NSW Maritime, NPWS etc) on stormwater, endemic plantings, bushcare, boating maps, seagrass maps, aquatic weeds, etc	Implemented and Ongoing
Swimming	135	Educate recreational users/general visitors about estuary values and the estuarine system, recreational impacts, and actions they may take to reduce impacts on priority areas (seagrass, harvest areas, recreational swimming) in the estuary (e.g. signage, boating stickers, brochures etc)	Implemented and Ongoing
Swimming	137	Participate in community events to highlight unique values of estuary and promote estuary management program	Implemented and Ongoing
Swimming	144	Undertake periodic surveys of the types, numbers and locations of various recreational activities on all foreshores and waterways of the Lower Hawkesbury.	Implemented and Ongoing
Swimming	**Pittwater CZMP**		
Swimming	5a	Install new and/or upgrade and repair existing waterway access locations / points, and foreshore access and facilities, giving consideration to the environment	Implemented and Ongoing
Swimming	8a	Community Education - No discharge status of Pittwater	Implemented and Ongoing
Swimming	**Brisbane Water CZMP**		
Swimming	P41	Prepare a Brisbane Water Estuary Users Plan which addresses such issues as equity of access, boat storage, conflicts of usage, mooring types and caps, number and type of public access points (wharves and jetties), coverage and consistency of foreshore Plans of Management with priority areas identified for new Plans of Management, estimation of an estuary carrying capacity with respect to development intensity, fishing/fisheries and boating. Reference should be made to the *Brisbane Water Estuary Processes Study* (CLT, 2008), particularly Appendix N, for further details on existing recreational patterns, conflicts and future opportunities, as well as details of where recreation may be impacting on other estuarine processes (e.g. on ecological processes). It is noted that implementation of this action is also dependent upon the provision of supporting information via the implementation of other management actions (as indicated).	
Swimming	R31	Conduct an audit of existing land-based and water-based infrastructure for boating (e.g. picnic tables, playgrounds, BBQs, jetties, boat ramps, dinghy storage areas, moorings, trailer parking areas, car parking, garbage bins, toilets, shared pathways, etc.) focusing on: - Patterns in patronage/usage, - Condition and maintenance requirements, - Characterisation of neighbouring land uses, - Proximity to key habitat, heritage items and other environmentally sensitive areas, - Proximity to key locations (e.g. pump out stations, marinas, popular fishing spots, etc.), and - Safety. Based on the outcome of the audit, assess the need to upgrade, maintain or de-commission existing infrastructure. The purpose of this audit is primarily to rationalise recreational access and amenity. The findings may be used to inform Action P41, the Users Plan.	
Swimming	**Gosford Beaches CZMP**		

Stressor	Action ID	Description	Status (where available)
Swimming	O19	Increase information signage near surf clubs on the ecology and history of Umina/Ocean Beach	**Completed**
Swimming	O21	Maintain current signage and facilities on a regular basis	**Implemented and Ongoing**
Swimming	O23	Development of local area (Umina/Ocean Beach) online fact sheets and encourage local educational programs in schools regarding the dunes	**Not Commenced / Outstanding**
Swimming	O27	Repair of beach accessways and revegetation of dune following erosion in a large storm event	**Implemented and Ongoing**